Navantia's Digital Twin Implementation Perspective in Military Naval Platform Life Cycle

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ABSTRACT

Digital transformation is a cornerstone to increase efficiency and productivity in today's businesses and enterprises, and Modelling and Simulation (M&S) play a critical role in the successful implementation of the Digital Twin (DT) seen as a holistic approach: starting from the early conception and design phases, where models of a wide variety of types are supporting the process, afterwards stepping into the production, including validation and verification phases, right up to the final phases where the product is to be delivered and the end user needs to be trained to effectively make use of it, and to sustain it during the entire life cycle.

Navantia is facing the incorporation of the Digital Twin into the internal processes and delivered products as a differential factor, adding significant value not only to the production processes but also to the system´s life cycle. During the operation of the systems, Modelling and Simulation are becoming more and more important for end user training, especially in complex scenarios, and to enhance the system maintenance, where models are also used to carry out maintenance intervention before the system fails, preventing unplanned downtime.

This paper will show Navantia's view on the Digital Twin in the Smart Factory, and the use of M&S techniques to develop tools for User Training and System Maintenance.

1.0 INTRODUCTION

One of the most attractive investments in relation to enterprise digital transformation is the implementation of the digital twin concept in its products development roadmap, achieving a truly smart product portfolio. New value-added services exploiting this digital twin are open in new formats, either human centred and/or machine centred. Customer and contractor are benefited from that in their respective interest spheres, specifically the use experience including the availability and performance for navies, and the product development improvements for the shipbuilder.

These two spheres of interest overlap in terms of opportunities (e.g. efficiency improvement, asset´s running cost reduction, etc) but diverge with respect to specific use case´s goals. Naval shipbuilder´s improvements are mainly achieved in the design and development phases. Customers will reap improvements in operation and sustainment phases. Due to intrinsic uncertainties in terms of DT requirements fulfilment including an optimistic target ambition level, the DT development must be evolutive in such a way that investment and return criteria is addressed as an iterative process. The agile methodology provides the basic concept for achieving it. Digital twin implementation evolutive strategy is a must and scalability and robustness are key characteristics for harmonizing investment level and profit return in each step.

Naval shipbuilding deals with complex systems, so digital twin implementation level must be progressive and evolutive as well, in terms of enabling technology maturity and complex modelling algorithms availability. Overall investment is significant so incremental waves in digital twin´s functionality specification is unavoidable, ranging between functional models of simple systems up to adding health prediction along time, extension to other systems with increased complexity up to extending this concept to the integrated System of Systems as it is a modern naval ship.

Navantia´s digital transformation plan includes new smart product and services development programs. This paper deals with challenges derived from DT strategy and rationale for digital twin investment, objectives and technology bases, the Digital Twin Methodology approach and the step-by-step agile development, the conceptual architecture and system definition, and finally some references about real cases and future developments.

2.0 NAVANTIA'S DIGITAL TWIN APPROACH

2.1 Rationale for Digital Twin Investment

There are plenty of reasons why shipbuilders and naval assets owners must adhere to Digital Twin development and implementation. The benefits are at least those already achieved by other industry sectors stakeholders, in general benefits from having product configuration and real status fully characterized, but especially since naval assets operate at open seas with limited reinforcing deployment capability for repairing or operating by skilled people. It is also remarkable the life cycle cost reduction (15-20% is a widely accepted improvement for smart maintenance functionalities) along with the safer operation and higher availability of the assets for the mission. A highly efficient Navy is the overall target of many nations with limited defence budget.

DT as a high-resolution digital replica allows crew and land personnel, both navy and shipbuilder, to know the status of different parts of the ship and personnel integrated as a system.

Availability for the operations and consequently readiness for the mission´s understanding is much faster as DT functions using a central information system both for equipment and people status. Systems and components behaviour monitoring with respect to historic data and against to their corresponding models, allow for detecting anomalies early, giving time to the system to anticipate the symptom, giving time before incurring in malfunctions or eventually a failure.

Basic components of a DT are the Digital Mock up (DMU) with the static or persistent product description and behaviour characterization information structured in a data base along with configuration management tools, and the dynamic information compiler where product as an asset shows the real status.

DT is consequently an information system with advance data and model's management capabilities, with application´s development and execution environment for exploiting this digital information as a set of smart assistants to the relevant end-user.

As it is described in this paper, DT is an overarching technology that involves and puts in play more than 12 digital transformation technologies with the goal of providing better products to customer (safer and easier to operate, higher maintainability, achieving more performance, etc).

2.2 Objectives and Technology Bases

The main objective of the Digital Twin is to enable the replicability of real things like those on board a naval asset, as reliable and confident cyber-physical systems. There are different complexity levels to be faced and integrated up to getting a hierarchy of well-structured lower complexity element´s digital twins. A naval ship DT will consist consequently of a set of system´s DTs which at the same time will be a set of element´s DTs. Smart products consist of smart systems composed of smart elements (things), all with analysis capabilities and interconnected.

Smart attribute for things will consequently include computing and communication capabilities suitable to recognize its own functional and health status and to communicate with other elements in the upper and lower levels of the product hierarchy in terms of orchestration.

Intelligence level steps are initiated from implementing simple algorithms and a basic human to machine interface, up to complex artificial intelligence algorithms capable of extracting deep insights suitable to support upper level´s decision or eventually to even take those decisions, this will be possible once situation awareness and evolution estimation achieves required maturity and confidence.

Enclosed figure shows the different goals for smart products development.

As a summary, objectives in the different evolution staircase steps must be aligned with enabling technology maturity and availability. It is mandatory to specify basic technology and specifically derived needs for addressing each step for solving either more complex systems or simplest one's implementation.

Each product must be broken down allocating priority to systems returning high value in the short term to customers and/or developing company.

2.3 DT Methodology Approach

In accordance with prioritizing objectives in terms of service´s potential attractiveness for customer, considering reliability, total cost of ownership, functional and performance capabilities as well as shipbuilder interest in terms of product development´s efficiency improvement for achieving the digital return of investment, the corresponding target specifications and goals must be sequenced in time.

A high demanding target requirement in a short-term interval would require a high investment and a high-risk profile particularly if the necessary technology is still not sufficiently mature and vice versa, if the goals were too basic they would not allow to drive with enough intensity to build a robust roadmap.

A robust foundation base from which models and data are being managed for performing the right analytics is paramount for success.

2.4 DT Stepped and Agile Development

Navantia is adopting an agile methodology for establishing technology and modelling robust foundations, addressing only one type of challenge at a time and scaling results for feeding back an incremental number of targets and/or its level of complexity.

DT is currently being managed at concept development stage through a moderate low investment with short term validation loop in terms of results evaluation, scalability and progression climbing in the ambition level staircase.

Company executive level approves each investment, once the program is running, providing an instrument for tracking real interest in internal axis (efficiency, smart integration, quality, etc) and external axis (customer demands, real value provided and overall satisfaction). New advanced services supported by DTs are potentially huge, so it constitutes the practical target. Applications and configuration management for either hardware and software require a new system architecture for DTs.

2.5 Conceptual Architecture and System Definition

The architecture of reference for DT must be at least modular, scalable, data oriented and driven. It consists practically of an information system with a runtime execution infrastructure providing basic data servers to support digital mock up data and behaviour models, an application server for applications either supporting analytics functions or other runtime managers in form of a set of applications. Once product virtual part is activated the DT shall get and record historic data, acting as an alive dynamic real status settler. DT must solve the needs of getting and aggregating adequate real-time data, exploiting functional and health behaviour models as this pre-conditionate data processing reducing ambiguous results and improving outcome value.

DT conceptual architecture for Digital Twin at Navantia is showed in the following figure:

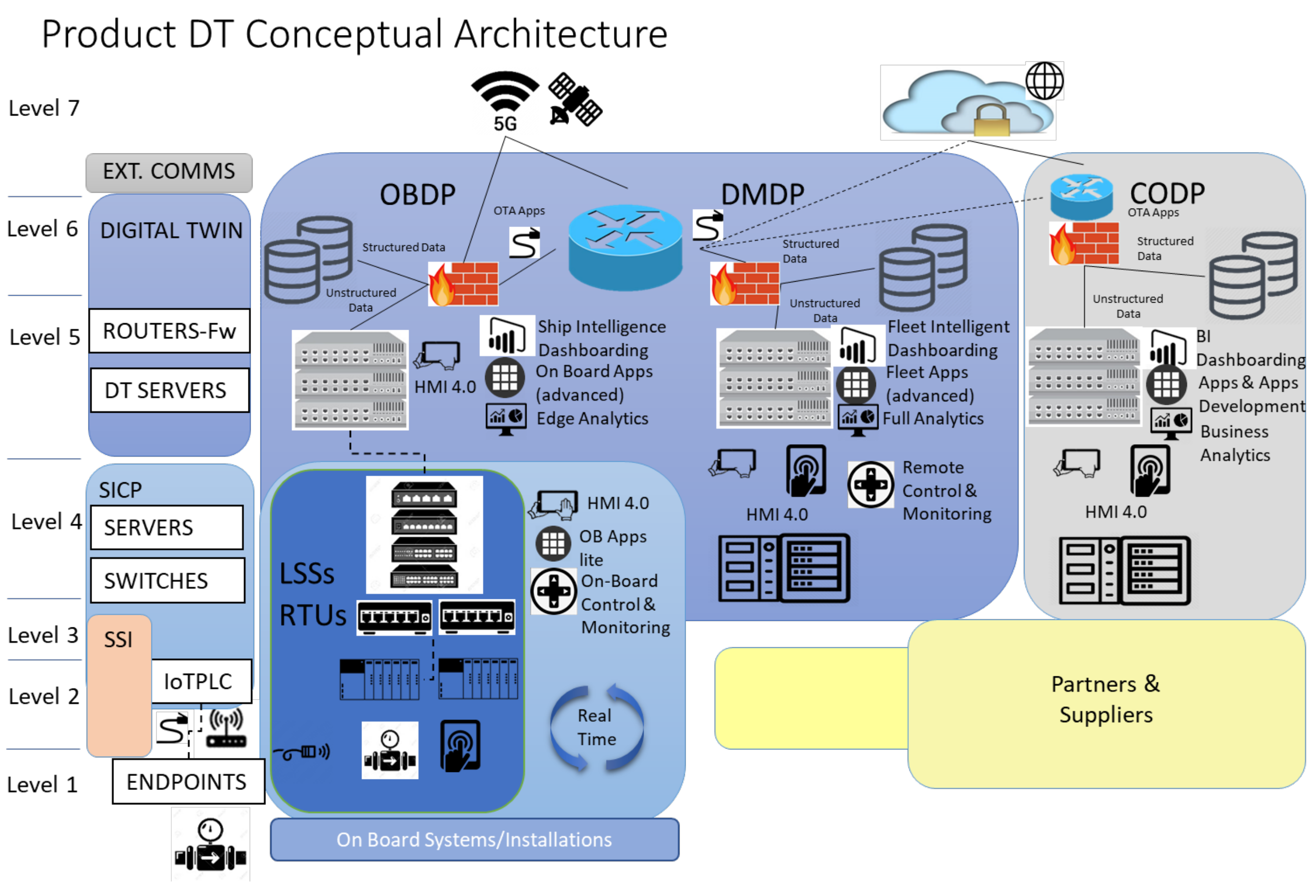

Figure 1. Product DT Conceptual Architecture

In this figure there are 6 levels of data management and decisions, the level 1 where there are simplest things as equipment or components, allow for a basic smart capability (processing simple algorithms with a reduced time response), the level 2 where the smart system uses IoT ready PLCs to allow policy directives for execution and orchestration of level 1 smart equipment, level 3 represents edge computing resource level, including integrated services system (SSI). Level 4 contains an enhanced IPMS (SICP in the figure) for health management as well as whole platform systems functionality management. Level 5 comprises of on-board digital twin digital platform enabling for use case interest analytics execution as well as managing the digital mock-up data set and applied algorithms under applications developed within a configuration management framework. Level 6 implements other digital platforms part of the DT eco-system normally at land (end user, Navantia). Level 7 represents the cloud resources, when needed, being under control in terms of cybersecurity.

For cybersecurity assurance, there will be intermediate levels in the architecture where adequate security firewalls and data traffic analysis devices, these levels assure that only permitted data flows between levels and zones are allowed.

Initially, the HMI for new advanced functionalities will be provided to people through a portable or wearable device, empowering them for their duties.

Currently, there have seen in the industry forums some simplified vision where DT is viewed as a simple synthetic physical model (CAD geometric, parameters and materials data) and its real status data is obtained by adequate sensors and aggregated for recording and displaying in a friendly and efficient style using a real + virtual representation.

Navantia´s mindset is focused on the long end and highest ambition, to fully exploit smart ecosystems we require powerful DTs, and this can only be achieved if specific product engineering information about modelling and data are developed from the first design phase, in addition to classic needs for constructing real systems from engineering. DT is consequently the opportunity of getting more value from engineering investment within a product development effort and further towards the last segment of the lifecycle (end to end).

Architecture must deal consequently with functions managing static data, simple models (digital mock-up or DMU) and basic engineering behavioural models as well as dynamic data and advanced models using machine learning or deep algorithms.

Integrated Platform Monitoring System (IPMS) will continue evolving, managing ship platform subsystems, taking smart actions over real time decisions influencing the ship´s systems whilst DT goal is to establish the general operations scenario framework parameters for IPMS and decision makers (on board crew, off board crew and/or AI algorithms).

Data models for addressing information structure is another key aspect for DTs architecture definition and implementation. Depending on information processing complexities and required quality in feeding processes, the architecture must allow for and support different reaction or decision loops needs. Achievable span or margin is modulated depending of the capabilities of the different architecture levels nodes for processing and data interfaces bandwidth as well as allowed latency by consuming processes.

Various decision loops will be executed concurrently in the architecture, could be HIL types being understood as human in the loop (local / external) or machine to machine (M2M).

Naval ships operate all over the world over brown and blue waters. These special circumstances limited the highest ambition in terms of decision or decision support loops as having access to internet in the sense of a universal cloud cannot be guaranteed 100% of the time because of satellite data links availability or bandwidth limitations.

DT architecture must incorporate enough on-board processing capabilities for closing the loop for action at corresponding information management levels for these dark situations. Cloud computing must switch to act as a private distributed cloud, an on-board cloud, or as normally overall designated edge computing when sailing in blue seas.

When ships approach the coast, these loops can be wider as interconnection with land infrastructures is available. Maximum capability is considered when ship is in the naval base peer with maximum communication capabilities within system platforms communication range and the cloud.

Due to the sensitivity of the information supported in a DT, all elements of the architecture must be secured in terms of cybersecurity.

2.6 Conceptual Architecture and System Definition

An agile approach has started running first MVPs (Minimum Viable Product) over which is relevant the DT concept exploration in a smart system. Once project evaluation is performed, those aspects suitable to be scaled directly will be identified as well as those that require further refinement or to be reconsidered.

An initial experience based on functional models for a simple HVAC (Heating, Ventilation and Air Conditioning) system is currently running and an extension with focus on predictive and smart maintenance is under preparation for overseas market. The initial MVP experience identifying exploring options is summarized in the following figure:

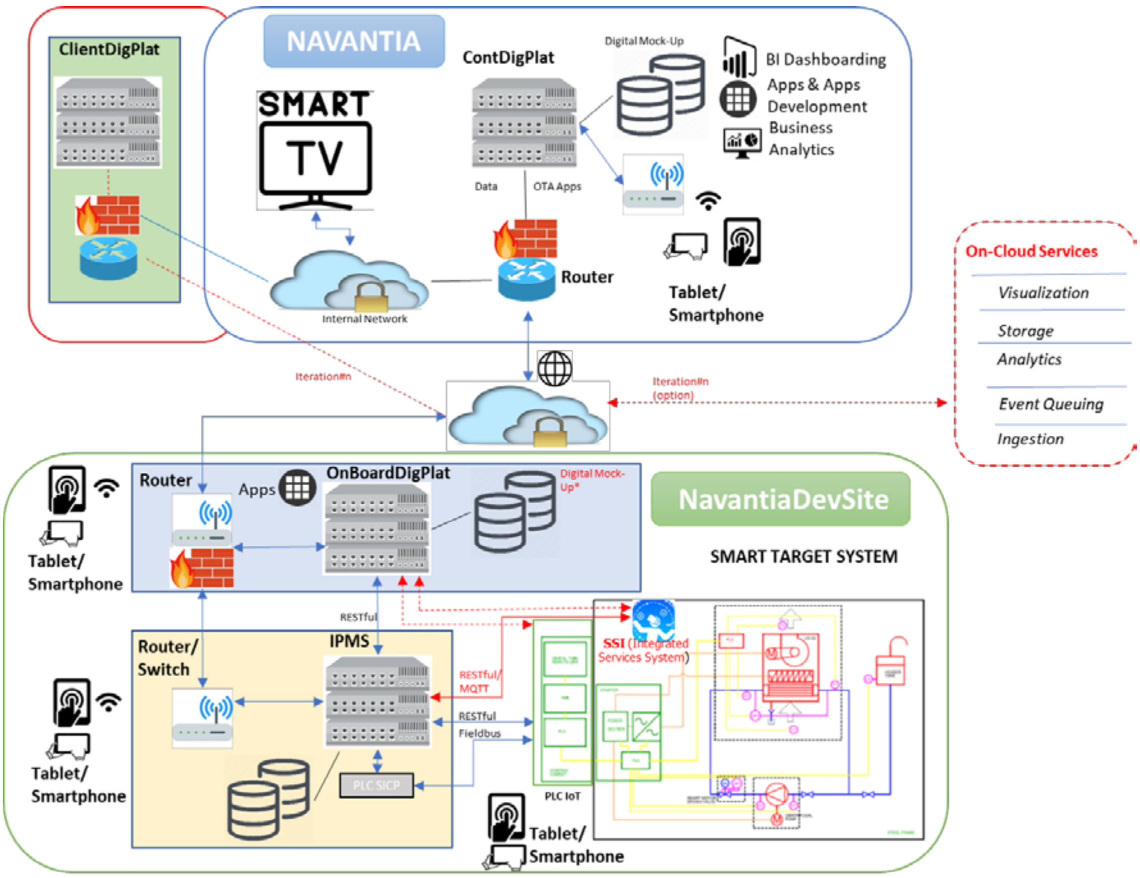

Figure 2. Initial DT Minimum Viable Product Experience

New ships are currently under development being this experience of great value in showing the right ways when it comes to dimensioning a DT. Flexibility to upgrade and scale for custom-specific requirements is embedded in the approach.

Finally, autonomous and/or autonomous for X ships are in the further levels of the roadmap. Here, solutions robustness must be maximum and dynamic situational awareness based on self-learning algorithms are key for success.

2.7 Real Cases and Future Developments

New F110 class frigate includes a Digital Twin exploiting several customer interest dimensions, the operations and life cycle management for total ownership cost reduction during the expected life cycle span, improving reaction time in case of incidents either derived from a damage or a fault/casualty, etc.

This DT system uses all architecture levels as consisting of land-based installation digital platform at customer premises as well as shipbuilder, and the corresponding on-board installation in each of the frigates. Those data aggregation and processing capabilities requiring intensive data analysis could be developed off-board but synchronized with the overall DT platform ecosystem, using a dedicated analysis centre capable to interchange improved and calibrated algorithms in the usage applications from land to sea assets. Configuration management is a cornerstone for controlling each ship as built configuration and as sustained one either for hardware, for digital mock up and for applications suite update over the air (OTA).

This new frigate class incorporates a state-of-the-art IPMS+ fully integrated with the Digital Twin system and the Integrated Services System (SSI). The F-110 IMPS+ is capable to connect, extract data and process on board equipment and crew members data along all spaces of the ship. SSI allows the interconnection infrastructure to be either wireless or wired and local computing nodes for aggregating data and fast-paced reaction.

In terms of future developments, DT applications will be extended in accordance with Customer and Navantia needs once a broad data model and exploitation policy is consolidated. New digital services are being defined to be supported using smart apps and assistants.

The Appendix 1 provides further details of one of the capabilities to be incorporated into the DT, the NAVANTIS training suite, that is a family of products and tools under development with existing successful results to train the manoeuvring and piloting of the ship in an immersive and realistic environment, that is also integrating additional already developed functionalities for Combat System and maintenance training, and finally will provide an integrated environment to facilitate the training at different levels.

Appendix 1

Navantia Training Integrated System (NAVANTIS)

As said previously, Navantia is facing the DT development and implementation through an agile approach, to de-risk the investment and elude inappropriate decisions, and to take advantage of existing developments already undertaken to reach intermediate goals that cover a portion of the overarching solution. NAVANTIS is one example of this, since it is an already developed system to provide an integrated training solution to a variety of necessities, from the early phases to educate the user in the maintenance of the system, to the final phases to provide an interactive and realistic simulation to train the end user in the operation of the system at any level.

A.1.0. WHAT IS NAVANTIS

NAVANTIS is a new family of products and tools oriented to support the end user training in the operation and maintenance of the Navantia ships and their systems. It has a modular and scalable architecture to be able to adapt to any required configuration of ships and systems, and also be ready to accommodate any future equipment and capabilities during the life cycle of the delivered products. The next figure shows the general structure of Navantis concept:

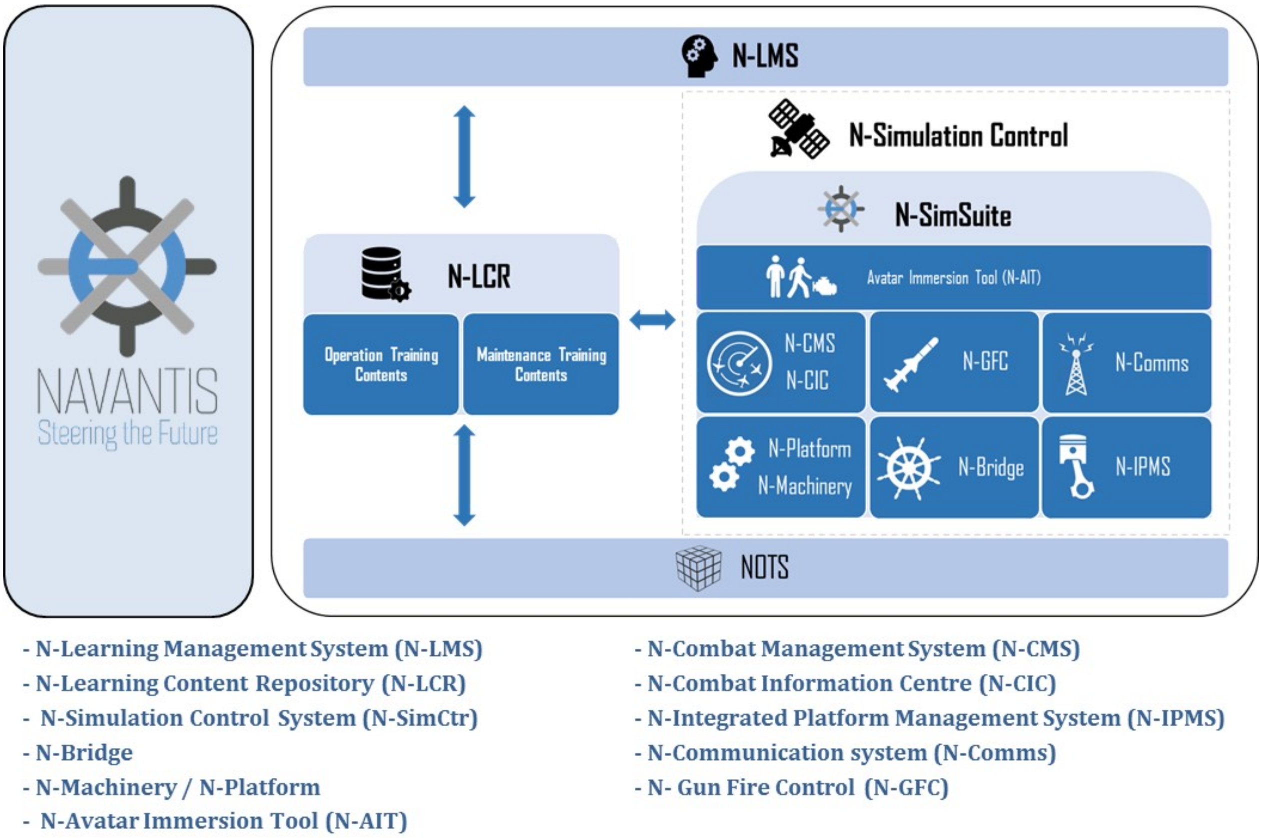

Figure A- 1. NAVANTIS Conceptual Architecture

NAVANTIS is the integrated training solution for ships designed by Navantia. The training is carried out in two stages:

- An initial stage based on e-learning, for a first contact with the ship systems. This first stage allows access to mass training of as many members of the crew as necessary. Since it is based on Web technology, it does not involve resources or take up specific premises, allowing the crews to become familiar with the tools needed to operate a vessel.
- A second in-depth stage is carried out using hands-on exercises, where the trainees operate, by means of highly realistic virtualized HMI interfaces, on real-time simulators. This second stage is for selected crew members with specific responsibilities and the training sessions take place in dedicated NAVANTIS classrooms.

Figure A- 2. NAVANTIS Typical Layout

A.1.1. Navantis Classroom

The NAVANTIS classroom houses the equipment used to operate on the simulated vessels. Its main features are:

- It is modular and **configurable**; generic NAVANTIS hardware modules are arranged in the room to suit biggest platform and then specific software for each particular ship is loaded for every training session. A single classroom covers all single-ship simulator training.
- Software specific modules provide **particular ship HMI**. Virtualized hardware panels are implemented at a high degree of detail resulting in a close familiarization with real hardware interfaces of each ship in particular.
- It **integrates** local platform systems operation training, remote platform operation training (IPMS), bridge crew training, Communications and more.
- It is **inter-connectable** with other NAVANTIS classrooms.
- It allows to impart **collaborative** training, so that the key members of the ship's crews interact together in the same session and face the same scenarios in a coordinated manner.

- The NAVANTIS facilities are **multiuse** since not only can they be of use as a training classroom, but also as an engineering laboratory to debrief real ship logs in order to study any real platform issue, discuss or develop new IPMS features and also test new IPMS versions before being installed on board.

The disciplines which are contemplated as potential contributors to NAVANTIS are:

- The ship Platform equipment and systems (engines, valves, rudders, pumps,…)
- Integrated Platform Management System
- Navigation System
- Communications System
- Combat System

All systems end up having their representation or their effects in the virtual natural environment. During the training sessions the environment outside the vessel is represented, aiming to provide the operator with a subjective view of the physical surroundings. Each NAVANTIS room allows each of the different crew members to see from their own perspective both the world that is outside and the environment within the ship.

A.1.2. Navantis Training Levels

NAVANTIS is structured with different training levels within a single product, as explained below.

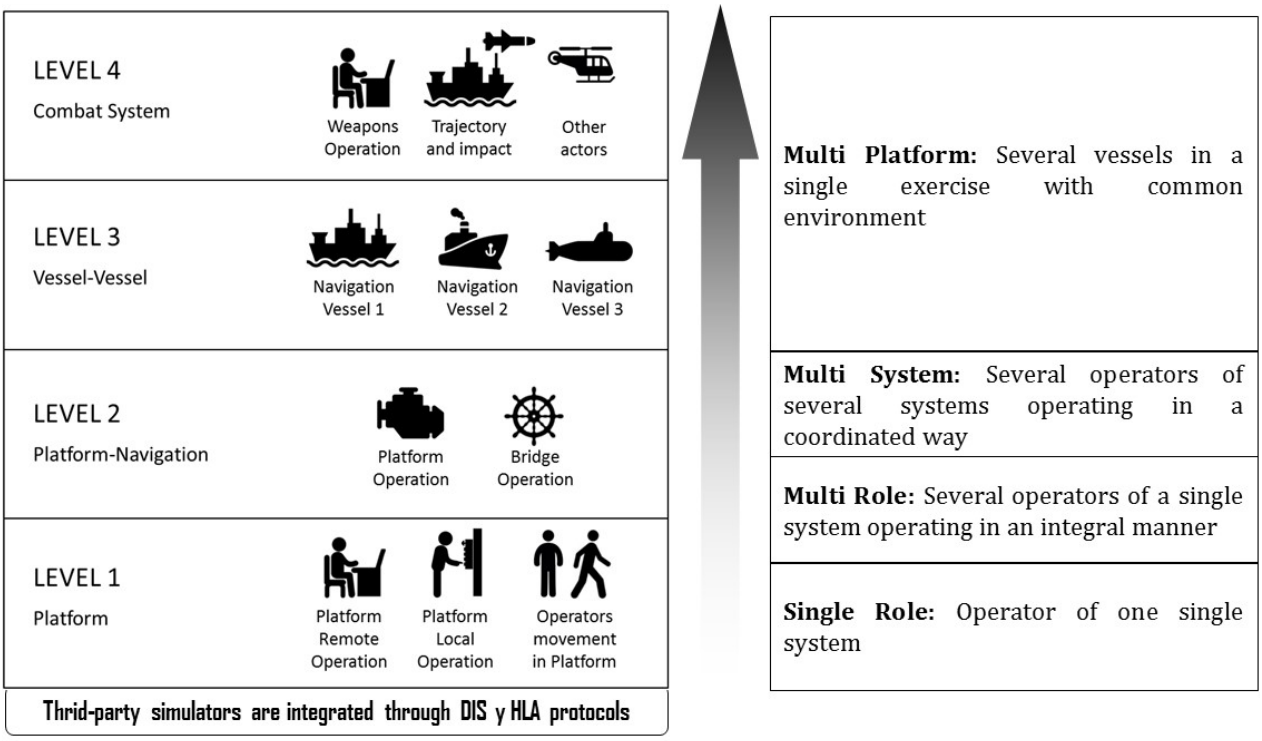

Figure A- 3. NAVANTIS Training Levels

- LEVEL 1: Platform.

  NAVANTIS teaches the crew how to operate the multiple ship platform equipment and systems that make up the ship Platform, combining the remote operation from the Integrated Platform Management System (IPMS) consoles, with the local operation at the equipment and system local operation panels. Mechanical, Electrical and Damage Control specialists will be able to execute control actions by acting on the remote interface (IPMS mimics) and from the local control panels (by means of virtualized physical panels). Above all, they will learn to coordinate among themselves and they will also gain a deep ship geographic knowledge of the physical environment where they will have to move.

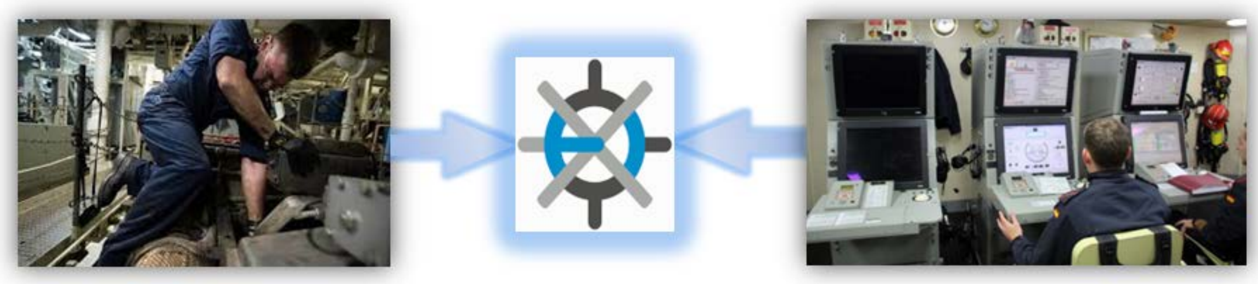

Figure A- 4. Level 1 training: how to operate systems

- LEVEL 2: Platform – Navigation.

  NAVANTIS has the capacity to simultaneously cover the Engine operators training and the Bridge operators training within the same ship, covering to the maximum detail all aspects each type of operator must know, but also contemplating the interrelations that there exist between the two worlds. For example, if while the Bridge operator is practicing a manoeuvre of entering and docking at the port, a problem rises in the power generation plant whose consequence is a black out of the ship, the Engine operator must know how to react to resolve the situation in the minimum possible time and recover bow thrusters availability to the Bridge operator. During this transitory risk situation there must exist a dialogue and coordination between both kinds of crews, which is necessary to have practiced in advance. Engine operators operate virtually from locations such as the machinery control room, the electrical switchboards or the engine rooms, and get a good vision of the ship from the inside. At the same time, the Bridge operators act virtually from the bridge and, through their windows and the navigation equipment located at the steering console (nautical charts, radar, AIS), get a vision of what happens outside the vessel.

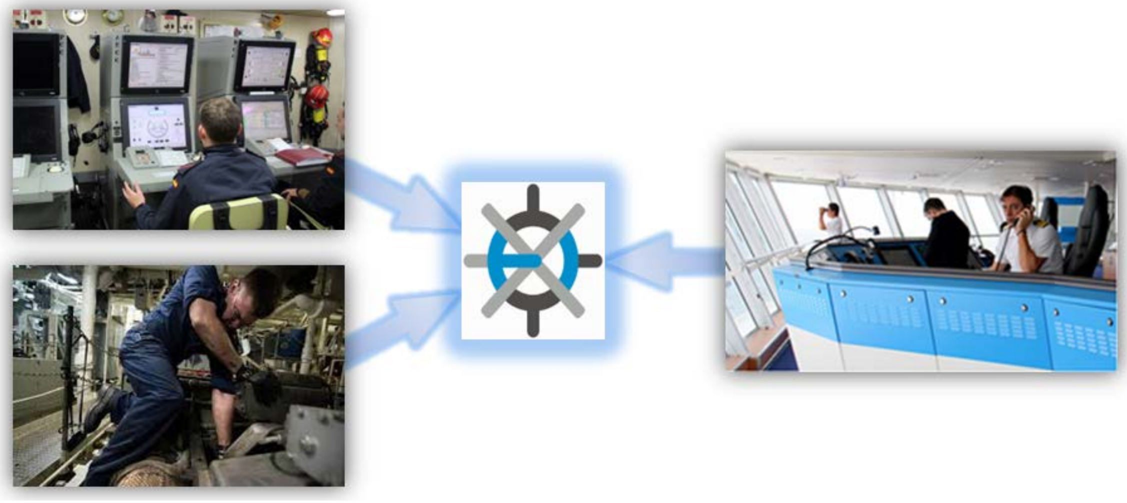

Figure A- 5. Level 2 training: manning the ship

- LEVEL 3: Ship-to-Ship

NAVANTIS takes a step beyond the concept of integrated platform training, since it allows joint and coordinated training operations execution involving different vessels and crews. For example, landing crafts docking manoeuvres to and from amphibious transport vessels, practice any ship's RHIB surveillance missions or even ship to ship supply in Replenishment At Sea (RAS) manoeuvres. NAVANTIS power is particularly demonstrated with this last specific scenario since allows ship to ship bridge pilots coordination, together with crew engineers training on fluids or loads transfer once the connection is achieved.

Figure A- 6. Level 3 training: Ship-to-Ship

- LEVEL 4: Combat System.

Once Navantia vessels training is fulfilled at platform and Navigation level, NAVANTIS can also incorporate other training solutions for systems or crafts existing on board. Full ship mission simulator is then complete. This is achieved since NAVANTIS has been developed using Military Scenario Definition Language (MSDL) and distributed simulator interface standards. Exercise situation is distributed via data-link simulation network to all participants, sharing virtual representation in a coordinated coherent way.

Figure A- 7. Level 4 training: full ship manning

NAVANTIS in its concept, is a live product and not exclusive to a single ship or Navy. Depending on the protocols established international training sessions among NAVANTIS centres could even be held.

An inherent feature of NAVANTIS consists of transferring to the professional training certain concepts typical of the video gaming world, with the goal of turning the apprenticeship into something attractive and user friendly for the trainees, thereby increasing their level of interest and participation. This is achieved by using very realistic visual and sound interfaces, and by introducing challenges to the trainees to promote competitiveness.

Figure A- 8. NAVANTIS classroom