# FUNCTIONAL MODELLING AND SIMULATION OF OVERALL SYSTEM SHIP – VIRTUAL METHODS FOR ENGINEERING AND COMMISSIONING IN SHIPBUILDING


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## KEYWORDS

**Functional Simulation, Systems Engineering, MBSE, SysML, Virtual Commissioning, Co-Simulation, Operator Training System, Shipbuilding**



## ABSTRACT

Shipbuilding industry is undergoing a change, in which many European shipyards focus on special purpose vessels. This field of shipbuilding places very high demands on engineering, commissioning and operation of the vessels. To support these fields of activity with virtual methods an innovative approach is introduced which strengthens the shipbuilding process by using a uniform common model of the overall system ship. The model is steadily increasing and gets more detailed through the phases of the shipbuilding. The presented approach fills the gap in the virtual support of the complete shipbuilding process, taking into account the specific structural needs – short time, high cost pressure and high quality demands.


## INTRODUCTION

Rising international competition especially from the Asian market and still existing overcapacities on the shipbuilding market are the reasons for many European shipyards to concentrate on the special shipbuilding sector. Modern special purpose vessels are characterised by a high degree of automation and a strong interconnection of systems. These are not only special systems for the primary special task of the vessel but also the essential ship operating systems, which are connected, sharing sensor data and operating together in a coordinated cooperation without any user interaction.

Increasing automation is also seen in other industries, especially in machinery and plant engineering as well as energy transmission and distribution. Core of these trend, with the keywords industry 4.0, digital factory or smart grid, is that systems and plants do autonomous actions based on sensor data without any interaction of a human being. In these industries the use of virtual methods for engineering and commissioning are successfully realised. A transfer of these methods into the shipbuilding market was not done yet, although there is a great demand for virtual support in the production of special purpose vessels. This is mainly caused by the specific structural needs of the shipbuilding process and the operating conditions. Short terms for engineering and high cost pressure are in contrast to high demands on the quality. This balancing act will reinforce in the future and only innovative processes and modern methods can meet the challenges.

## STATE OF THE ART

### Shipbuilding Industry

Currently the possibilities and advantages of system simulation are not used in shipbuilding industry. It is more the case that during trials and testing errors in sequences and interfaces are found. There are some supplier of systems, mainly supplier of ship automation systems, who have simulation tools for validation of their own system to deliver; but they are not available by the yard to realise a complete virtual commissioning, because not all ship systems are included and the simulation model contains proprietary know-how. In some cases these simulations get enhanced by some additional applications to an operator training system. This situation fits the trend in shipbuilding industry where many yards hand over the complete electrical engineering to major suppliers, which assume de jure or de facto the responsibility for the whole automation system with integration of systems, i.e. interface coordination and determination of higher level functions. Often the agreement of interfaces is done without participation of the yard between the suppliers and as a consequence the design departments of the yard are insufficiently involved in the engineering of the automation system. The overall system "ship" which works together via the automation system by executing higher level functions is insufficiently designed. This is even more critical, as there are no functional acceptance tests before commissioning where interfaces between systems and cross-system functions could be tested. Errors occur during commissioning when systems where brought into service and the interaction of systems is tested. This regularly causes time delays during commissioning and trials which can lead to a delayed delivery of the ship. This gives rise to additional costs which must completely be borne by the yard.

Not that there are no virtual modelling tools or simulation tools used in shipbuilding industry. 3D CAD tools for detailed design and spatial coordination are well established as well as simulation tools for several engineering fields; for example hydrodynamic analysis, torsional vibration analysis, multibody simulations and mechanical stress analysis. There are also simulation tools present for support of production - for optimisation of production process and control (Wang, 2014) as well as for technical simulations of specific tasks like welding (Fricke and Zacke, 2014). Visualisation tools based on Virtual and Augmented Reality (Freiherr von Lukas, 2010; Pérez Fernández and Alonso, 2015; Olbrich et al., 2011) are used to support arrangement and spatial coordination during engineering and production by 3D visualisation of rooms.

3D Operator Training Systems are used as well in marine industry, mainly by cruise lines like AIDA for training of bridge operation. There are some specialised companies (e.g. CSMART (Fairbrother, 2013)) and some shipbuilding suppliers on the market (e.g. Kongsberg "Ship's Bridge Simulators"). In most cases the modelling is done after the engineering phase as an additional effort. Currently there is no actor in the whole process who owns all necessary data for a 3D operator training system. The system models and simulation are on suppliers' side, often not in a closed system, and the CAD data for 3D graphic are on yards side. Bringing both together needs additional effort, in time and cost.

**Further Industries**

Modelling and simulation of complex, interconnected and interdisciplinary systems has been brought to the focus by the cyber-physical systems (CPS) which resulted by rising automation and interconnection of industrial systems. In the machinery and plant engineering sector the keywords in this evolution are smart factory or industry 4.0 (Lasi et al., 2014); smart grids are the equivalent cyber-physical systems in the domain of power generation and distribution (Chia-han Yang et al., 2013). The rising degree of automation leads to an increasing interconnection of electronic control systems and mechanical components. This is combined with a spatial deployment of subsystems which are connected via local area network or public internet. Such cyber-physical systems make high demands on the engineering and by use of only conventional engineering methods there would be a high error rate in commissioning. Knowing this, many supplier of plants try to establish the virtual commissioning, to simulate and correct if necessary the whole plant in good time before real commissioning (Hoffmann et al., 2010).

The Automation Initiative of the German Automotive Industry (AIDA) published a study in the year 2005 showing that 50% of the costs for the automation of a plant are needed for engineering and 10% for commissioning. The first measure was the development and standardisation of the data transfer format AutomationML for the smart factory, which is not a modelling or simulation tool itself, but it is the base for a common model for mechanical components and control functions (Hirzle et al., 2013).

Additionally there were attempts to establish functional modelling and simulation by including functional components into the digital mock-up. One project with this aim was "FunctionalDMU". Different simulation tools are connected via wrappers to a master simulation that provided time synchronization and data (Wagner et al., 2011; Filippo et al., 2014). A second project in this topic was „MODELISAR (Chombart, 2012). As result the Functional Mock-up Interface (FMI) was standardised, which is an open interface standard for co-simulation or model exchange between simulation tools (Blochwitz et al., 2011; Abel et al., 2012). The framework for co-simulation must be realised separately, but a lot of different frameworks have been tested successfully, among others: HLA RTI (Awais et al., 2013), Matlab® (Vanfretti et al., 2014), Assimulo/ PyFMI (Andersson, 2013), GridLAB-D (Stifter et al., op. 2014; Elsheikh et al., 2013), mosaik (Schütte et al., 2011) und Ptolemy II (Müller and Widl, 2013).

**Transferability of Results**

The results from research projects in the other industries may be used as base for similar tools in shipbuilding. But it is not possible to transfer it directly with the same positive effect. The specific characteristics of shipbuilding need a substantial extension of the approaches. Building special purpose vessels means permanent prototyping within very short time slots and with different prototypes in parallel each in a different construction stage. Because of the short times the modelling of the components and systems cannot be done after the design phase, it rather must be in parallel to project planning and engineering. Furthermore as prototyping is normal business the modelling itself has to be part of the standard processes and might be done for every ship to be constructed. Otherwise there is no efficient way for doing modelling and simulation for two or three vessels in parallel. A further special characteristic of special purpose vessels is the high degree of interconnection of systems which are caused by the limited space on board. Basic hydraulic systems and energy supply systems are used by all relevant systems and components together. This requires a lot more effort for integration and control, than it would be required for separated individual supply systems. These special structural needs in shipbuilding process and in ship technology prevent a direct transfer of the results and standards from other industries.

## INNOVATIVE APPROACH

Our novel approach has the aim to involve the functional modelling and simulation of the overall system ship with respect to the special structural needs of shipbuilding. Three phases in product lifecycle which are affected by the rising complexity of ships automation, are supported by the approach of functional modelling and simulation - engineering, production and operation (see Figure 1).

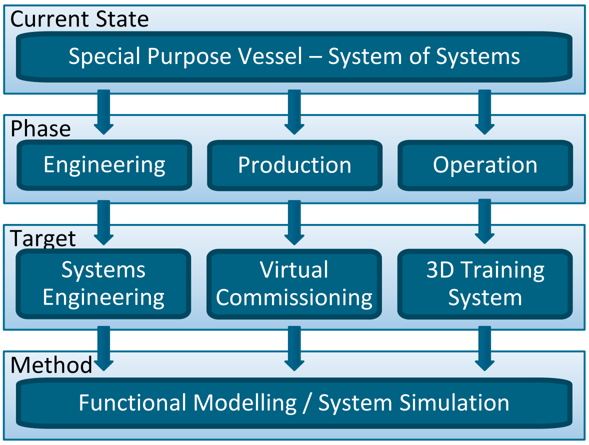


Figure 1: Overview of areas which require development caused by rising complexity of ships

The increasing interconnection and integration of ships systems lead to a difficult work and correlation during engineering phase. Different departments have to work on the same system with different aspects and focus. Model based systems engineering (MBSE) is supporting the engineering process with a uniform system model, which points out all requirements and dependencies and makes it possible to systematically pursue and realise them. The second supported area is commissioning during the production phase. By using a system simulation based on a functional behavioural model, a virtual commissioning can be performed prior the real commissioning. In doing so faults inside the interfaces between systems can be found. These errors normally occur during trials and testing shortly before delivery of the vessel and frequently lead to late delivery. Rising complexity does not only affect the engineering and production in shipbuilding, the operation of the vessel is getting more complex as well. On the one hand, the automation of processes relieves the crew of some tasks, but on the other hand, the operation of the systems gets more complex – especially in rare cases when quick manual intervention is necessary. The previously build interactive simulation of the overall system ship together with 3D graphic data based on CAD data from engineering are the basis of a 3D Operator Training System. This training system is available short time after completing engineering; hence, training of the crew is possible before the delivery of the vessel.

Our new approach is a modelling process with three steps, as shown in Figure 2.

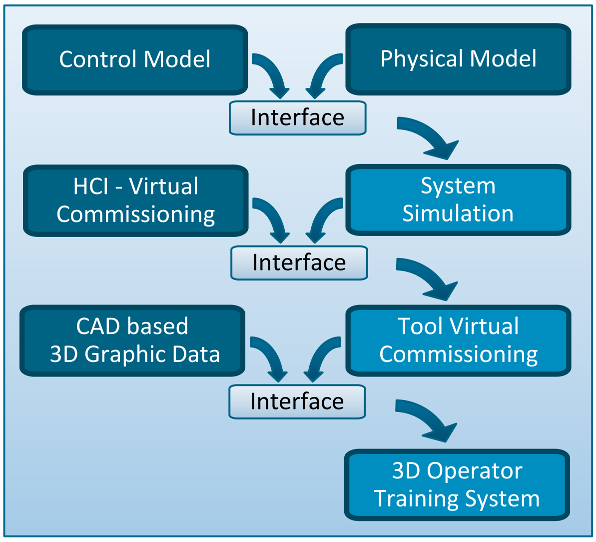


Figure 2: Three step concept for System Simulation, Virtual Commissioning and 3D Operator Training

The **first step** comprises the functional modelling of control sequences and of physical behaviour. Functional modelling of the control sequences for the system simulation shall not be a post-mould work; it is rather necessary to include it as part of the Model Based Design into the engineering process to support and simplify this process. Therefore the principles of systems engineering shall be implemented into the shipbuilding process by using the SYSMOD approach (Weilkiens, 2014). It is an optimized procedure for engineering and design of systems with high complexity; from requirement analysis to commissioning. During this procedure the overall system is modelled in SysML, a modelling language created for system development, which is suitable for modelling of complex systems on different levels of abstraction in a uniform model (Bassi et al., 2011). The control sequences are described on a higher level and the real physical realisation is not considered. The aim is to describe the functional behaviour of the system with suitable methods and validate with the model. Modelling starts with the requirement analysis and higher level functions and the model will be refined during the design process from concepts and functional drawings to components with detailed information regarding interface and behaviour. The work is done in parallel to the proceeding “project planning – basic design – detailed design” and the model can be used as a requirement for the following phase. The functional model contains all logical connections between systems and components, among others the reaction of a system on the change of a physical input value. It does not contain the information under which circumstances a value changes. For simulating the real states of the system ship a physical behavioural model is needed. This model shall developed by using Modelica because of the large number of existing preconfigured models in libraries and the real-time capability. By combining the model of control sequences and the physical behavioural model via an interface a model of the overall system ship is created which allows real-time simulations on suitable simulation platforms, for instance Modelica-based platforms or Matlab/ Simulink (Palachi et al., 2013).

In the **second step** the system simulation is taken as core for the virtual commissioning tool. Therefore it has to be enhanced with an user interface, which can be used for changes in the parameters of the ships systems. Therewith different operating states and scenarios can be realised, to test the interaction of the systems during the virtual commissioning. This can be done for single components or systems as well as for the overall system. In addition it is possible to implement a hardware-in-the-loop (HiL) functionality which allows the yard to do specific trial during the factory acceptance tests.

The comprehensive simulation of the ship shall in the **third step** also be the base for the 3D operator training system (Mesing and Lukas, 2014). By linking the physical behavioural models of the components with 3D data a graphical model is build which reacts in a physical correct environment. The necessary 3D data can be generated from the 3D CAD data which are usually available on the yard. Additionally there will be interaction and control functions for the trainee. The needed input options for the instructor to change operating states or parameters and to define, start and save scenarios are mostly given by the tool for virtual commissioning.

## CHALLENGES AND SOLUTIONS

The above-described three-stage approach as shown in Figure 3 contains several technological and process-related challenges. The biggest challenge is the large number of systems and components which build the overall system. This results in a high modelling effort, which is critically, especially in context with the short development times. All three models, the functional model of the control sequences, the physical behavioural model as well as the geometrical model will be very extensive and interconnected.

The several problems in each phase shall be mentioned in the order of the common process according Figure 3:

### Modelling

The problem of modelling effort can be reduced by importing delivered models from the suppliers. For the functional model of control sequences this concerns mainly the internal logics and dependencies of a system, i.e. the sequences which decide how the systems react on a changed input value or how an output value changes. Especially complex systems like main engines have control programs with some hundred input and output signals. The technological implementation of an import functionality is complicated because of missing established standards. While there are standards for PLC programming languages defined in IEC 61131-3, which are used successfully for virtual commissioning (Carlsson et al., 2012), soft PLCs and industrial PCs are mostly modular based programmed in a supplier

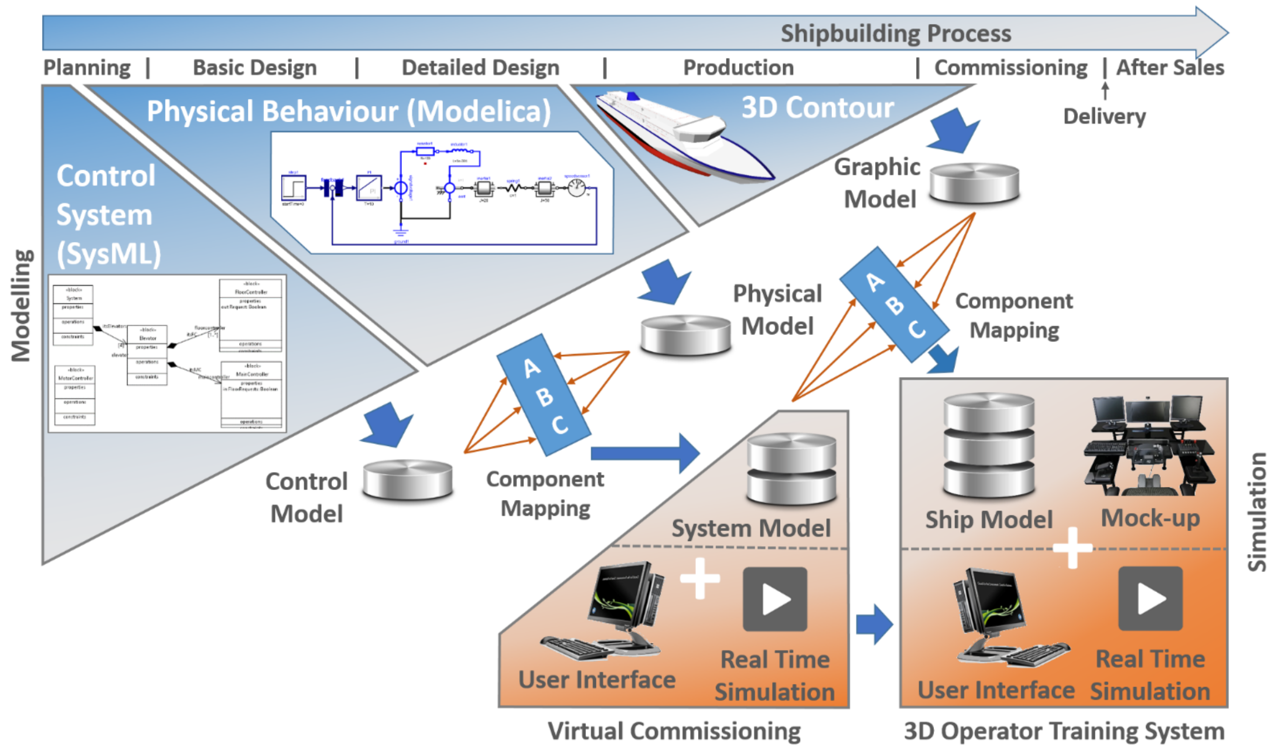


Figure 3: Concept of stepwise modelling and simulation during shipbuilding process from planning to after sales service; the three models are generated one after the other with overlap; after mapping the control and physical models and connection with user interface and simulation platform the virtual commissioning can be done in good time before the real commissioning; by enhancing the tool by the graphic model and a mock-up the training system is finished

specific programming environment. Especially for the systems with extensive and complex control programs there are no established standards available, which means that all the import interfaces have to be individually adapted for each supplier.

In physical modelling the import function is not a big challenge, because with the FMI interface an established standard exists. More critical in this case is the granularity of the model. The large number of components and systems and out of that the large number of parallel running physical processes limits the real-time simulation with highly detailed physical behavioural models. The granularity of the models must be decreased to keep the real-time capability of the simulation. Despite expected problems with the simulation size there is the problem of intellectual property protection. Detailed models with high granularity can only be realised with the support of the suppliers, but they will not give the needed support if detailed know-how will be disclosed. That is why only simplified models can be used for physical modelling. Possible ways to achieve a simplified model are the reduction of an existing detailed model by the supplier or the reproduction of a new simplified model. In both cases the supplier has to be taken into the modelling process, as only the supplier can ensure that the behaviour of the simplified model is equal to the detailed model in all relevant parameters and properties. The challenge is to explore the degree of detail which is on one hand sufficient for a realistic physical behavioural model and on the other hand allows a real-time simulation with a large number of subsystems and is supported by the suppliers.

The preparation of a navigable 3D graphic model out of 3D CAD data is well established and widely used. These models are used as assistance during interior design and for operator training systems. In this project it has to be considered that some mechanical components change their geometry during the simulation, for example a bow visor or several switches.

**Interfaces**

Beside the previous mentioned challenging aspects of modelling and model import there are some procedural problems. The different models of the components and systems – control model, physical behavioural model and geometrical 3D model – have to be connected by interfaces. As the different models are build up at different times during engineering the correct **mapping of models** has to be ensured by a uniform and consequent nomenclature. This linking does not only affect the components itself, the single inputs and outputs have to be mapped. If physical sensors like revolution counters or pressure indicators are used in components which are directly looped through to an analogue output signal, then these output has to be linked automatically to the equivalent input signal within the control model. Linking input and output signals by hand can – in view of the size of the overall system model – only be done in exceptional cases.

There are several methods available for the **software realisation** of the interfaces. The SysML-Modelica Transformation (SysML4Modelica) is an enhancement of the SysML by some Modelica specific stereotypes, which lead to an integration of the Modelica language in SysML, hence the complete physical Modelling is done in SysML (Vasaie, 2009; Paredis et al., 2010). A second method for combining SysML and Modelica is co-simulation in hybrid models using FMI (Baobing and Baras, 2013; Feldman et al., 2014). For integration of SysML models into Matlab/Simulink there are also solutions present (Qamar et al., 2009; Sakairi et al., 2013). The human machine interface and its connection to the model and the simulation depends on the used modelling and simulation software. But no matter which solution is selected, the creation of a customized user interface for displaying values and for input of user parameters is available by default. For connection of the system simulation with the graphic model there are some solutions present. One of these is Instantreality (Behr et al., 2011), a framework for virtual reality methods, which allows users direct interaction via touch screens, even with multi-touch screens.

**Simulation**

Besides the mapping of the different models of components and systems the interfaces must ensure the time synchronous processing of the three simulation parts and the efficient data transfer. Such frameworks for co-simulation of different simulation platforms already exist. However, the direct usage in this application is not possible because based on the large number of parallel interconnected processes the framework has to ensure a particularly efficient data transfer and hence the interfaces must be optimized regarding this requirements. It has to be analysed with a sufficient large model if it is possible to enhance or adapt existing frameworks or if it is necessary to build up a new framework.

**Process**

Along with the mentioned technological and procedural problems there are process-related challenges. Modelling and simulation of the overall systems have to be **implemented as sub-process** in the existing shipbuilding process without extending the total time until delivery. For modelling the control sequences the principles of systems engineering shall be used. This closed process for engineering has to be assigned and linked to the corresponding phases in the shipbuilding process. It is important that both processes are running in parallel without delay. Otherwise the model of the overall system ship cannot be provided in time to ensure an extensive virtual commissioning in good time before the real commission.

For each single challenge in this novel approach there is a solution available or can be derived from other industries. The task is to bring the solutions together and create a software framework that combines the existing tools on an efficient way.

## CONCLUSION

The presented approach fills the gap in the virtual support of the complete shipbuilding process, taking into account the specific structural needs – short time, high cost pressure and high quality demands. Although virtual support for product development has gained acceptance in shipbuilding industry since last years, there mostly are single solutions for specific problems in hydrodynamic or mechanics and systems for supporting production process. There are no approaches known for the continuous support of the project planning, engineering and design process. Especially the early phases in the shipbuilding process are essential for successful delivery of a ship because cost-intensive decision are made here and errors in this phase often lead to problems in design which can only be solved with an enormous invest of time and money.

We presented a concept for such a comprehensive modelling and simulation approach for the shipbuilding process including after sales service. The consistent application of the principles of system engineering and the preparation of the system model in SysML assists and strengthens the project planning process and the design process for the complex system ship. The combination of the control model for the systems and the physical behavioural model enables a system simulation which supports the system integration during engineering and production by use of virtual commissioning. The extension of the system simulation by linking with 3D geometrical data leads to a 3D operator training system, which can be offered by the yard as service for the owner during final trials and after delivery. Hence this innovative approach with one continuously developed model covers nearly all phases of product lifecycle and supports in product lifecycle management. There are many methods and professional tools present for single tasks of this approach. The main task will be the connection and integration of these methods and tools to a unified lean process which is supported by efficient customized software tools.

## OUTLOOK

The previously introduced innovative approach can only be realised with additional applied research with industrial partners, research institutes and engineering service providers. It is necessary to combine the fields of systems engineering and modelling of control sequences, modelling and simulation of physical behavioural models, programming and linking of 3D graphical applications, as well as creating and optimising processes. Although there are a lot of products and knowledge existing in the mentioned topics, research and investigation are needed to achieve the goal of a uniform model of the overall system ship for simulation and training. While the research will mainly be done by the research institutes and engineering companies, the industry partners have to contribute critically and constructively. First and foremost the shipyards have to be the driving forces behind the project – they define the requirements, specify conditions and mainly benefit from the results. But also the maritime suppliers have to support the project with openness and cooperation. With effort, openness and cooperation on all sides the project can bring the shipbuilding industry a clear step forward.

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