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Innovative Solutions for Cooperative Training in the Maritime Domain

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CHAPTER 1:
Modeling & Simulation Foundamentals

1.1 Modeling & Simulation basic concepts

Acting on a real system is the only way to know how it reacts when specific actions are undertaken but unfortunately, this approach is not always possible or convenient. Therefore, most of the time a physical or abstract model of the system under investigation is developed and trials and experiments are carried out on it. To this end, both physical and abstract models can be considered as a simulation of a particular system. Think of, for instance, the scale model of a ship that is used for model tests with the aim of estimating its hydrodynamic coefficients ant its performances parameters. This approach is usually preferred to traditional methods, based on physical laws that may be too difficult to deal with or to implement. On the other end, it is highly unfeasible, owing to the large amount of financial resources it requires, to build a real ship for sea trials. For this reason, resorting to a model can often be a useful approach when direct trials on a real system/object are unfeasible. However, it should be noted that an abstract model may entail two options:

- The model is simple and can be solved by an analytical /numerical or statistical approach, for instance:
    - Differential equations;
    - Linear programming theory;
    - Queuing theory;
- The model is complex (like it really happens in practice) and if it is not possible to detect the mathematical laws governing its behavior and the stochastic component cannot be neglected then simulation is applied.

Simulation allows recreating a real system behavior through an artificial system that is a computational model. The process that leads to a computational model is in two stages. During the first stage, that is well-known as modeling, the system components, operating principles and functional relations are detected. Afterwards, a computational model (that can be either algebraic or algorithmic) for each component is developed based on the functional requirements previously detected. During the second stage, that is simulation, all the computational models run jointly and, the behavior resulting from their mutual interactions should be as close as possible to that of the real system. The comparison between the model and the real system is very important in both phases. During the modeling phase, the comparison involves each component and aims at adjusting the parameters they depend on to make the overall model recreating with accuracy the real system behavior. Therefore, correctness should be evaluated under two different perspectives:

- The correctness of the overall model (black box validity): the model outputs are very similar to the real system ones;
- Correctness of the single components (white box validity): each single component is consistent with reality.

Modeling is an abstraction process that entails many approximations based on assumptions whose validity has to be continuously called into question. Such approximations are related to the definition of the system main components (deciding to neglect the components that components having a secondary role respect to the phenomenon that is investigated), the identification of main working mechanisms and the related representation in terms of mathematical relations and algorithms.

The resulting model is valid only if the underlying hypothesis and assumptions are valid and in particular if all that is neglected is irrelevant. Indeed, a particular phenomenon can be deemed negligible depending on the purposes of the study. It means that the validity of a model should be evaluated within its own application and respect to the use it is meant for. Therefore, when the same model is going to be reused in another context the model validity should be checked prior to proceed. The main model components include:

- Variables

  Simulation techniques may involve three different types of variables:
    - State Variables: numerical and logical variables that include all the information needed at any time to describe the system with satisfactory accuracy. In other words, this category includes all the variables that are able to describe the system configuration while the system evolution during the simulation results from the dynamics of each of them. In addition, for

such variables, it is needed to specify the value they take before the simulation starts that is the system initial state or in other words the system initial conditions).
  - Input Variables: such variables include the solicitations the system reacts to while the simulation executes.
  - Output variables: such variables depend on state and input variables and are the quantities that are observed during the simulation like for instance system performances indicators.

- Events
  An event is whatever occurrence that makes at least one state variable change. For instance, the user arrival in a queuing system o a service completion are examples of events. There may be:
  - Events that are external to the system (exogenous events);
  - Internal Events (endogenous events);

  For instance, processing a user in a queuing system is an endogenous event because it occurs inside the system while a new user arrival is an exogenous event.

- Entities and attributes
  Entities are single elements of the system that have to be defined. For instance in a queuing system, user and servant are two different entities. In addition, considering the user entity, since it flows through the system, it is defined as a dynamic entity while the servant is a static entity. Entities may be characterized by attributes that provide the values of data the entity has been assigned to. For instance in a single servant queuing system where the only entities are the servant and the users an attribute of the user entity is user arrival time while the servant can hold the attribute status that may take the values "free" or "busy". It is worth mentioning that attributes definition depend on the system under study as well as on the aims of the study. Furthermore, entities can be grouped into classes encompassing entities of the same type. Considering men and women the users of a queuing system, entities can be grouped into two classes based on the value taken by the attribute "sex".

- Resources
  Resources are elements of the system that provide services to the entities. An entity may call for one or more resources and in case of resource unavailability the entity may enter a queue waiting for the resource availability or take a different action. Otherwise if the resource is available, it can be accessed by the entity, retained for a while and then released.
  For instance, a resource could be an operator that oversees a machine. In case of technical and economic constraints that prevent the machine from being used if the operator is not available, the resource availability has to be checked whenever an entity calls for the resource. After the availability check, if the resource is free, the request can be fulfilled and as a consequence the resource will be retained for a while and afterwards released. In case of unavailability, the entity has to wait until the resource is released. It is worth noticing also that a model component can be considered as a resource or as an entity depending on how the model has been built.

- Activities and delays
  An activity is an operation whose duration is not known a priori when it starts. Such duration can be constant such a random value from a probability distribution or an input data, or a value that is calculated according to contingent events occurring within the system; for instance the service time in a queuing system. Conversely, a delay is a period of time with undefined duration that depends on the system conditions; for instance the time an entity spends in a queue before a resource is available.

1.2 Development phases in a simulation model

The step that are required to develop a simulation model are part of a methodological approach that includes a set of fundamental steps. It is not a simple sequence of stages but a rather iterative approach that may require reviewing and integrating activities when new knowledge on the system is available or when the expected results are not achieved. The development phases of a simulation model are illustrated as follows:

- Problem formulation: this is a preliminary phase where the main problem the model is devoted to investigate is defined thus the system under investigation and its boundaries are identified. This way, the main elements that have to be included in the model because of the relevance they have in characterizing the system structure and its behavior are detected. In the same way, unnecessary elements that do not provide a meaningful contribution to the system characterization are neglected. For instance, if the purpose is to investigate an industrial process, the boundaries of the system have to be carefully identified and the attention should be put on the most important aspects only. It may result in focusing on a particular production line and on the machines that are part of it if a performances analysis is required or on the raw materials and finished products warehouse if the goal is to investigate inventory management policies.

- Setting the goals: it means that the objectives of the simulation study have to be set. At this stage, it is required to detect the questions the simulation study will answer as well as the expected results. To this end, it is worth noticing that simplifying assumptions directly depend on the objectives of the simulation study that have been set at this stage. The objectives can be:
    - Performance analysis : with reference to resources, flow time, system outputs, etc;
    - Capability analysis: that means to verify if the resources are properly used;
    - Comparison: that means comparing alternative configurations in order to detect the most suitable solution given a set of constraints;
    - Optimization: find the best solution among a wide set of alternatives;
    - Sensitivity analysis: understand which variables and to which extent they affect the system;
    - Visualization: develop a visual solution of an non-existent system.

  Taking the example previously given, the aim of a production line study could be the need to find out an optimal set of technical parameters for each machine so as to maximize the line performances while the objective of a study focused on warehouse could be to detect the best inventory policy. At this stage, once the objectives of the study are clear, it is also required to evaluate the time and the resources are required to carry out the simulation project as well as the costs and the financial resources it entails.
- Conceptual Model Definition: in this stage it is required to decide the level of detail and abstraction of the model detecting its main entities, attributes, resources, functional requirements and structural complexity. As a matter of facts, well detailed models are difficult and expensive to develop, to correct and to maintain. On the other hand, a simple model a oversimplification or a high degree of abstraction, makes the model far from representing the real system. The level of detail, therefore, has to be evaluated under two perspectives: the complexity it brings in and the results accuracy it allows achieving. Indeed, it may happen that to complex models may bring about unreliable results while too simple models may result in too approximate outputs. Afterwards, rules and logical, mathematical, causal relations among the system structural components have to be detected so has to gain a detailed knowledge of how the system works. The aforementioned elements made up the conceptual model of the system that has to be simulated. To develop a conceptual model a "top-down" approach is usually adopted, it means that starting from simple elements the model is then refined until the desired complexity is reached. However, it is worth considering that as complexity increases as errors are more likely to occur and the simulation costs and times grow. Taking once again the production line example the main modeling elements include machines, work pieces and operators; interactions among this element result in processing operations while the rules that are needed to recreate a faithful operational picture of the system include operations scheduling criteria, priorities policies for processing different production orders, how exceptions are handled, machines maintenance policies, shifts, etc. A conceptual model may be not so useful when simple systems are simulated but is unavoidable for complex system simulation. Indeed, conceptual models that are often in the form of diagrams (such as UML diagrams, flow charts, etc.) should be the preliminary activity of each simulation study where a complex system is to be investigated. Moreover, conceptual models are qualitative in nature and can be considered a fundament step toward the development of a dynamic simulation model. Therefore conceptual model are drawn before the system model is encoded so as to be processed by a computer.
- Data Collection: in this phase quantitative data and information on how the system works are collected. In other words, data on operating parameters, layout, operational procedures, and whatever input to the system are gathered. Particular attention should be paid on stochastic data for which the statistical distribution they belong to has to be identified so as to correctly represent such data within the simulation model. When the probability function cannot be supposed a priori, historical data should be retrieved and the best fitting distribution has to be detected. For instance, if a production system is under investigation, data collection may involve operating times and failure rates that are

random variables whose statistical distributions have to be identified. Data can be available in an electronic format and organized in a database.

- Model Encoding: the conceptual model previously drawn up and enhanced further to data collection, is encoded in order to be processed by a computer. In other words an executable program is developed. It may happen through an ad hoc programming code or through simulation software that automates the encoding phase thanks to the availability ready to use objects and applications. The major criticalities at this stage pertain to the encoding tool/ programming code selection for a proper translation of the conceptual models previously expressed.
- Verification: it pertains to faults detection further to the encoding phase. As a matter of facts the executable program should implement the conceptual model without any syntactic or semantic error.
- Validation: it aims at testing the simulation model reliability. Among the possibilities available for model validation, pilot simulations can be carried out to assess whether simulation results are compliant with the real system outcomes (it may happen also that a reference model is referred to instead of the real system) and if such results are not in agreement either the model or the collected data have to be adjusted.
- Design of experiments: this phase consists of an experimental plan including different simulation scenarios. Experiments may be carried out by using the simulation model with two different approaches: an iterative and a comparative approach. The former implies that the model is running and its outputs are observed. In other words, it comes to implement an action and see how the model reacts. The latter, instead, means that one or more critical parameters are changed once or more than once and the model outputs are compared. This analysis allows investigating the influence of such parameters so as to detect the best solution in terms of system operating conditions. In such a case, the experimental plan is made up of several experiments where different system configurations in terms of control parameters and external conditions are considered. Furthermore, the number of replications of each experiment, the simulation run length as well as the rump up period (that is the system transition time before a steady state is reached) are to be established.
- Experiments execution: execution of the experiments according to the experimental plan.
- Results analysis. In this phase the output values for each system configuration are to be evaluated. Thus the results are processed using statistic techniques to build the confidence intervals of the system performances. Moreover, techniques for sensitivity analysis (such as Analysis of Variance, ANOVA) can be successfully used to detect the main factors affecting output data and therefore require particular care during the modeling phase.
- Presentation of the results. The simulator, the underlying assumptions and the results have to be documented as a final stage of a simulation study. Results and analysis are organized in tables, diagrams, and a useful mean for communicating with stakeholders that are not familiar with M&S concepts. Furthermore, verification and validation have to be validated as well to promote the simulator trustiness and make people confident of the simulation outputs reliability. Thus as a further step, if results are deemed valid can be used for reconfiguring and optimizing the real system.

1.3 Simulation Models Classification

A rather general classification of the simulation models can be done based on the main features of the system representation and on the experiments that are carried out:

- Static or dynamic simulation: static simulation analyzes the system in a particular point in time and does not consider how it evolves over time while conversely dynamic simulation allows monitoring the system states as time goes by.
- Deterministic or stochastic simulation: deterministic simulation does not consider uncertainties that may affect the real system while stochastic simulation does include random variates.
- Discrete or continuous simulation: dynamic simulation can be further classified into continuous and discrete simulation based on time management along the simulation. Discrete simulation means that time changes in a discontinuous way because simulation results are evaluated over a well established set of points in time and therefore all that happens between two subsequent points in time is neglected. On the other hand, continuous simulation means that time evolves on a continuous base. Choosing between a continuous or discrete model does not necessarily depend on the system features but can be mainly related to the purposes of the study. Indeed, a discrete model can be used as a representation of a continuous system. A typical example is a railway line where the train

position can be represented as a real variable that defines the distance from the departure station or , instead, with a set of binary variables that define the state of each block the line is made of.

1.4 Interactive simulators

Flexibility and dynamism are unavoidable requirements of modern economical systems. It implies that operators, especially those operators that are in charge of specific means such as plains, trains, ships, straddle carriers, quay cranes, etc., are required to fulfill their tasks effectively. In such a context, owing to practical, economical and security reasons training on the real system and with real equipment may be unfeasible. To this end, there are simulation based systems that allow training in a tridimensional virtual and immersive environment. Thus, operators can exercise and acquire the abilities required to do their job without endangering their safety and those of the operators sharing the same working environment and without any risk of economic damage. In this perspective, simulation based training results in an effective tool with lower costs compared to traditional training approaches.

1.5 Architectures for distributed simulation: The High Level Architecture (HLA) and its evolution

The HLA has evolved over the past decade; in terms of architecture it has been equipped with a Run Time Infrastructure (RTI) that is a software devoted to manage communications among different models so as to address the simulators toward interoperability concepts without caring the issues pertaining to communication protocols. The RTI has been distributed by the DMSO (Defense Modelling & Simulation Office) since 2004 free of charge upon registration to the DMSO website. The relevance of such a tool has been widely highlighted by the NATO M&S Plan that has encouraged adopting this solution even if different European Nations part of the Alliance have put it in practice at different rates. As a result while simulation projects in the military domain carried out in North America are HLA compliant as a mandatory requirement of the DoD since 90’s, in other NATO countries the adoption of such a standard that has never been questioned has been delayed because of the background of the main private contractors. In response to this issue, over the period 1996-2000 the HLA Outreach Program was launched in USA. The main goal of the program was to educate and distribute, among Universities, knowledge pertaining to this standard in order to train students and provide them with the required skills and capabilities getting them ready to be employed in the main companies of the field. The U.S. Department of Defense entrusted the project to the McLeod Institute of Simulation Science (MISS) (where the and the MISS Italy - Genoa Center and the MISS Germany - Hamburg Center were particularly involved) and to the California State University Chico. In 2000 a similar initiative was activated: the SIREN (Simulation Report & Networking) for technology transfer in European companies. The project was led by the the McLeod Institute of Simulation Science and in particular from the Italian branch in cooperation with Liophant Simulation. As a result of the SIREN initiative, advanced training courses on HLA have been organized providing the audience with competencies certifications both at academic and professional level. In parallel to the initiatives in the military domain, further developments based on the integration of simulation models in a HLA cooperative environment took place in the industry sector (i.e. the IMS Integrated Manufacturing System initiative of the NIST, the WILD Web Integrated Manufacturing System project of DIPTEM , the E²M Project of the CIDISI from Argentine). In particular the first documented experience where a HLA federation distributed over a WAN/GAN network (a non-military network) has been carried out on December 6, 2000 from the DIPTEM of Genoa and the Riga Technical University. During the experiments, COTS non HLA- COMPLIANT simulation tools (i.e. Arena™, Simple++™, Simul8™) have been integrated into the HORUS (Hla Operative Relay Using Sockets)architecture aimed at developing a M&S methodology for Supply Chains through interacting simulators geographically distributed over a distance of 2100 Km. Further to such initiatives and with the support of other leading Institutions such as SISO (Simulation Interoperability Standards Organization's) e SCS (Society for Computer Simulation International) HLA became an international standard in 2000 (IEEE 1516 Standard for Modelling & Simulation). The standardization process has deeply encouraged the HLA adoption process to such an extent that the majority of distributed and interoperable simulations rely on the HLA standard.

In 2003 the HLA as a IEEE standard has undergone some modifications and new releases, where some relevant advances are absorbed into, are going to be issued. Indeed, since 2005 a revision process promoted by SISO has started with the aim of taking advantage from the latest development in different application domains (i.e.healthcare, logistics, etc) and in ICT technologies to ensure greater interoperability and reuse of simulation components. The main topics covered include IEEE 1516 - Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Framework and Rules:

- IEEE 1516.1 - Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Federate Interface Specification – devoted to define the interface among the federates (utilities, or interfaces with real systems) highlighting the software services that are needed to ensure the mutual support of federates in a distributed environment.
- IEEE 1516.2 - Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Object Model Template (OMT) Specification – where storage formats and syntax for objects data and HLA models information are defined. Thus, it is possible to detect data exchange at runtime.

Among the main befits, technical solutions for Distributed Simulation Environments (DSEs) obtained through a phased approach cannot be neglected. As a matter of facts even if the standard is focused on scalability, maintainability and bandwidth, the RTI interface needs to be improved to allow for a better scalability and a more flexible Data Distribution Management as far as data filtering for the different federates. In addition, Object models, in the latest versions, have been extended using XML AND Unicode to take advantage of new opportunities. Furthermore it is worth introducing an interesting initiative called XMSF (Extensible Modeling and Simulation Framework) has been carried out by a set of research centers (i.e. SAIC, MISS, VMASC, MOVES, George Mason University, Naval Postgraduate Monterey, etc.). The basic concept under the XMSF is the combined use of a set of different standards and best practices for web based M&S. The main idea is to use Markup languages based on XML as well as on web technologies and services for a new generation of distributed interoperable simulators.

CHAPTER 2:
Modeling & Simulation for Training in Marine Ports: Approaches, Methodologies, Best Practices Criticalities and Requirements

2.1 Introduction

This thesis was developed as part of the research project PON01_01936 – HABITAT, Harbor Traffic optimization System carried out in cooperation between the MSC-LES lab of the University of Calabria and some major Italian stakeholders working in the field of Logistics and Transportation.
As far as the objective of the Doctorate course is concerned, particular attention was paid to the development of a simulation based Training & Exercise system for pilots and port traffic controllers involved in the last mile of navigation. This simulation based Training & Exercise System is based on distributed simulation (the standard for distributed simulation used is the IEEE 1516 HLA, High Level Architecture) that enables both the training of individual operators and the cooperative training of more operators at the same time. Training of more operators (for example, a pilot of a vessel, a pilot of a tugboat and a port traffic controller) becomes possible because the different simulators are interoperable each other and they are therefore able to exchange information while sharing the same virtual environments (the latter are used to provide users with the sensation of being in the real system). As mentioned, the simulators interoperability requirements are guaranteed by the fact that the simulators architecture is built according to the standard for distributed simulation HLA.
The objective mentioned above been achieved through three specific activities, namely the development of the training & exercise system for pilots (we will refer to this activity also as the development of the Ship Bridge Simulator), the development of the training & exercise system for port operators (we will refer to this activity also as control tower simulator) and the development of the teleportation functionality for port traffic controller.
Therefore the different chapters of this thesis present the general architecture of the two simulators (the ship bridge simulator and the control tower simulator) and explain how different problems have been faced and solved. Among others, specific attention has been paid to interoperability issues explaining how (from an architectural point of view and from a development point of view) these issues have been solved. As far as the ship motion at sea is concerned, this can be regarded as the main modelling and analytic effort of the entire work; indeed a 6 Degree of Freedom (DOF) model for a containership motion at sea is proposed, coded, tested and validated. Concerning the training scenario, this is based on 3D virtual environments that recreate the Port of Salerno, Italy (this because the port of Salerno is involved as end-user of the project HABITAT). In addition, as part of this PhD work, a ship bridge replica has been designed and recreated including all the on board instrumentations used for ship navigation (e.g. Radar simulator, Conning Display system, AIS simulator). The ship bridge replica, that is part of the system, has been designed to be a faithful representation of a real ship bridge. To this end, at the early stage of the design process some real ships were surveyed. In particular, much time was spent on board of two ships: a platform supply vessel that was standing in the port of Crotone (Italy) and a container carrier that was entered into the port of Salerno. These visits were really useful to have a faithful representation of the ship bridge in terms of geometry and technical equipment for ship maneuverings and navigation. Concerning the control tower simulator, this allows the user monitoring and controlling the traffic within the harbor area by using different panoramic views on the virtual environments and by exchanging information with the vessels moving in the harbor area. The control tower simulator is also equipped with the Teleportation functionality; thanks to this functionality the port traffic controller can be virtually teleported on board the ship bridge and have the same view perceived by the ship pilot. This functionality provide the port traffic controller with a tremendous advantage for skills improvement and training effectiveness: he can see the traffic within the harbor area from the same point of view of all the pilots currently working on board the different ships within the harbor area.
As far as this chapter is concerned, it provides the reader with a detailed state of the art overview, pointing out how Modeling & Simulation based approaches have been used over the last 30 years to support training in different areas: from Industry to Logistics, from Defense to Homeland Security. The survey of the state of the art reveals that in the logistics area and, in particular, in marine domain, a lot of researches have been done to support training of operators working on the land-side (e.g. operators working in container terminals and car terminals, such as quay cranes operators, trucks drivers, straddle carrier operators, car drivers, etc.). Concerning the last mile of navigation, different solutions for ship pilots training are already available (ship bridge replica simulators); however, there is a lack of research on cooperative training of ship pilots, port traffic controllers and tugboat pilots (indeed the project HABITAT also includes a simulator for tugboat

pilots training). Therefore, the major innovative aspect of the work done during the PhD is the development of interoperable and distributed simulators that can be used to support cooperative training of multiple operators.
Before going into details, this chapter is organized as follows: in the first part an overview of Modeling & Simulation for training (with particular attention to Logistics) is given; then an overview on the most known used graphic engines and software for 3D models development is proposed. Finally training needs in harbour terminals are identified and discussed and a summary of the main processes, activities and actors involved in the last mile of navigation is given.

2.2 Acronyms List

The following table reports the list of acronyms used throughout this chapter and where needed also in the successive chapters of this thesis.

M&S	Modeling & Simulation
HLA	High Level Architecture
VV&A	Verification, Validation & Accreditation
DIS	Distributed Interactive Simulation
TENA	Test and Training Enabling Architecture
API	Application Programmer Interface
ALSP	Aggregate-Level-Simulation-Protocol
GOTS	Government Off the Shelves
COTS	Commercial Off the Shelves
DOF	Degree of Freedom

Table 2.1 - Acronyms List

2.3 Modeling & Simulation for training in Logistics

The purpose of logistics is to move objects and people while minimizing costs and respecting constraints on delivery times and service levels provided to final customers. Indeed, companies operating in the area of logistics and supply chain are nowadays required to readapt quickly and efficiently their structures, processes and activities to face continuous increases in freight volumes and significant changes in procedures and standards. Speed, ability, agility, resilience are only some of the properties required to a company for surviving in a global market and are the keys to success. In this scenario, training is the crucial element for all the people involved, from managers to operators and workers.
As far as training is concerned, it is not always possible to adopt the so-called training on the field; let's consider as example the equipment used in a harbor terminal for containers handling. Inexpert operators may easily cause accidents with severe damages to goods as well as injuries to people and sometime even deaths. Regarding marine ports and harbor terminals, this is also true when the training of ship pilots and port traffic controllers is concerned. Ship pilots are required to control very large vessels and to executes very complex maneuvers in narrow spaces; wrong procedures as well as wrong maneuvers may cause congestion in port traffic, high security risks and, sometime, even terrible accidents (as happened in 2013 when the containership Jolly Nero was exiting the port of Genoa in Italy).
In such a context, Modeling & Simulation (M&S) has largely proved to be one of the most powerful methodologies for training of operators working in complex systems (such as ship pilots and port traffic controllers). Over the last 30 years, M&S based approaches have shown their potentials not only for training but also for decision support. Indeed, within harbor terminals, M&S can be used for different purposes including maximize the space for storage services in yard areas, schedule arrivals and berth assignment,

optimize routes, resources assignment and loads, test emergency procedures, schedule work plan of workers, etc.
Over the time, the advantages of M&S for training activities have become increasingly significant; as result, M&S has emerged as a powerful training tool. M&S based training system aims at improving trainees' performances with virtual and synthetic environments. Such environments are created in order to teach competencies, attitudes, concepts, knowledge, rules and skills providing trainees with the opportunity to practice the required competencies and receive real-time feedbacks (Salas et al., 2008). Trainees may act in synthetic environments as they usually act in real systems (learning how to put into practice the theoretical concepts) and can easily see the consequences of their actions in a visual manner. The main benefits associated with simulation based training approaches rely also on the possibility to set-up and design training sessions that include all the possible working conditions (that cannot be easily recreated in a real system). Therefore, well trained operators are prepared for any risky situation since they are aware of a great variety of cases and know exactly the consequences and effects of their behaviors and actions. A synthetic environment is safe, there is no danger, therefore, trainees can explore possibilities and test the effects of different actions in a cost-effective way (it is evident that both direct and indirect costs can be reduced). Another important aspect is the possibility to collect data from each training session so that instructors can analyze trainees' performances evolution over the time, providing feedbacks to improve lessons learned and eventually compare the performance of different trainees based on different key performance indicators.
As before mentioned simulation based training has been successfully applied in the most important sectors from Defense to Industry, from Logistics to Healthcare. Considering the military sector an overview about military simulation based training systems can be found in Page and Smith (1998) and Smith (2010). Practical examples of research works in which simulation is used for training can still be found in Page and Smith (1998), Zeltzer et al. (1995) and many others (for instance, Zeltzer et al. (1995) present a simulator for the training of submarine officers operating on the deck).
The analysis of the literature about simulation-based training systems cannot neglect industrial applications. Examples can be found in Jiing-Yih et al. (1997), Tam et al. (1998), Cramer et al. (2000), Anon (2000). In the Industry sector, many are the examples of driving simulators such as cars, excavators, construction machines, buses etc. References can be found in Greenberg and Park (1994), Lee et al. (1998), Freund et al. (2001), Park et al. (2001) and many others. Also riding simulators (mostly for bicycles and motorcycles) are proposed, see Carraro et al. (1998), Ferrazzin et al. (1999) and Kwon et al. (2001). However, among the existing visual interactive simulators, the flight simulation is the most mature and representative application; as a matter of fact a tremendous amount of researches has been published in this area, see Melnyk (1999), Bernard and Menendez (2000), Chin-Teng et al. (2001).
Also in the Healthcare sector, simulation based training has been extensively used and it has been found out its efficacy for teaching of technical and non-technical skills, learning and improving on patients' outcomes. Simulation based training for healthcare is a wide research area in which many sub-areas can be detected, e.g. anesthesia, surgical operations, intensive care, laparoscopy, endoscopy etc. Examples of research works can be found in Gaba and DeAnda (1988), Suwa (1992), Swank and Jahr (1992), Lussi et al. (1999), Morris et al. (2006), Daenzer and Fritzsche (2008), Semeraro et al (2008), Yoshida et al (2009), Sun et al. (2010). For instance, Murray (2011) provides reviews about the use of simulation to reduce human error during the administration of anesthesia.
In most of the cases the development of simulators for training purposes is based on the paradigms of distributed simulation in order to allow the cooperative and concurrent training of multiple operators. The High Level Architecture (HLA) standard, developed by the Department of Defense in the United States, provides a concrete example of approach to distributed simulation. An overview of standards and architectures for distributed simulation can be found in Fujimoto (2003). In additions, hardware integration as part of the simulators architectures is needed to increase to the feeling of realism and make the training experience pervasive and engaging. For example, Kwon et al. (2001) propose an interactive bicycle simulator including a Stewart platform to generate 6 DOF motions, able to provide force feedback on pedals and equipped with a dedicated visualization system. Melnyk (1999) develops a flight simulator in which the realistic feeling of takeoff, landing and in-flight turbulence are provided using a Six Degree-of-Freedom (DOF) motion system.
It is now clear that Simulation and virtual reality are tools that help strengthen the effectiveness of training because they allow suppressing constraints and limitations that are typical of traditional training approaches while maximizing the transfer of skills and competencies. If we subdivide learning activities between cognitive and psychomotor, scientific studies show that the use of simulation and virtual reality facilitate

both types of learning. In the case of cognitive learning, simulation and virtual reality allow avoiding certain logical steps providing the trainees with the possibility to arrive instantly to the core of understanding. Considering learning as a mental process that aims at the acquisition of reality, simulation and virtual reality are framed in the form of learning by doing. Indeed, the latest technologies behind the development of virtual environments allow trainees manipulating objects and acting in an autonomous and creative environment; virtual environments are therefore considered as tools that can profoundly transform the mode of communication and improve the learning skills.
In addition, the use of virtual, interoperable and interactive simulation to support training and education has considerable growth during the last 30 years benefiting from the rapid advances in computer technologies that traditionally is the backbone in the use of these methodologies. Originally used to solve costly and risky stages of pilots training in aviation, today simulators are used to simulate various types of vehicles and handling equipment, for both Industry and Military applications, including cars, ships, helicopters, submarines and even spacecraft.
In this context, where the ability of operators involved in the control and command of complex equipment represents an element of critical importance for the correct use of the equipment itself and where the use of a real equipment in the initial stages of training it appears not possible (vehicle design phase), or expensive (huge costs related to the use of the equipment for training) or even dangerous for safety and security reasons, simulators based virtual environments must be regarded has the best available solution for training purposes. Two events in particular have favored the development of simulators for training:

1. the first one was the rapid growth of computers, which allowed the modeling and the digital control of complex systems and equipment starting from the equations governing their physics and dynamics;
2. the second one was the rapid development of digital graphics that allowed experiencing realistically what the operator sees and feel while operating the real system. Indeed trainees once immersed in virtual environments are subjected to the perception of visual and audio effects as well as movements, velocity and accelerations (e.g. by using motion platforms) that are quite similar to those perceived in the real system. The hardware integrated as part of the simulator (e.g. steering wheels, pedals, gear, joysticks, etc.) provide the virtual environments with all the inputs (given by trainees) needed to let the system itself evolve as the time goes by (e.g. in a driving simulator, pushing the acceleration pedal will result in an increase of speed of the simulated vehicle).

On the basis of these considerations, in this thesis M&S based training has been used to pursue:

- more standardization, quality, and effectiveness of training procedures of the operators involved in the last mile of maritime navigation through the simulations of critical operations and emergency procedures with the aim of training the staff involved to handle situations otherwise too dangerous to recreate in real systems;
- significant reduction in the cost of staff training through a substantial reduction of the working hours of expert operators that are not directly involved in training of inexperienced staff;
- reduction of direct and indirect costs attributable to the occurrence of accidents during training.

2.4 An example of simulation based training: driving simulators

The following section provides the reader with an example of the potentials of simulation based training considering the case of driving simulators. Driving simulators are mainly used for vehicles tests, personnel training and entertainment.
Indeed, even in the case of simple functional tests of vehicles, a simulator can introduce significant advantages: for example, in the automotive industry simulation is commonly used to improve quality in terms of performances, safety or cabin ergonomics, reducing at the same time development costs and the number of prototypes. Simulators combined with motion platforms are also used to recreate the forces acting on the vehicles during its use (and as consequence of the driver behavior) allow studying how the driver perceives the vehicle comfort and how the comfort can be improved (specific sensors are used to measure noise, shock absorber behavior as well as the reactions of the drivers and other people in the car).
Furthermore, an interesting application of driving simulators is the study of new security systems such as the Electronic Stability Control (ESC). The ESC system detects when a vehicle moves in a direction different from that indicated by the position of the steering wheel and automatically activates the brakes (controlled by a computer), on specific wheels in order to stabilize the vehicle and help the driver to avoid accidents.
As example, consider the National Advanced Driving Simulator (NADS) that is a research center affiliated with the University of Iowa and with the Department of Transportation of the United States leading a

research project on this subject. This research started by a proposal of the Department of Transportation of the United States to introduce the ESC on vehicles weighing less than 4536 kg and designed to carry passengers. This research has involved more than 500 volunteers between 16 and 74 years of age and is focused on driver's response to dangerous situations and on the corrective effects of the ESC. Volunteers are required to use an immersive driving simulator; the scenario includes multiple obstacles that suddenly appear on the road and the drivers are required to avoid obstacles. The results collected from the simulations show the different behavior between cars equipped with ESC system and those that do not have it, showing the benefits of ESC.

Driving simulators can be also used to study the impact of the human factor on the causes of accidents. An example is again given by the NADS. The NADS has indeed done research on the effects produced by alcohol, drugs, medicines and other distractions such as telephone conversations while driving a car. In addition, driver's eye movements are also monitored and analyzed during the simulation.

However, the most widely known use of driving simulator is to train staff and operator. If we include in this area also flight simulators we can easily assert that these are for sure the most advanced applications (both for pilots operating in the military sector and commercial airlines). Vice-versa if we consider the driving of ground vehicles, driving simulators can be profitably used in car terminals to train drivers to load and unload new cars and vehicles on board/from ro-ro vessels.

Driving simulators can be also classified according to their capability to generate inertial feedbacks that is the capability to let the driver perceiving movements, velocity and accelerations that are normally perceived while driving the real vehicle or equipment. This classification divides the simulators in:

- static simulators: this are simulators that do not generate inertial feedback. These simulators are usually equipped with the real replica of the cockpit even if there are no motion platforms used and therefore the trainee can feel the sensation to drive the real vehicle just because he is immersed in a virtual environment where also advanced audio systems are used. This category also includes those simulators equipped with vibrations systems provided that the feedback perceived by the trainee are much lower than feedbacks given by dynamic simulators (the latter usually equipped with motion platforms).
- Dynamic simulators: these simulators are usually equipped with 3 degree of freedom or 6 degree of freedom motion platforms and therefore they allow trainees to perceive inertial feedback due to movements, velocity and accelerations. Motion platforms are usually equipped with electric or hydraulic actuators and are controlled real-time by a computer that, according to specific programs, is able to simulate movements, velocity and accelerations of the real vehicle/system. It should be said that, while the use of motion platforms (or similar tools) tremendously increase the training effectiveness, there are many cases in which their use is not indispensable. This is the case, for instance, of simulators used for study the ergonomics of new vehicles cockpits; inertial feedbacks in this case are not essential for finding out optimal and effective ergonomics of the vehicle cockpit. In addition, when the feedbacks provided by the motion platform are not correctly recognized by the human brain this may cause as dizziness, vertigo, nausea and vomiting (cybersickness). This usually happens when the stimulus perceived by the eyes is misaligned with the one perceived by the ears that control the movement and the equilibrium of the body in the space.

2.5 An overview on software tools

This section presents an overview on the most important and known software tools currently used for the design and development of simulators using for training. This overview has been then used to select the software used to develop the bridge ship simulators and the control tower simulators that are the final goal of this thesis.

The first step was the identification of the graphic engine, therefore an analysis of the current available graphic engines has been carried out.

A graphics engine can be defined as a set of methods, functions and classes that are used to implement a graphical application. Some engines only provide purely graphic functionalities while others integrate additional functionalities. The core functionalities typically provided by a graphic engine includes a rendering engine ("renderer") for 2D and 3D graphics and a physics engine or collision detection, sound, scripting, animation, artificial intelligence, networking, and scene-graph. If a particular feature or functionality is not already built-in, then it is entrusted to the developer to add this functionality implementing them personally or by using other software/middleware.

Based on this definition, many libraries provided by different programming languages can be considered as graphics engines. Let us consider for instance Visual Basic, it can be considered as a simple graphics engine because it offers a simple interface to create buttons, menus and all those components that allow the user creating an application in Windows environment. To achieve something similar in C ++, the user is required developing classes needed to create and manage windows. At higher level, there are graphics engines like DirectX and OpenGL that offer an extensive list of components to render 3D graphics, sound and controls. It can be said that DirectX and OpenGL have dedicated packages ready to be used to create real time graphics applications.

Whereas the graphics engines are very diversified according to the level where they work and the functionalities they offer, we have tried to outline the differences between the most known graphic engines. Among the criteria adopted for the graphic engines classification, one of the most important was the possibility to use as programming language C++; indeed, while C++ is used for the development of graphical applications it is also widely used to real-time and interoperable simulation. Tables 2 and 3 report the comparison among the graphic engines considered as part of this overview. Among others, additional criteria include the cost of the license, the availability of support, the availability of a physics engine, the terrain, the path finding and the blending animation.

From tables 2 and 3 it is clear that the Unreal Development Kit is the most powerful in terms of functionalities and in terms of non-commercial licenses cost. This graphic engine presents, however, some drawbacks that have led to its exclusion:

- high difficulty of use due to the large number of built-in features;
- very high costs for the commercial license;
- possible problems if rendering is performed by using low or medium level computer (indeed this engine is currently used for the development of the most recent video games).

For these reasons, as second instance, it has been considered the possibility of using an open source engine considering as main criteria the size of the community currently using the open source engine, the existing documentation and the level of use for research and development activities; to this end we have considered OSG (Open Scene Graph). As far as OSG is concerned, we have experienced a number of problems and issues including, among others, compatibility issues with other software currently used for distributed simulation and difficulties in installing the compiler and plug-ins required to support its functionalities. These aspects together with the need of having a graphic engine able to be easily integrated with standard for distributed and interoperable simulation (e.g. HLA, High Level Architecture) has driven the final choice toward Vega Prime by Presagis. Indeed, this graphic engine was prevalently born to support real-time simulation applications for training; therefore, it provides many of the features necessary for the development of simulators. In addition to the graphic engines, an overview on software for 3D models development was carried out. The results of these overviews are reported in the following tables.

	Irrlicht	Ogre	OSG	Unreal Development Kit	3dvia Virtools	Quest3d	C4	Torque	3d Game Studio	Vega
Version	.	.	.	.	.	Power	Academic	Torque 3d	Team Commercial (3 users)	.
Non-commercial license	*Free*	*free*	*Free*	*Free*	189€	2499€	250$ (per student min 4)	100$ (per developer)	59€	*Possibility to negotiate according to the available budget*
commercial license	*Free*	*free*	*Free*	$ 2,500 + $ 99 for up-front + 25% of the rights to earnings exceeding $ 5,000	?	2499€	350$ until 5 programmers	1000$ per developer	+ 225$	*Starting from 9000 €*

Table 2.2 – licenses comparison for different graphic engines

	Irrlicht	Ogre	OSG	Unreal Development Kit	3dvia Virtools	Quest3d	C4	Torque	3d Game Studio	Vega
Physic	*not integrated*	ODE, Novodex and Tokamak	Vortex physics (add-on)	*NVIDIA PhysX*	*Ipion (add-on)*	ODE-Newton Game Dynamics	*integrated*	*integrated*	*integrated*	Vortex (add-on)
Support	forum	forum	Forum	forum	10 token per year/forum	forum	forum	forum	forum/with ticket	Email support
terrain	?	?	√	√	?	**X**	√	√	√	√

path finding	***X***	**X**	**X**	√	√ (add on)	√	?	**X**	√	√
decision making	***X***	**X**	**X**	√	√ (add on)	√	?	**X**	√	√
fluid simulation	***X***	**X**	**X**	√	?	√	√	√	√	√
cloth simulation	***X***	**X**	**X**	√	?	√	√	**X**	**X**	**X**
bump mapping	***X***	√	**X**	√	√	√	√	?	√	**X**
mip mapping	***X***	√	√	√	√	√	√	√	√	**X**
water rendering	√	√	**X**	√	?	√	√	√	√	√
particle simulation	√	√	√	√	√	√	√	√	√	√
animation blending	√	√	√	√	√	√	√	√	√	**X**
special input device	?	?	?	?	?	**X**	?	?	√	√
dynamic shadows	√	**X**	**X**	√	?	?	√	?	√	√

Table 2.3 – Functionalities comparison for different graphic engines

		Autodesk 3dSM 9	Autodesk Maya complete 8.5	Blender	Luxology Modo 301	Maxon Cinema 4D R 10.1	Newtek Lightwave 9.3	Softimage Xsi 6.2
teaching license	price	6 months free or 130€	6 months free or 250 €	free	125 €	85€-300€	230 €	220 €

version	standard	Unlimited	standard	Standard	Base-study	Standard	Advanced
Non-commercial license	about 5000€	2.500 €	free	745	€ 720 base (+ € 800 probable plugin)	695 €	450 €
first market	Viz-Games	Games-Film	Viz-Realtime	Viz-Games	Motion-Design	VFX-Viz	Animation-Games-Film

Table 2.4 – licenses comparison for different software for 3D modelling

	Autodesk 3dSM 9	**Autodesk Maya complete 8.5**	**Blender**	**Luxology Modo 301**	**Maxon Cinema 4D R 10.1**	**Newtek Lightwave 9.3**	**Softimage Xsi 6.2**
platforms							
export collada	very good	very good	very good	good	?	No	very good
language	FR ING	ING	Many but the best ING	ING JAP	ING FR IT SPA JAP	ING JAP	ING JAP
Distribution commercially	very good	very good	low	low	good	very good	good
Age of Technology	old	old	old / renewed	modern	renewed	old / renewed	modern
learning time to be productive	< 2 month	< 3 month	< 3 month	< 1 month	< 1 month	< 2 month	< 2 month

Support of the company for individual users	low / good	good	community	very good	very good	very good	very good
Supports reactivities for single users	good	good	community	very good	**Excellent**	very good	low
interface	CAD style, clean and efficient	How Forge, flexible and powerful, but not intuitive	not as standards - fast workflow, it might be more intuitive	**Excellent**	clean and intuitive	old enough	texts logical and clean interface
Documentation	good	**Excellent**	good	very good (many videos)	very good	**Excellent**	very good
Rendering	Inside, MentalRay	Inside, MentalRay	Inside	Inside	Inside	Inside	Mentalray
Quality	**Excellent**	**Excellent**	good	**Excellent**	good	**Excellent**	**Excellent**
tools di animazione (IK, Char Rig, Bones, Controller, Blending,...)	very good	**Excellent**	good	scarce	scarce	good	**Excellent**
UV tools (Unwrap, Pelt...)	very good	**Excellent**	**Excellent**	**Excellent**	**Excellent**	good	**Excellent**
Painting	absent	very good	scarce	**Excellent**	**Excellent**	absent	very good
Modelling	**Excellent**	very good	good	very good	very good	**Excellent**	**Excellent**
Modifiers	**Excellent**	very good	good	very good	good	good	very good

Table 2.5 – Functionalities comparison for different software for 3D modelling

		Autodesk 3dSM 9	Autodesk Maya complete 8.5	Blender	Luxology Modo 301	Maxon Cinema 4D R 10.1	Newtek Lightwave 9.3	Softimage Xsi 6.2
Unique functionality main		***Biped ParticlesFlow***	***PaintFX Fluids** Nucleus***	***3DRT Sculpting Video edit***	***Painting Render Sculpting***	***Bodypaint***	***Hypervoxel Render!***	***Anim tools Gator Illusion****
Community of users and popularity	North America	**Excellent !**	**Excellent !**	good	**Excellent !**	good	very good	**Excellent !**
	Europa	very good	**Excellent !**	very good	**Excellent !**	good	good	good
Careers	VIZ / Design	**Excellent !**	good	good	good	**Excellent !**	good	scarce
	Film	good	**Excellent !**	scarce	scarce	scarce	Very good	**Excellent !**
	Game	**Excellent !**	very good	scarce	good	scarce	good	very good
	Web designer	scarce	scarce	good	good	**Excellent !**	good	scarce
	3D Realtime / VR	**Excellent !**	very good	very good	good	Scarce	good	scarce

Table 2.6 – Community and Application areas comparison for different software for 3D modelling

From the tables presented above we can see that Autodesk 3D Studio Max presents considerable advantages such as:

- 6 months free educational license and accessible license costs
- good export functionalities (e.g. collada, a standard format for 3D modeling);
- low learning times;
- easy to use and powerful user interfaces;
- good community support.

Furthermore, the compatibility with the graphics engine OSG, confirmed the goodness of 3D Studio Max as possible solution for 3D models development. However, the final choice was directed toward Creator by Presagis, mainly for the following reasons:

- this software is provided by the same software house providing Vega Prime and therefore the two software are completely compatible;
- Creator allows a modelling approach that is characterized by a relatively low number of polygons thus making possible the development and implementation of simulators able to run on normal commercial PCs.

Finally, the choice of the compiler has been dictated by the graphics engine and, on the basis of previous experience, the Visual Studio 9 was selected. Below some additional information about the software selected are reported.

Vega Prime 5

Vega Prime is an Application Programmer Interface (API). Specifically, it is a cross-platform development kit for real time visual simulation and virtual reality applications made by Presagis. It is based on Vega Scene Graph, a scene-graph API advanced cross-platform, and consists of a graphical interface called Lynx Prime and function libraries written in C++.

Using LynX Prime the user can set the background of the simulation (the virtual world), the atmospheric phenomena, collisions and basic handling operations.

In addition, the functionalities of Vega Prime are extended by additional modules that must be used to equip the simulators with specific functionalities. Besides that, the user can develop custom modules that work with all components of Vega Prime.

Indeed, Vega Prime can be regarded as an ideal platforms (extensible through plug-ins), for the design and prototyping of 3D real time simulations. A very interesting feature is that Vega Prime supports the following standard for interoperable and distributed simulation: DIS (Distributed Interactive Simulation) and HLA (High Level Architecture); the latter has been used to guarantee interoperability between the ship bridge simulator and the control tower simulator (that will be presented later in chapter 3).

Creator 4.2

Creator is a software program developed by Presagis for the development of three-dimensional models and environments for real-time graphics applications. It includes a set of useful tools for the construction of 3D models equipped with a hierarchical database view. These databases view are made in accordance with the format Open Flight, that is developed and managed by Presagis and it is a widely used database for visual simulations. This format and its editing tools allow a high degree of control over the organization of the database and the ability to attach attributes to all the elements of the 3D models. Conversion utilities are also available which make possible to import models saved in other formats, such as those used in animation and CAD applications.

Microsoft Visual Studio 9.0

The Visual Studio version was selected to be compatible with Vega Prime 5. Visual Studio is the well-known multi-language development environment of Microsoft. It allows creating standalone applications, web sites, web applications and web services that run on the platforms supported by the .NET Framework (including Microsoft Windows servers and workstations, PocketPC, Smartphones and World Wide Web browsers).

The languages supported by the development environment are:

- Visual Basic (.NET)
- Visual C ++
- Visual C]

- Visual J
- ASP.NET

Visual Studio was used for the implementation of the programming code that, as explained in the next chapters, rules the behavior of the bridge ship simulator and the behavior of the control tower simulator.

2.6 Modeling and Simulation in marine ports and harbor terminals

Marine ports are extremely complex systems; complexity relies both on the organizational structure and on the multiplicity of actors involved in the processes taking place in port environments. This scenario prefigures the typical context in which the training is a critical activity with strategic importance. In fact, only well trained operators can successfully face the complexity arising from the use of heavy harbor equipment and from the need of mutual coordination and cooperation. Training gaps can have dramatic effects in terms of costs as well as in terms of injuries to people; any mistakes might have unexpected and tragic consequences not only for the operator involved but also for other operators working in the same area (Cimino et al. 2010). These considerations suggest that training in marine ports is another challenging application area for M&S and the literature review confirms that simulation as already been successfully applied to satisfy the specific training needs of different kinds of operators, i.e. operators manipulating different types of cranes, trucks, straddle carriers, etc. (Seron et al., 1999; Kim, 2005, Bruzzone and Longo, 2008). In the sequel some examples of simulators for training in marine ports are reported.

Fernandez at al. (2009) present an advanced simulator that allows the simulation of different types of container handling equipment: Quay-Side Gantry, Rubber Tired Gantry, Reach-Stacker, Ro-Ro Tractors. Lau et al. (2007) presented a real-time distributed simulation system for container terminals. The system includes an immersive cave (imseCAVE) developed in Hong Kong University. ImseCave is connected with a computer network to allow remote control and monitoring. Elazony et al. (2011) focused on interactive and reusable simulations for training in marine ports. Many simulators have been developed for training operators working on quay cranes (Wilson et al., 1998; Huang, 2003; Daqaq, 2003; Rouvinen et al., 2005. In all the cases, the crane simulator includes a virtual environment with 3-D models of crane and load motion. Sometime the structure of the simulation program allows the design and development of interactive visual simulations that include the quay cranes, the ships and in some cases the entire port area.

When the entire port area is recreated, together with other container handling equipment (i.e. forklifts, straddle carriers, trucks, etc.), then the simulators can be used for cooperative training including multiple trainees. This is the case for instance of the simulators presented in Bruzzone et al. (2011-a); simulators of different container handling equipments are presented that are connected (for cooperative training) by using the High Level Architecture. Simulators presented in Bruzzone et al. are also characterized by advanced solutions in terms of external hardware (i.e. motion platform, different types of external controllers from joystick to wheels and pedals, etc.) and by a containerized solution. In fact, all the simulators are installed within a 40-feet container divided in three different module: an immersive cave for advanced training, a small didactic room for operators basic training and a debriefing area for lesson learned enhancement.

Furthermore specific research works have been developed also for supporting training of operators for security procedures within terminal containers (Longo et al 2006; Longo, 2010,). Additional examples of simulators for operators training in container terminals can be found in Bruzzone et al. (2007), Longo (2007), Bruzzone et al. (2008-a), Bruzzone et al. (2008-b) and Bruzzone et al. (2009), Bruzzone et al. 2010, Cimino et al. (2010). Figure 2.1 and figure 2.2 shows a view of a simulator recreating the Gioia Tauro Container Terminal (located in South Italy) and a truck simulator; the environment includes three simulators for operators training: the straddle carrier, the truck (see figure 2) and the quay crane (see Bruzzone et al., 2011 for further information).

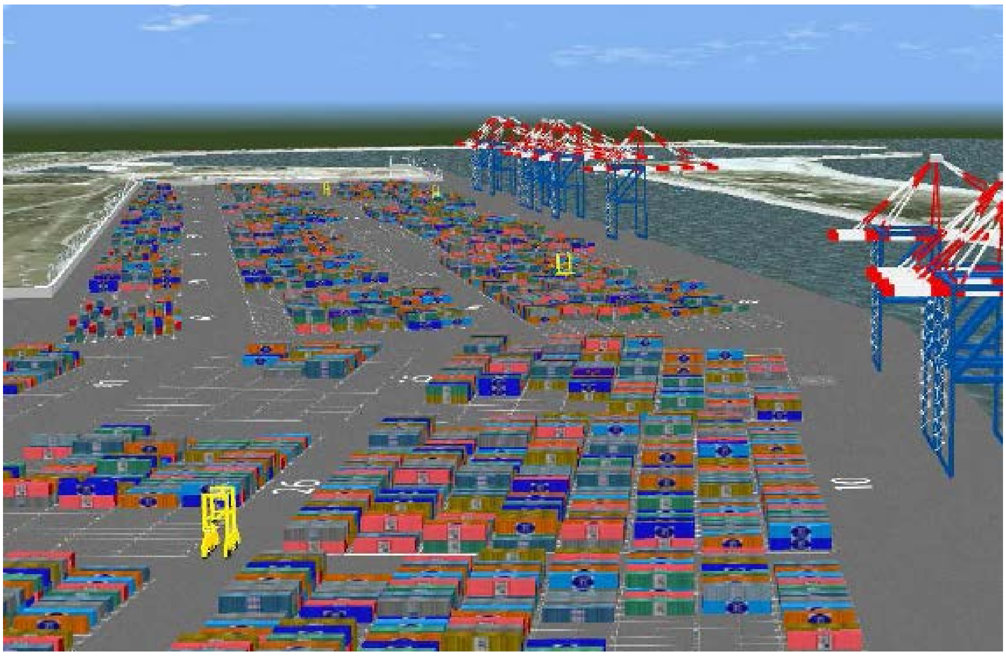

Figure 2.1 – 3D view of the Gioia Tauro Container Terminal (source: Bruzzone et al. 2011)

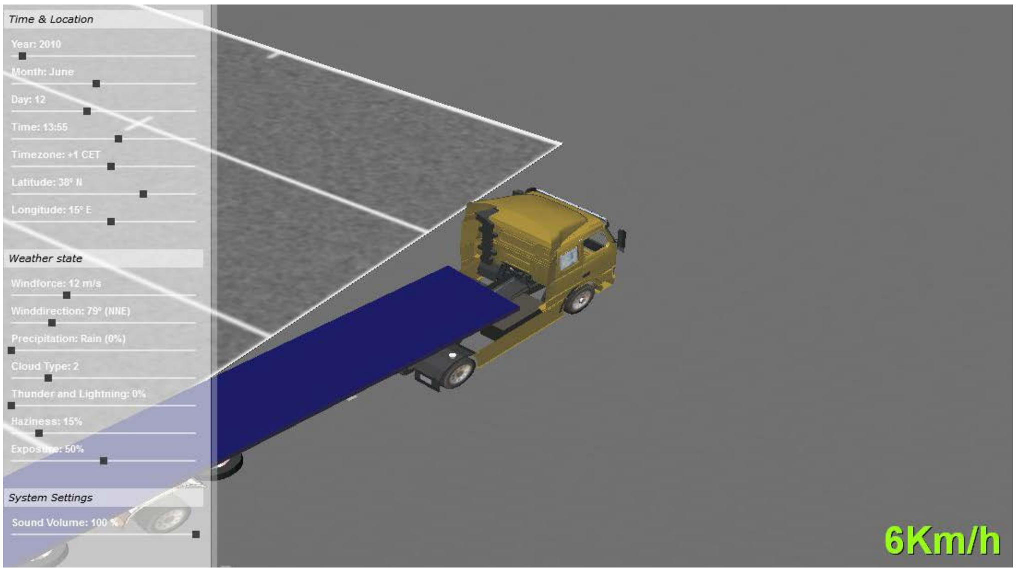

Figure 2.2 – Truck simulator within the Gioia Tauro container terminal (source: Bruzzone et al. 2011)

A comprehensive survey of research projects dealing with advanced simulation systems for operators training in marine ports is the main deliverable of the OPTIMUS project (Operational Port Training Models Using Simulators, financed by the European Community). The OPTIMUS project provides a detailed description of many commercial simulators for marine port operators training. The most important examples of simulators developed in industry (with suppliers) are:

- KraneSim developed by Drilling Systems (http://www.drillingsystems.com) is an advanced tool that allows to model a great variety of quay cranes and vehicles.
- Oryx Simulations AB (http://www.oryx.se/) offers crane simulators with a great variety of scenarios and different options regarding the cage, the real time graphics, the motion system, the background sounds etc.
- ARI (http://www.ariworld.com/simulation/default.asp) and Total Soft Bank Ltd (http://www.tsb.co.kr/) offer a wide variety of simulators for training on different cranes (Quay Cranes, Rubber Tire Gantry, Rail Mounted Gantry, Ship Gantry, Pedestal Cranes, etc.)
- MPRI Ship Analytics (http://www.mpri.com/esite/) is able to provide crane simulators that faithfully reproduce the operational characteristics for different types of cranes.

- STC Group http://www.stc-group.nl has developed simulators for different types of cranes: containers crane, bulk crane and off-shore crane.
- MISS-DIPTEM University of Genoa as part of the Simulation Team (www.simulationteam.com) have developed interoperable simulators based on the HLA standard for different container handling equipment (gantry crane, transtainer, reach stacker, truck, etc.). These simulators are devoted to the training of operators, performance and biomedical analysis, as well as for the virtual prototyping (see figure 2.3).

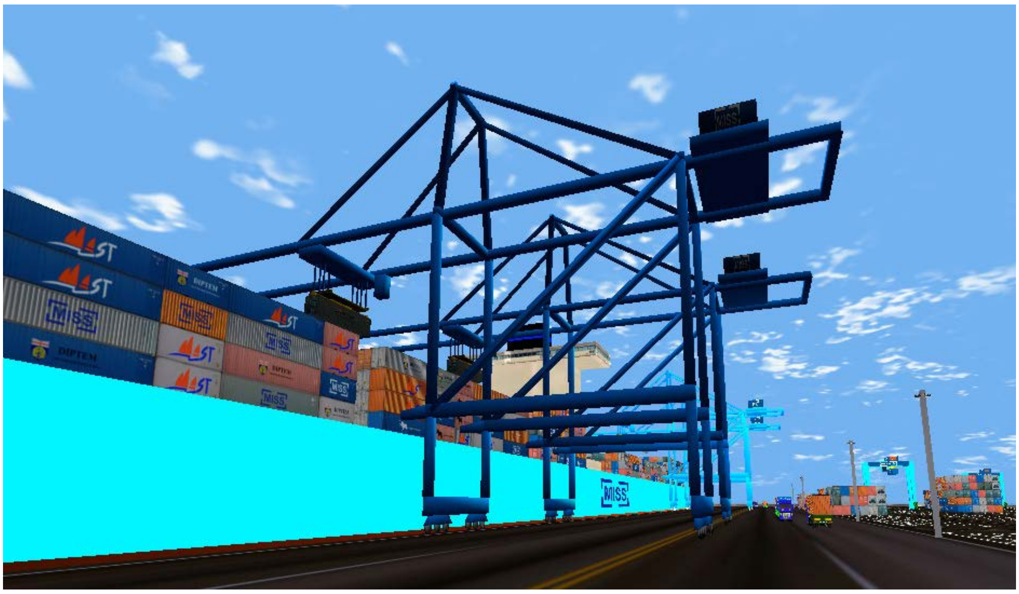

Figure 2.3 – Crane simulator solutions developed by Simulation Team (source: Bruzzone and Longo, 2008)

The state of the art reported above clearly shows that while a lot of research activities have been carried out to support land-side operators training (e.g. quay cranes operators, straddle carriers operators, trucks operators, etc.), there is still a lack of research on solutions to be used for the training of operators working in the last mile of navigation. We refer specifically to ship pilots training and to port traffic controllers.

2.7 Training Needs in the last mile of navigation

In order to identify correctly training needs in the last mile of navigation it is of crucial importance to provide a description of the main processes and activities that are performed during the last mile of navigation. Such processes and activities can be summarized as follows:

- Pilot Boarding. 6-12 nautical miles before reaching the port, the vessel contacts the port authority that in turn alerts the pilots that will support the vessel when it will arrive at the entrance of the port. Before entering the port, the pilot is escorted on board and information about the berth position (according to vessel dimensions and berth positions availability) are received.
- Definition of the route for accessing to port area. Once the information about the berth position has been received, the pilot establishes the correct route and maneuvers needed to access the port area and reach the assigned berth position. It is of crucial importance to align the heading of the vessel with the entrance of the port at least half mile before in order to have a clear view of the access channel.
- Entrance/Exit in/from the port. If the entrance (or the exit) is authorized by the Port Authority then the pilot proceeds starting the related maneuvers. Freight vessels usually have the right of precedence both during enters and exit maneuvers; priority must also be given to exiting freight vessels.
- Approach to the berth position, docking and mooring operations. Depending on the type of anchorage to be made, the ship approaches the berth by positioning the correct side toward the dock position
- Mooring operations. There are three types of mooring:
    - the vessel is arranged parallel to the berth and is then blocked with different wire ropes (usually 6 in a typical mooring scheme, three on the stern and three on the bow).

  - The stern is positioned adjacent to the dock while the bow is out. The stern is then secured to the ground by means of wire ropes and the bow is fixed through one or two anchors or it is secured to a dead weight or to a buoy.
  - The bow is positioned adjacent to the dock while the stern is out. The bow is secured to the ground by means of wire ropes and the bow is fixed through one or two anchors or it is secured to a dead weight or to a buoy.
- Support activities from the control tower. All phases of input/output and mooring operations are supported and monitored by port traffic controllers working in the control tower (if available). Their position usually provides a clearer picture of the traffic situation in the port area and allows, therefore, providing pilots with relevant information for executing safely and correctly all the maneuvers.

The main professional figures involved in the activities mentioned above are:

1. The Captain that directs, in agreement with the pilot, the various operations, defines the routes, warns the engine room an hour before the starting of the operation and, when the operation begins, or when a reduction of the speed is required to take on board the pilot.
2. The Pilot that directs (on the main bridge) all the operations together with the Captain; please note that the captain is usually unfamiliar with the port configuration and therefore he usually follows all the suggestions provided by the Pilot.
3. First Officer that assists the Captain and Pilot on the bridge; he monitors the on-board instrumentation and communicates their status (in particular if anomalies are detected).
4. The Helmsman that executes the instructions dictated by the Captain; the Helmsman actually performs the maneuvers by acting on the rudder and the levers of power.
5. The Boatswain that participates in the mooring operations from the bow and he takes care of the wires ropes.
6. Two officials located at stern and bow respectively follow mooring operations. These are in communication with the bridge, receiving orders and give information about distance, speed, presence of obstacles. In the engine room there are also a first and a second officer.
7. The Sailors execute instructions and work with the wire ropes.
8. The Tugboat pilots follow the instructions of the pilot to support the mooring operations.
9. Control Tower Officers (Port Traffic Controllers) that assist the crew operating on the ship bridge by providing information on the traffic situation within the port area.

The organizational complexity and plurality of actors who take part in these activities are elements that clearly show the key role of training activities. The figures involved are extremely different and have specific training needs; however, the figures for which training plays a critical role are the pilots and the captains (as well as first and second officers). At the same time, also port traffic controllers that support operations from the ground are required to have a strong training because their information related to the traffic situation within the port area are used by both the pilots and the Captains.
In such a context, errors may have extremely serious consequences for the safety of the crew as well as for people on the ground and may also cause huge economic damages. Such operators are required to be prepared to face scenarios characterized by different levels of risk and dangerousness, dictated by the configuration of the ship, the layout of the port, the traffic conditions, the weather and sea state. Within this scenario, it is clear that pilots, captains and port traffic controllers can operate only if properly trained and exercised and therefore able to deal with a variety of challenges that may emerge.
The training activities are traditionally articulated through a pull of lectures aimed to envisage the various scenarios that may occur and how to behave both in ordinary conditions and in case of risky situations. These activities are complemented by on the field training where operators involved face similar activities (and problems) that they will experience in daily operations. Next to the initial training, which is essential for all the operators involved in the maneuvering of a ship, it is also necessary to provide additional training activities in order to explain and disseminate to the lessons-learned on the field and to communicate improvements to procedures and best practices currently in use.
Having determined the relevance of training activities in the last mile of navigation, it is now clear that such training and exercise activities should be carried out by reducing as much as possible the costs and increasing as much as possible the training effectiveness. As mentioned throughout this chapter the best solution to this problem is given by the use of Modeling & Simulation. Indeed as mentioned in Bruzzone and Longo, 2010 the main advantages in using simulation based training systems are given by the possibility of

- practicing the theoretical concepts that have been taught and shows the consequences of the actions in a very immediate and visual manner;
- providing the instructor with a controlled environment where a large amount of data can be recorded and analyzed to evaluate the trainee’s evolution;
- avoiding the danger of an inexperienced user manipulating the real machine in the working environment;
- reducing the cost associated to training;
- providing the trainee with the possibility of working in any desired conditions (i.e. arbitrary weather conditions).

The next chapter presents and describes in details the architecture of two simulators: the bridge ship simulator and control tower simulator. These two simulators are part of a more complex system (that also includes a tugboat simulator) that is the final result of a research project carried out at Modeling & Simulation Center – Laboratory of Enterprise Solutions of University of Calabria. The project aim was the design, development and prototyping of an advanced training environment for vessels operations in the last mile of navigation. The main idea behind the project is to recreate the typical conditions in which operators are usually involved in the vessel last mile of navigation: manoeuvres of large ships within the harbour area (executed by ship pilots, captains and first officers), tugboat operations to support ship manoeuvres (executed by tugboat pilots), traffic control executed by officers on ground (port traffic controllers). The system architecture includes three interoperable simulators and this PhD thesis focuses on two simulators: the ship bridge simulator and the control tower simulator. The next chapters present the system general architecture, the software design and development phase and the hardware integration. In particular, Chapter 3 presents the architecture of the simulators with particular attention to interoperability issues solved by using the standard for distributed simulation IEEE 1516 HLA. Chapter 4 presents the ship motion equations at sea (based on a 6 Degree of Freedom model); chapter 4 also introduce and describes the 3D geometric models and the virtual environments (based on the port of Salerno, Italy). Finally, Chapter 5 provides the reader with specific information about the hardware integration (recreation of a ship bridge replica).

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3.1 Introduction

The contents provided along the chapter are devoted to illustrate the main goals the research has been aimed at as well as the general reference framework and the effort underpinning the development activities that are discussed in the following chapters. In agreement with the HABITAT Project (PON01_1936) this PhD belongs to, research and development activities have been focused on the design and development of a training & exercise system for ship pilots and port traffic controllers (control tower operators). As far as the training & exercise system for ship pilots is concerned, it consists of a ship bridge simulator equipped with a ship bridge replica and the main controls and instrumentation (available on board of real ships) that are recreated through input devices or simulators running on a set of dedicated screens. Thus, inexperienced pilots involved in training sessions can receive real time feedbacks in response to the actions he/she undertakes. Such feedbacks are displayed by the instruments and by the visualization system where the port scenarios as well as the ship dynamical positions are shown.
The training & exercise system for port traffic controllers consists of a simulator (the control tower simulator) that provides control tower officers with a visualization platform that allows monitoring all phases of vessels maneuvers for entering into or exiting from the port.
The two simulators (the ship bridge simulator and the control tower simulator) are integrating according to the IEEE 1516 HLA standard for distributed simulation to allow joint and cooperative training sessions. Thus the simulators are able to share and act within the same 3D environment and the trainees that are the ship pilot and the port traffic controllers can exchange information using audio/video communications systems. Moreover, the HLA integration allows providing the training system with a new functionality that is called “Virtual Teleportation function” and allows port traffic controllers teleporting on board of a ship to get information on how the operational area is perceived and seen by ship pilots.
As well known, HLA is an integration standard for distributed simulation devoted to address interoperability, modularity and the reuse of simulations components. As a result, when HLA is adopted any number of physically distributed simulation systems (called *federates*) can be integrated to form a single simulation environment (called *federation*). Therefore, in the sequel, particular attention will be paid on the Training System Architecture design with particular reference to the HLA framework.
To this end, first the High Level Architecture and its conceptual underpinnings are provided then the general Hardware and Software architecture is dealt with. Such architecture has been carefully considered under HLA perspective and therefore the HLA view along with the federates and the Federates Object Models and the performance measures are outlined.

3.2. The “Training & Exercise” system: goals and scope

As mentioned, the training & exercise system is aimed at:

- Supporting ship pilots training on last mile navigation maneuvers;
- Supporting control tower operators training, monitoring and control tasks.

Therefore, the training & exercise is made up of two main simulation components: the simulator for Pilots’ Training (ship bridge simulator) and the simulator for Control Tower Operators’ Training (control tower simulator).
The simulation components are devised to be able to work in two operational modes, namely in a standalone mode and in a fully integrated operational mode. So as to allow operators to train in individual training sessions or, instead, in joint cooperative sessions where both pilots and controllers are simultaneously involved. The training system has been released in the form of a prototype system that is able to allow training on different port scenarios such as the port of Salerno, the port of Livorno and the port of Gioia Tauro. Moreover, it provides ship pilots with different training opportunities in terms of ships configuration since during the training session there is the possibility to choose among three different types (tanker, containership, bulk carrier). However, as part of this thesis, only one port scenario (the Port of Salerno, Italy) and one ship (the containership) are considered.

3.2.1 The Ship Bridge Simulator

The Ship Bridge Simulator (we will refer to this simulator also as Ship Pilots Training Simulator) is able to simulate the ship behavior based on the actions undertaken by the trainees interacting with ship controls (steering wheel and the engine power lever, side propellers, etc...) and on-board instrumentation (AIS, CONNING and RADAR). The pilot-ship interactions evolve real-time based on the ship responses and the pilot's courses of action and the outcomes of such interaction processes are immediately shown by an immersive visualization system. In other words, the training system implements "man in the loop" solutions to make the training experience extremely realistic and immersive.

Real-time information available to the pilot includes:

- Information such as the rudder angle, ship speed, ship position, heading, etc. which is represented by the Conning Emulator part of the on board navigation instrumentation. In addition there is the information provided by the radar simulator that shows the targets detected in the local scenario and AIS simulator that shows the current location of the OS (own ship) on an electronic chart.
- Pictures and Sounds of the Virtual Scenario (view from the ship bridge) such as to make the pilot absorbed into the scene feeling as if he/she was in a real port environment and maneuvering a real ship.

In addition to the ship bridge replica, the following elements are provided:

- The Virtual Scenario Representation that allows showing the 3D representation of the virtual scenario through a sound and visualization system made up of video projectors, monitors, etc.
- The Ship Dynamics Module that based on the inputs provided by the pilot acting on the ship controls, on the weather conditions and on the sea state is able to simulate the dynamical behavior of a ship at sea.
- The Scenarios Supervision system (it is actually part of the Instructor workstation) that deals with the configuration and monitoring of the simulation scenarios, it allows changing viewpoint, choosing the type of ship for training and setting weather and marine conditions.

The Ship Pilots Training Simulator involves, indeed, the following entities:

- OS (the Operative Vessel) that is the ship whose bridge as well as the dynamic behavior are reproduced;
- Other vessels, e.g. vessels that may be part of the scenario, but are distinct from the OS.
- The Pilot, that is, the operator that governs the ship acting on the ship controls.
- The Supervisor (Instructor or Tutor), which is the operator managing the "Training & Exercise" system.

3.2.2 The Control Tower Simulator

The Control Tower Simulator (we will refer to this simulator also as the control tower operator training simulator) is devoted to simulate a control station and therefore it is equipped with a multi-display system, which shows the virtual scenario including traffic conditions inside the port area. The trainee, in particular, can act on the control console to change the view of the simulated scenario, both in the form of 2D maps and of a 3D immersive environment as if he/she was in a real control tower. Furthermore, based on real-time information provided by instruments such as the AIS and the RADAR emulators, he/she can also visualize the navigation data of a particular ship or the port traffic conditions. However, the trainee can also enable the virtual teleport function that allows him/her to be teleported on board of the ship sharing the same view and the perceptions of the pilot about the operational scenario. Needless to say that, thanks to this functionality, the control tower operator is able to improve the information and the instructions for ship pilots.

The real-time information available to the control tower operator includes:

- Information on the maritime traffic within and in the surroundings of the port area, information on the each ship that is going to enter/exit such as heading, position, speed, etc. Besides, there is also the information provided by the RADAR emulator (that shows the targets in the local scenario) and the AIS emulator (which displays the current location of the ship on 2D map) the Control Tower is equipped with.
- Virtual Scenario Images (the control tower view and view from the bridge of the ship which is the object of teleportation) which make the trainee feeling as if he/she were in a real control tower or on a ship bridge in case the teleport function is activated.
- Information on weather and sea conditions.

In addition to Control Tower Operator Training Simulator includes:

- The Virtual Scenario Representation that allows showing the 3D representation of the virtual scenario through a sound and visualization system made up of screens, etc.

- Typical Instrumentation such as a RADAR emulator and an AIS emulator to display port traffic conditions on 2D maps.
- The Scenarios Supervision system that deals with the configuration and monitoring of the simulation scenarios, it allows changing view point and activating the teleport function.

The most involved entities are:

- The OS (Operative Vessel), that is, the ship whose bridge is simulated by the Navigation Bridge Simulator;
- Other vessels, e.g. vessels that may be part of the scenario, but are distinct from the OS.
- The control tower operator.
- The Supervisor (Tutor or Instructor), which is the operator managing the "Training & Exercise" system.

3.2.3 The Tugboat Bridge Simulator

As already mentioned in the first two chapters, the main goal of this thesis is to present the design, development and prototyping of two simulators: the ship bridge simulator and the control tower simulator used for cooperative training of ship pilots and port traffic controllers respectively. However, the full system also includes the tugboat bridge simulator. This tugboat bridge simulator works together with the other two simulators allowing the cooperative training of tugboat pilots. The description of the design, development and prototyping of the tugboat bridge simulator is outside the scope of this thesis.

3.3 Architectural design of the Simulators Federation

The overall architecture of the Simulators Federation is shown in figure 3.1, highlighting all the component modules and the data stream exchanged between them according to the HLA standard. In addition, figure 3.1 also depicts an overlapping of the hardware and software architectures (please note that according to section 3.2.3, the tugboat bridge simulator is included in figure 3.1 but it will be not described as part of this thesis).
The main software/hardware modules are summarized in table 3.1 and are presented in this and in the next chapters.

SHIP FEDERATE (SDN)	This federate recreates the ship bridge simulator and it is used for ship pilots training
CONTROL TOWER FEDERATE (STC)	This federate recreates the control tower simulator and it is used for port traffic controller training
TUGBOAT FEDERATE	This federate recreates the tugboat bridge simulator and it is used for tugboat pilot training (not included in this thesis)
GEOMETRIC MODELS	These models includes all the 3D geometric models that are used to fill the virtual environments and recreates, as consequences, different training scenarios (see Chapter 4)
SHIP MOTION EQUATIONS	These equation are used to simulate the ship motion at sea according to a 6 Degree of Freedom Model (see Chapter 4)
HARDWARE IN THE LOOP	Basically it includes all the hardware needed to recreate a replica of the ship bridge (see Chapter 5)
AIS SIMULATOR	This module recreates the simulation of the Automated Identification System (AIS), one of the technologies available on board to support navigation
RADAR SIMULATOR	This module recreates the simulation of the Radar, one of the technologies available on board to support navigation
CONNING SIMULATOR	This module recreates the simulation of the Conning Display, used to display the most important information and data during navigation (speed, position, heading, engine power, compass, wind, etc.)
SUPERVISION SYSTEM	This module recreates the Instructor workstation that is devoted to set-up the training scenario, collect data and trainees' performances, carry out de-briefing activities
GRAPHIC USER INTERFACE	This module is part of the supervision system and represents the interface used by the instructor to access the system functionalities

SETTINGS	This module includes all the scenarios training settings
CONTROL	This module provides functionalities such as initialization procedures, starting, interrupting, terminating the simulation and verifying the simulation advance
ANALYSIS	This module is used to save data and information along the simulation execution

Table 3.1: Main Software/Hardware Modules

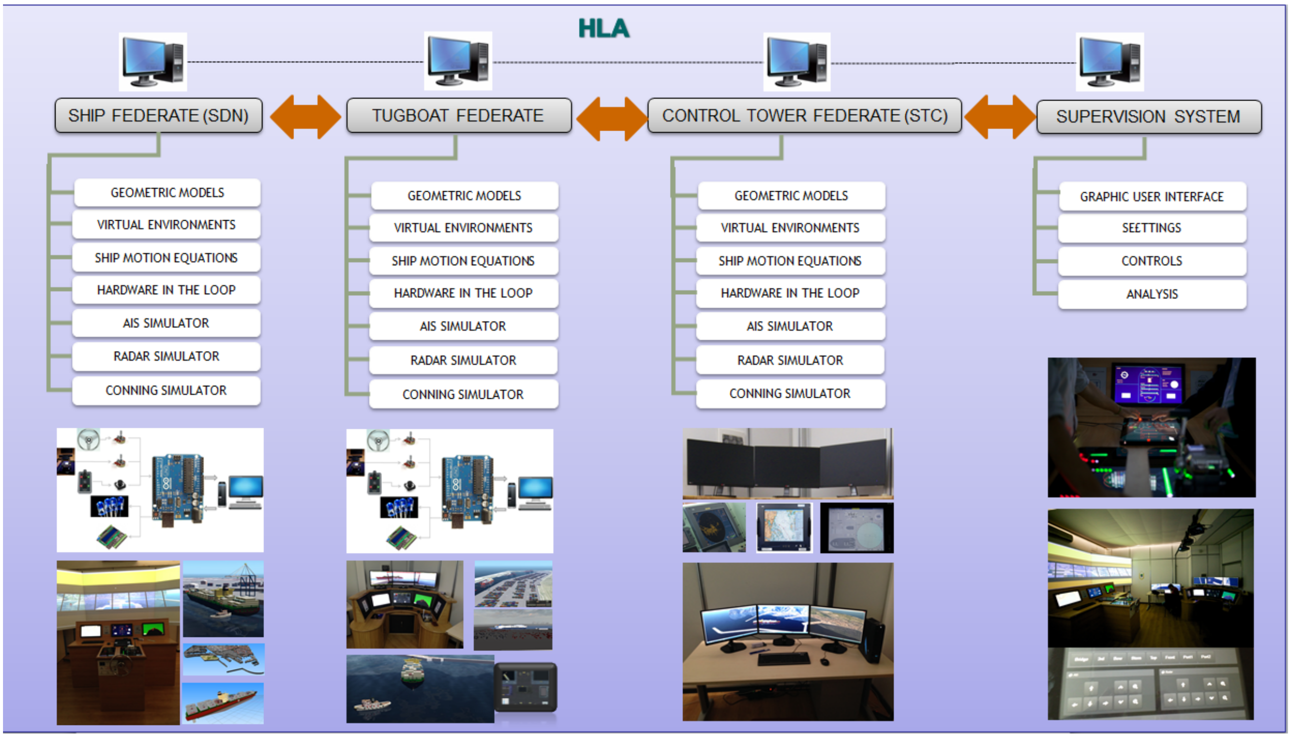

Figure 3.1: Overall Architecture

It is worth saying that the most important modeling and analytic effort of the entire thesis is the definition and implementation of the Ship Motion equations that rule the ship motion at sea according to a 6 Degree of Freedom Model. Indeed, this module plays a crucial role because, as a matter of facts, it is responsible for the behavior of a ship at sea and how the ship evolves over the time under specific weather and sea conditions. In other words, this module is required to provide real time information on the ship position and on the interactions with the virtual environment (e.g. collisions). Therefore, at each point in time, positions, velocities and accelerations along the main axis are evaluated, namely: surge, sway, drift, heave pitch and roll.
As a consequence, this module includes equations devoted to recreate the ship behavior at sea that depends on multiple variable and parameters (e.g. engine power, propeller size and pitch, hull shape, etc..) and on the ship operating conditions such as translation and rotation speeds, velocity and acceleration of the propeller at the previous instant, engine speed and propeller revolutions. Ship responses are evaluated for each interaction with the simulated environment (waves, wind, collisions, etc.) in the form of vectorial force acting on the ship (see figure 3.2). Moreover, such module is required to manage rudder orientation, engine power, propeller pitch, side thruster's power, etc., based on the inputs provided by the external hardware integrated as part of the ship bridge replica.
In particular, the module aims at calculating forces and moments generated by the propeller, the rudder, the hull, the side thruster, the wind and the sea state that are function of the rudder angle, propeller RPM, hydrodynamic parameters, ship geometry, weather conditions. Thus based on such forces, ship speeds, accelerations and position are calculated and such information are sent to the virtual environment to move the ship 3D model accordingly (obviously such information are also sent to the Control Tower Simulator to represent correctly the ships movements within the virtual environments recreating the harbor area). The Control Tower Instrumentation module manages the interfaces between the instrumentation available on the control Tower and the Virtual Environment; moreover, it provides the communication tools to allow the real time interaction with the ship pilot. Therefore, the Control Tower Instrumentation module allows recreating

the interaction between the ship and control tower that based on its knowledge of the overall traffic conditions can suggest or require route adjustments. The ship motion equations will be extensively presented in Chapter 4.

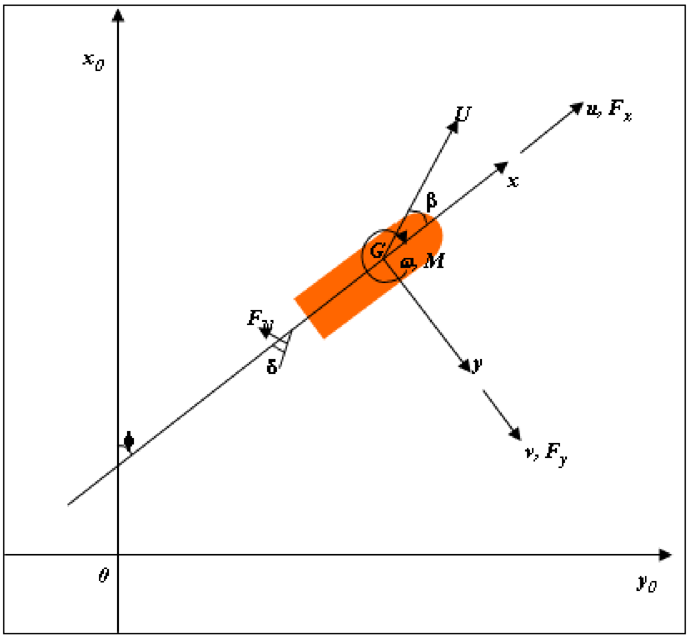

Figure 3.2: Ship Motion at sea reference systems, main forces and moments

3.3.1 Ship Pilot Training Operator Simulator Requirements

In this section, the technical requirements of the Ship Pilot Training Operator Simulator (Ship Federate, SDN) are introduced. The federate respects the following requirements:

- calculation of the hydrodynamic coefficients needed to apply the mathematical model of the ship dynamics which is based on ship dimensional and geometric parameters
- calculation of the ship response at sea;
- simulation of the ship engine based on the ship main features such as type of power, propeller size, engine power, efficiency, etc.; and taking into account the ship operating conditions (translation and rotation speed, propeller velocity and acceleration at the previous instant).
- calculation of the evolution of the ship position based on ship hydrodynamic coefficients, weather conditions, propeller RPM, rudder angle and collisions;
- management of the data exchanged with other federates, receiving information on
    - Sea state and weather conditions:
        - Sea force;
        - Waves direction;
        - Wind Intensity and direction;
        - Precipitations;
    - Positions and velocities, of other ships in the same operational area.
- publication of information ship position, acceleration and speeds.

As far as the main requirements of the virtual environments are concerned, the ship federate respects the following requirements:

- capability to recreate environmental effects as well as wave motion based on a specific mathematical model and on wind effects; in particular:
    - Daytime/ Night effects
    - Fog effects
    - Clouds based on weather conditions
- capability to recreate the Virtual Scenario including the port area and its surroundings.
- capability to show the evolution of the simulation and the ship motion;
- capability to provide an immersive visualization experience.

Finally, as far as the hardware integration is concerned, the main requirement is the design and development of a full replica of a bridge ship including the main instruments available on board of ships such as electromechanical controllers and auxiliary devices. In particular, the ship bridge replica of the simulation system includes RADAR, AIS and CONNING simulators. Such simulators allow providing the pilot with the information he/she needs to steer a ship. The main software requirements of this model include:

- the ability to display real time information on ship navigation conditions (CONNING);
- the ability to provide an operational picture of traffic conditions displayed on 2d maps even based on data collected from the real system (AIS);
- the ability to provide the ship radar functionalities;

3.3.2 The Control Tower Operator Training Simulator

The Control Tower Training Simulator fulfills the following requirements:

- Manages the tools that enable communication between system operators for pilots and system operators control tower;
- Gets information on:
  - Interactions among vessels and the port area
  - Position, speed and acceleration of the ship;
- Sends information on:
  - How to update the ships trajectory.

3.3.3 The supervision system

The supervision system deals with the configuration and monitoring of the simulation scenarios, it allows changing view point, choosing the type of ship for training and setting weather and marine conditions Therefore, it has been equipped with the following functionalities:

- A Graphical User Interface (GUI)
- Settings
- Control
- Analysis

The graphic user interface (GUI) includes the following features:

- It is multi-window;
- It includes a command bar that allows accessing the main functional menus as well as a console window for visualizing the alphanumerical messages launched by the system.
- It allows accessing the following functionalities:
  - Control
  - Settings
  - Analysis
  - Help

The Settings functionality includes the following:

- It is equipped with a section that allows setting the following parameters:
  - data and time of the simulation establishing whether the training refers to daytime or night
  - the geographical context (the port)
  - activation of audio effects;
  - activation of audio effects (e.g. alarms signals)
  - forbidden areas
  - type of ship selection;
  - initial position of the ship;
  - weather conditions;
  - fog;
  - sea state;
  - wave direction;
  - wind strength and direction;
  - wave direction;
  - traffic conditions;
- It allows saving and filing the settings of a particular scenario

- It allows retrieving a saved scenario or deleting it

The control section of the GUI allows initialization procedures, starting, interrupting, terminating the simulation and verifying the simulation advance. Moreover, the control section allows updating weather and environmental conditions as well as checking all simulation parameters.

The Analysis section allows accessing the data that have been stored along the simulation in log. Files including data about the trainees' performances.

3.4 Design of the Federation Architecture – HLA view

The module illustrated before interact each other through the HLA standard. Some of the figures reported in this section are taken by the High Level Architecture course by Roy Crosbie and John Zenor (California State University, Chico). Figure 3.3 provides a general view of the HLA architecture, its components and how they are related each other. As mentioned before, basically the federation is made up of two federates. The ship federate and the control tower federate. At a macro-level the simulation includes the federation whose single components are the federates.

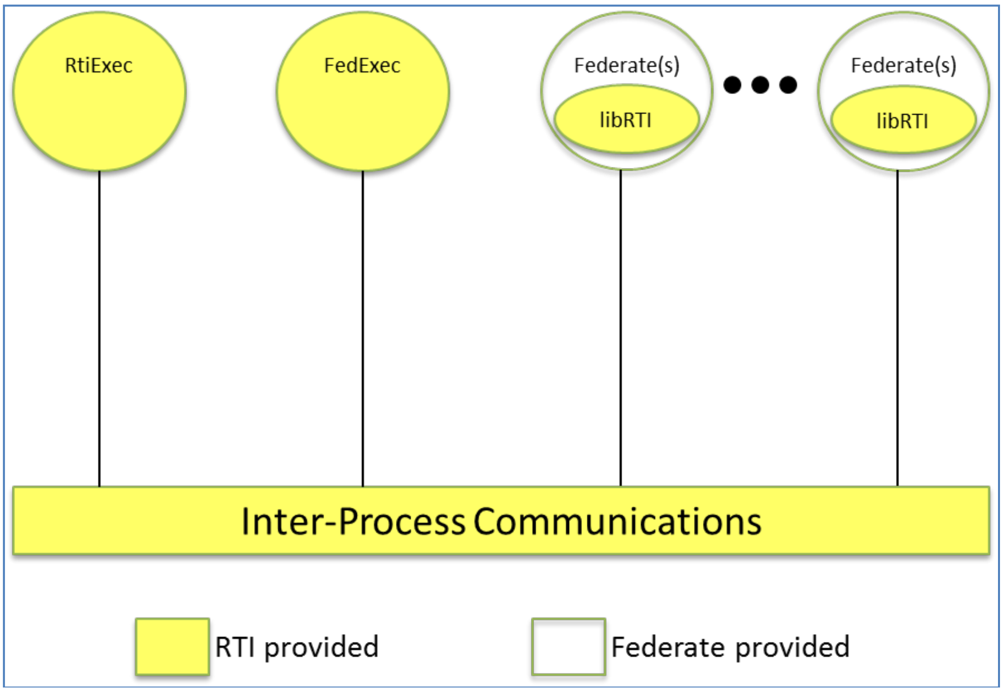

Figure 3.3: HLA Federation Architecture (a general overview)

Communication management among federates is managed by a middleware called RTI. Through the RTI each federate launches the RTIexec that allows the execution of one or more federations ensuring that each has a unique name; furthermore it acts as a listener to a given port. The Fedex is launched by the first federate that joins the federation and it manages Federates join and resign assigning a unique code to each federate for data Exchange. All the machines the federates run on are provided with specific libraries: libRTI. These are C++ libraries with interfaces that provide methods for data and time management (such an attributes publishing and subscribe, time synchronization, privileges management on attributes, etc.). As a result, the HLA architecture for the training and exercise system can be represented as shown in figure 3.4

The federates can communicate through the RTI and in particular using the RTIambassador and FederateAmbassador classes; the former is used to provide the federates with the RTI services, while the latter is an abstract class where callback functions are defined. Callback functions are those functions the RTI launches when specific events occur, for instance the Update Attribute function is launched if an attribute that has been subscribed by a federate is updated). Each federate, in turn, is made up a set of elements as shown in figure 3.5.

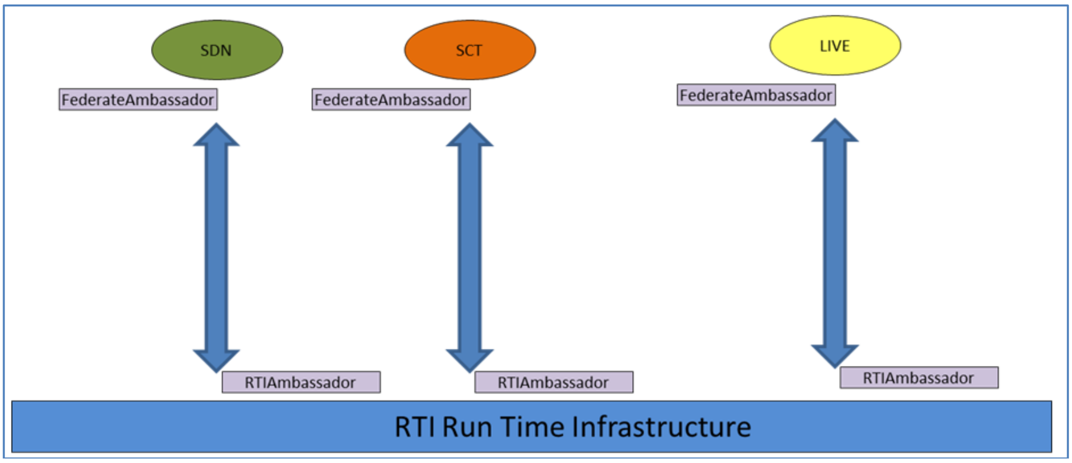

Figure 3.4: HLA Federation view

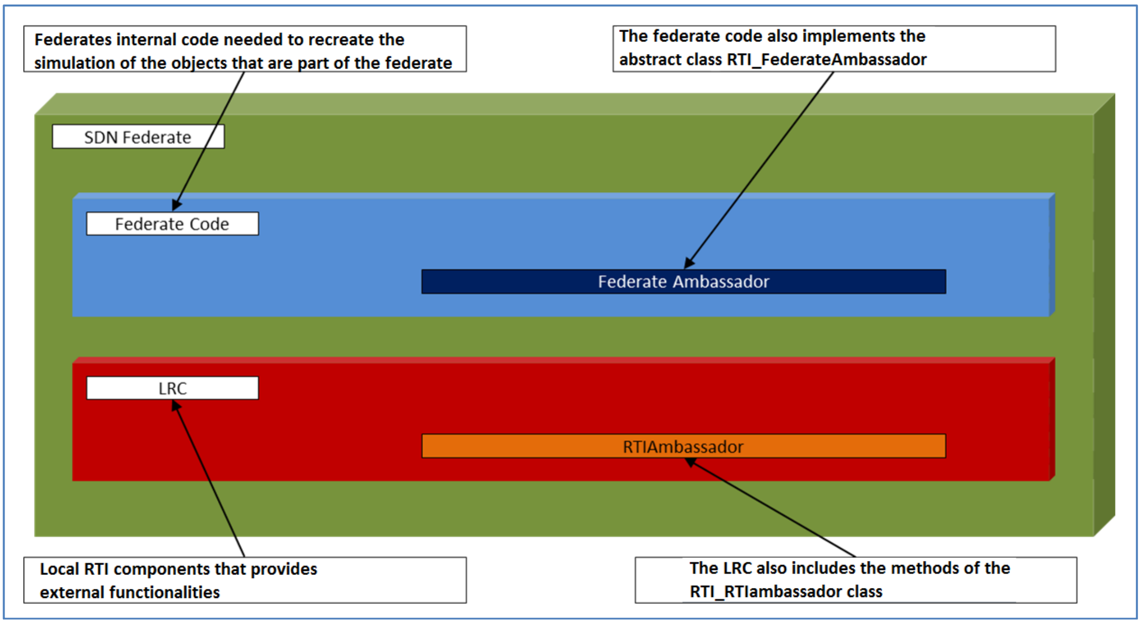

Figure 3.5: HLA Federate Architecture view

In particular, internal functions, that are part of the Federate Code, define the federate dynamical behavior and create the simulation objects. The RTI sends messages and answers to the federate code invoking the functions implemented in it. These functions are known as callback functions and are part of a class derived from RTI::FederateAmbassador class. The RTI::FederateAmbassador class is part of the libRTI library and includes virtual functions for each callback. For this reason, the functions of interest have to be implemented before they could be used. However, it is not necessary to implement all the functions but, instead, only those that are likely to be used. If a not implemented function is improperly called, it would generate an error message. External functionalities Local RTI Components allow using RTI services, for instance:

- Federation creation;
- Federates join and resign to/from an existing federation;
- Subscribe of attributes (e.g. subscription of attributes that defines vessels positions within the harbor area);
- Publish of attributes (e.g. publication of the attributes that define the position of the vessel – the one controlled by the trainees – within the harbor area);
- Objects instances definition;
- Update and Reflect of the attributed vales;
- Attributes ownership management;
- Time synchronization and management;
- Other Callback functions

Needless to say the other federates have the same architecture.

Figure 3.6 highlights the differences between the responsibilities of the federate code (provided by the user) and the libRTI provided by the Run Time Infrastructure.

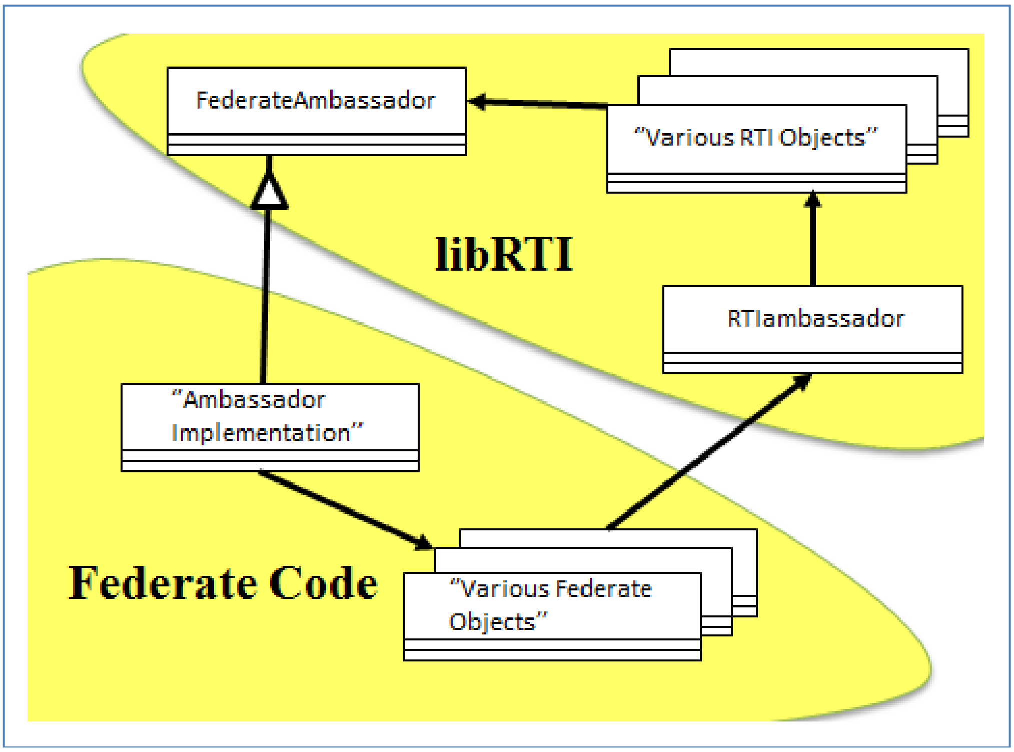

Figure 3.6: Code Responsibilities within the HLA Federate

The libRTI contain the RTIambassador class and the FederateAmbassador abstract class. The Federate code includes the programming code written by the user that define the behavior of the simulator and also implements a class derived from the RTI::FederateAmbassador class. This derived class contains the actual implementations for each of the callback functions so that the federate can receive messages and responses originated by the RTI.
The figure 3.7 shows the Federation Architecture during its execution (called Federation HabitatSIM). The federation includes:

- one RtiExec process that manages the execution of the Run Time Infrastructure according to the information included in the RTI.rid file (RTI vendor-specific information needed to run an RTI);
- one FedExec process that manages the execution of the Federation;
- one Federation Object Model according to the FOM Documented Data file (in figure 3.7 the FederationHabitatSIM.fdd);
- three federates: the SDN Federate (that is the Ship Bridge Simulator), the SCT Federate (that is the Control Tower Simulator) and the Live Simulator (this federate has been not currently developed but it is added to extending the system functionalities, in particular for using the system for monitoring and controlling vessels traffic within the real harbor area).

For the sake of completeness, the Federation Object Model (FOM) includes all the information that, at run time, are exchanged between all the federates (in terms of objects, attributes, interactions and parameters).
The Figure 3.8 demonstrates the steps in the process of starting a federation execution.

- When a federation is run, the RTIexec is started first.
- Then a federate, acting as a manager, creates a federation execution by invoking the RTI method createFederationExecution on its RTI Ambassador.
- The RTIambassador then reserves a name with RTIexec, and spawns a FedExec process, and that FedExec registers its communication address with RTIexec. The federation execution is underway.
- Once a federation execution exists, other federates can join it. That RTIambassador consults RTIexec to get the address of FedExec, and invokes joinFederationExecution on FedExec. Additional federates can join via the same process.

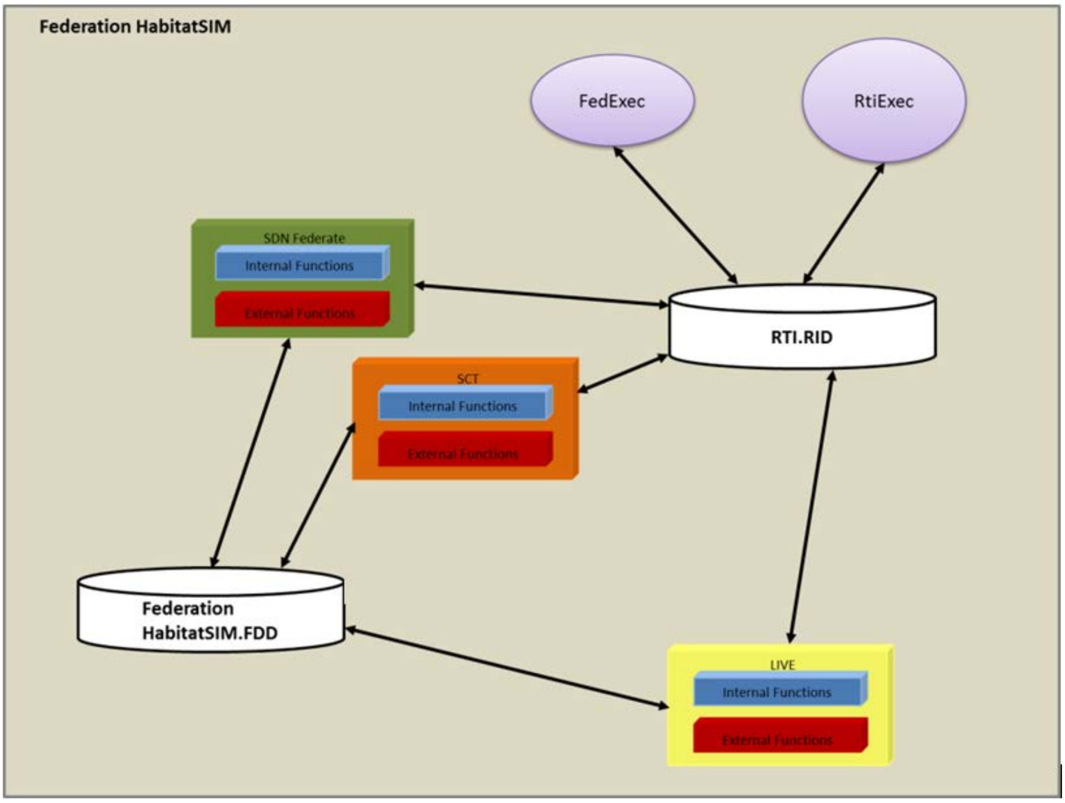

Figure 3.7: HLA Federation Architecture during its execution

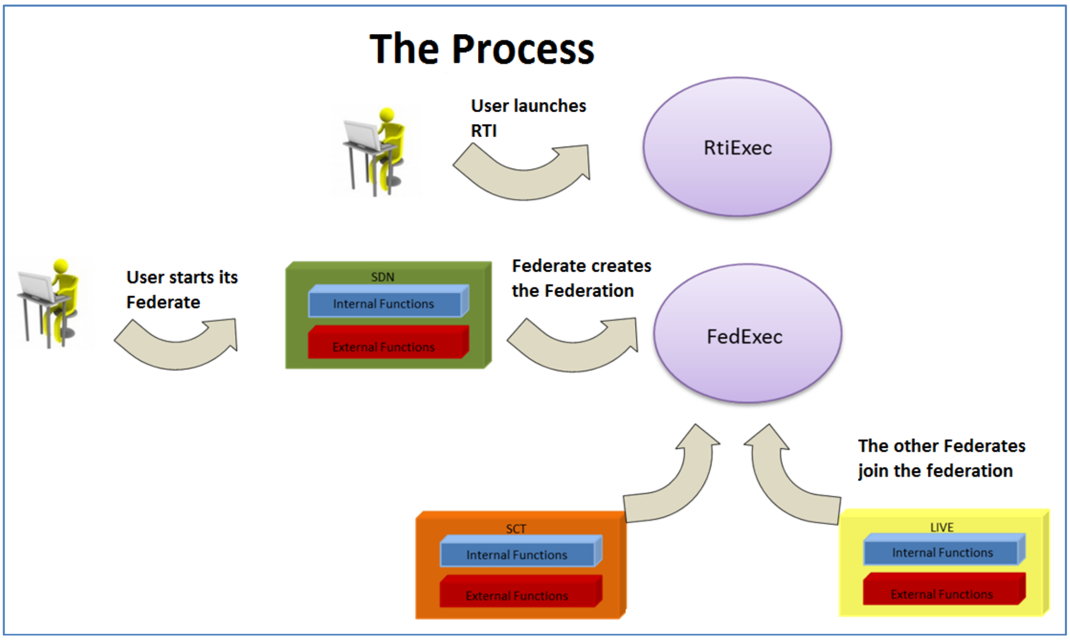

Figure 3.8: Federation Execution Process

3.4.1 Federation Development and Execution process (FEDEP)

This section briefly reports the processes and procedures that, according to the IEEE HLA 1516.3 standard, have been followed to develop and execute the federation including the SDN federate and the STC federate. The Federation development process can be subdivided in seven different steps:

Step 1: Define federation objectives.

The federation user, the sponsor, and the federation development team define and agree on a set of objectives and document what must be accomplished to achieve those objectives.

Step 2: Perform conceptual analysis.

Based on the characteristics of the problem space, an appropriate representation of the real world domain is developed.

Step 3: Design federation.
Existing federates that are suitable for reuse are identified, design activities for federate modifications and/or new federates are performed, required functionalities are allocated to the federates, and a plan is developed for federation development and implementation.

Step 4: Develop federation.
The Federation Object Model (FOM) is developed, federate agreements are established, and new federates and/or modifications to existing federates are implemented.

Step 5: Plan, integrate, and test federation.
All necessary federation integration activities are performed, and testing is conducted to ensure that interoperability requirements are being met.

Step 6: Execute federation and prepare outputs.
The federation is executed and the output data from the federation execution is pre-processed.

Step 7: Analyze data and evaluate results.
The output data from the federation execution is analyzed and evaluated, and results are reported back to the user/sponsor.

A detailed view of the Federation Development and Execution Process (FEDEP) is provided in Figure 3.9. According to IEEE HLA 1516.3 standard, this view illustrates the flow of information across the seven process steps identified above. Each activity description includes potential inputs and outputs of that activity and a representative list of recommended tasks. Graphical illustrations of the interrelationships among the activities within each step are also provided. Whenever outputs from one FEDEP activity represent a major input to one or more other activities, the arrow labels explicitly identify the activities that use these outputs. The arrow labels also identify the activities that produce inputs. However, there is a presumption embodied within the FEDEP that once a product has been created, it will be available for all subsequent activities, even though the product may not be shown as a major input or identified as an input in the activity description.
Additionally, once a product is developed, the product may be modified or updated by subsequent activities without such modifications being explicitly identified either as a task or output. Input and output arrows without activity number labels are those in which the information originates from outside or is used outside the scope of the FEDEP.
Although many of the activities represented in the FEDEP diagram appear highly sequential, the intention is not to suggest a strict waterfall approach to federation development and execution. Rather, this process illustration is simply intended to highlight the major activities that occur during federation development and execution and approximately, when such activities are first initiated relative to other federation development activities. In fact, experience has shown that many of the activities shown in Figure 3.9 as sequential are actually cyclic and/or concurrent. Users of the FEDEP should be aware that the activities described in this recommended practice, while being generally applicable to most HLA federations, are intended to be tailored to meet the needs of each individual application. For example, FEDEP users should not feel constrained by the federation products explicitly identified in this recommended practice, but rather should produce whatever additional documentation is necessary to support their application. The guidance provided in this section should be used as a starting point for developing the specific approach to federation development and execution for the intended application.
Finally, in order to provide a better understanding of the FEDEP, a tabular view of the activities inherent to each major step is provided in Table 3.2.

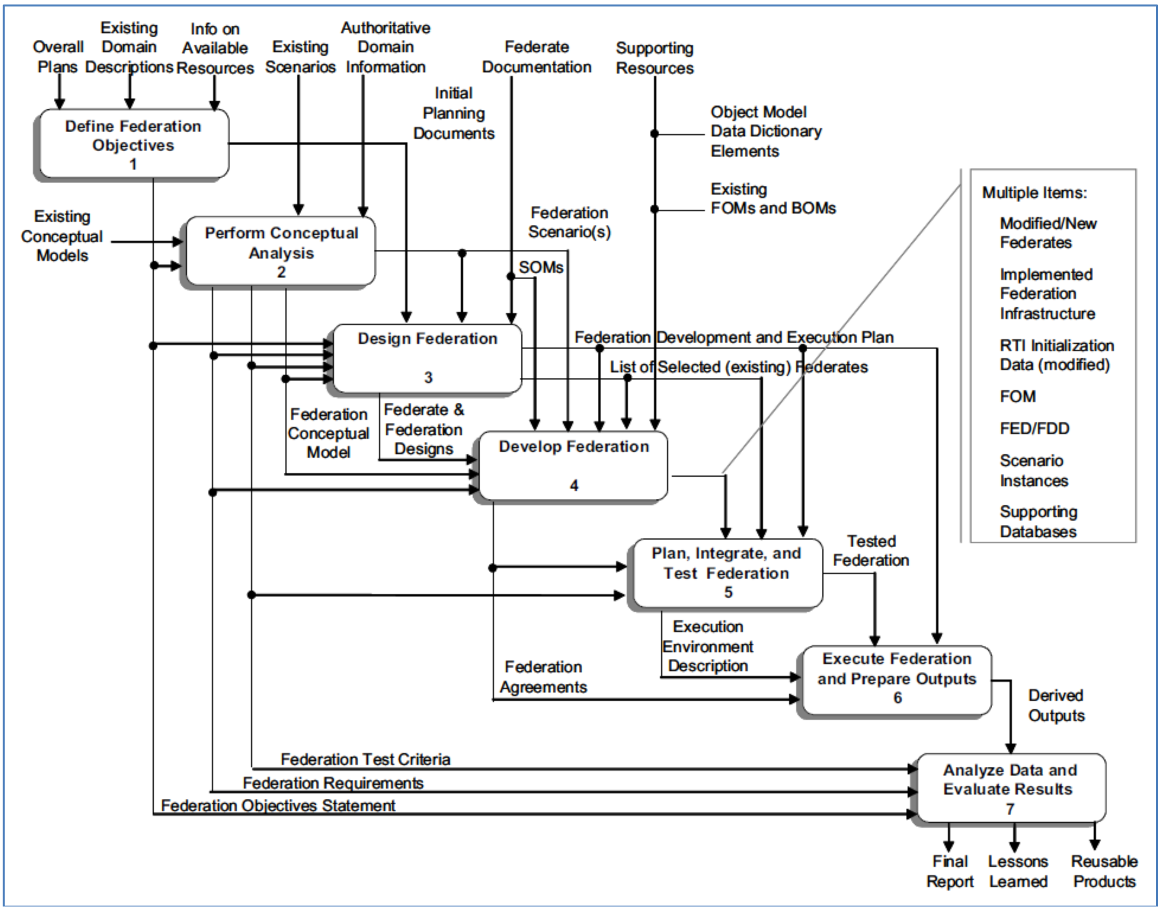

Figure 3.9 – Federation Execution Process (source: IEEE HLA 1516.3 Standard)

Step 1: Define federation objectives	**Step 2: Perform conceptual analysis**	**Step 3: Design federation**	**Step 4: Develop federation**	**Step 5: Plan, integrate, and test federation**	**Step 6: Execute federation and prepare outputs**	**Step 7: Analyze data and evaluate results**
Identify user/ sponsor needs Develop objectives	Develop scenario Develop federation conceptual model Develop federation requirements	Select federates Prepare federation design Prepare plan	Develop FOM Establish federation agreements Implement federate designs Implement federation infrastructure	Plan execution Integrate federation Test federation	Execute federation Prepare federation outputs	Analyze data Evaluate and feedback results

Table 3.2 – Tabular view of the main FEDEP steps (source: IEEE 1516.3 Standard)

References

IEEE Std 1516 (2000) IEEE standard for Modeling and Simulation (M&S) High Level Architecture, HLA.

IEEE Std 1516 (2000) IEEE standard for Modeling and Simulation (M&S) High Level Architecture - Framework and Rules.

IEEE Std 1516 (2000) IEEE standard for Modeling and Simulation (M&S) High Level Architecture - Object Model Template (OMT) Specification.

IEEE Std 1516 (2000) IEEE standard for Modeling and Simulation (M&S) High Level Architecture - Federate Interface Specification.

IEEE Std 1516.3 (2003) IEEE standard for Modeling and Simulation (M&S) High Level Architecture - Federation Development and Execution Process (FEDEP).

IEEE Std 1516.4 (2007) IEEE standard for Modeling and Simulation (M&S) High Level Architecture-Recommended Practice for Verification, Validation, and Accreditation of a Federation - An overlay to the High Level Architecture Federation Development and Execution Process.

4.1 Introduction

Large ships manoeuvres in the aim of the entry to or exit from the harbour area can be complex and dangerous operations for several reasons. Indeed, in standard traffic conditions, harbour pilots and port traffic controllers deal with a great number of vessels of different sizes (i.e. small motorboats, huge container carriers, cruise ships etc.). In addition, manoeuvres times (and reaction times) of vessels are very slow compared to other vehicles especially for large vessels. Indeed, due to their prominent size and mass, in case of mistakes and accidents, large vessels may cause enormous damages (as clearly demonstrated by the recent accident on May 7th, 2013 of the Italian containership Jolly Nero in the port of Genoa, Italy, check http://www.bbc.com/news/world-europe-22444421 for further information).

In large facilities like marine ports like in many other industrial facilities, operative and procedural training has widely proved to be an indispensable approach that can be effectively supported by simulation based systems (Merkuryev and Bikovska, 2012; Narciso et al. 2010). As far as the ship manoeuvres in the port area are concerned, simulation based systems can be profitably used for ship pilots training purposes, for procedures definition, evaluation and testing, for understanding vessels interactions within the port area, for evaluating the effects on ships of adverse weather conditions (including wind, sea waves and marine currents). As a matter of facts, simulation based system allows a greater standardization and effectiveness of training procedures. The trainees can control virtual ships in any critical or dangerous condition; they can perform both standard and non-standard manoeuvres and therefore they are trained to handle those situations that cannot be recreated during traditional training sessions in a real ship.

Therefore, simulation based training is also characterized by a relevant reduction of direct costs. These costs reduction is related to the increase of productivity when workers (in this case ship pilots) are well trained to perform their job. There is also a reduction of indirect costs caused by accidents during training and normal activities as well as the possibility of collecting a large amount of data about trainees' performance in a controlled simulated environment.

Moreover, simulation-based training is fruitful not only for beginners but also for expert operators. For instance, it can be useful to have the first approach with a new ship or to learn how to put in practice the procedures currently adopted in a specific port. The simulators can be used to understand how performing ship manoeuvres in critical conditions (i.e. strong wind and/or marine currents), how carrying out complex manoeuvres with the help of tugboats, how performing mooring operations and control the ship when close to the assigned berth area. A key feature of the simulation approach is the greater level of immersion it can provide compared to traditional training approaches. Indeed, immersion makes the training experience more captivating and therefore contributes to maximize the amount of information the trainees are able to acquire, the skills that can be developed and mostly the ability to transfer lesson learned to the real system. Basically, immersion can be diegetic and situated or intra-diegetic. The former occurs when the player gets absorbed into the virtual experience while the latter goes beyond the diegetic immersion and implies the player total engagement that is the illusion of existing and acting within the virtual environment. Needless to say that, in both cases, the virtual environment where the trainee acts and the hardware tools used to interact with the environment itself play a crucial role. To this end, the research proposed in this chapter has been focused on the development of a fully operational prototype training system (based on the architecture presented in Chapter 3). Such system that can be used for harbour pilots and port traffic controllers training includes not only the distributed virtual environments, but also a suitable hardware tools design and integration (the latter will be presented later in Chapter 5). The training system is currently installed in the MSC-LES lab (Modeling and Simulation Center-Laboratory of Enterprise Solutions) at the University of Calabria.

Indeed, the literature review confirms that there is quite a large amount of research works that show how simulation has already been successfully applied to support decision making (Bruzzone et al. 2012-a) and training of operators working within marine ports, e.g. cranes, trucks, straddle carriers operators, etc. (Kim, 2005). Many simulators are intended to quay cranes operators' training (Wilson et al., 1998; Huang, 2003; Daqaq, 2003; Rouvinen et al., 2005) and specific research works have also investigated the training for supporting security procedures integration in the marine port operations (Longo and Bruzzone 2005, Longo, 2010 and Longo 2012).

In addition, innovative approaches based on interoperable simulation have been proposed. Specific examples regards the training of marine ports operators, e.g. Bruzzone et al. 2008, Bruzzone et al. (2011-a), Bruzzone et al. (2011-b) propose interoperable simulators (based on the High Level Architecture, HLA, standard) for

different container handling equipment (gantry cranes, transtainers, reach stackers, trucks, etc.) offering advanced solutions in terms of external hardware, e.g. motion platforms, different types of external controllers from joysticks to wheels and pedals and even containerized solutions.
As for ship simulators, interesting applications can be found in Ueng et al. (2008), Sandaruwan et al. (2009), Sandaruwan et al. (2010) and Yeo et al. (2012). Although in such works an immersive visualization system and the dynamic behaviour of the ship have been implemented, there is still substantial room for improvement above all in terms of ship motions predictions and validation. Moreover, in these works no attention has been paid on the last/second last mile of navigation (including manoeuvring and mooring operations in the port area) that, as explained before, it is as important as offshore navigation. A review of the state of the art related to traffic controllers and ships pilots training in marine ports can be found in Bruzzone et al. (2012-b).
As already mentioned, the main goal of this thesis is to present an advanced simulation based system, equipped with dedicated hardware in the loop, for training, safety and security of operators involved in the last mile of navigation. The system includes a ship bridge simulator (with a full replica of a ship bridge), a full control tower simulator and a tugboat bridge simulator (with a full replica of a tugboat bridge; the last simulator is not described as part of this thesis). The proposed training system is conceived in order to provide its users with a realistic experience thanks to the possibility of experiencing a joint and cooperative training environment. To this end, the three simulators have been integrated according to the High Level Architecture standard (IEEE HLA 1516). The system overall architecture has been already presented in Chapter 3. As a result, pilots can exercise their operational and manoeuvring skills, became acquainted with the behaviour of the ship and with the effects of their interaction patterns. Moreover, the proposed system allows the harbour pilots to learn the procedures that are currently adopted in a specific port, and decision makers to design and test new procedures.
Along this chapter, different problems are presented and solved, namely:

- the sea-keeping problem in terms of implementation and validation of the ship motion equations at sea for a 6 Degrees of Freedom (DOF) model;
- the design and development of all the 3D geometric models and virtual environments
- the integration of the ship motion equations to control the ship within the virtual environment.
- the integration of the bridge ship simulator and control tower simulator through the IEEE 1516 High Level Architecture standard for distributed simulation.

It is worth mentioning that the prototype system presented in this thesis has been developed within the framework of the on-going research project: HABITAT (Harbour Traffic Optimization System). This project is co-founded by the Italian Ministry of Education, University and Research as part of the PON01_01936 research project.
Before going into details, the chapter 4 is organized as follows: section 4.2 discusses the sea keeping problem and explains the 6 DOF model used to simulate the ship motion at sea. Section 4.3 deals with the validation of the ship motion equations. Section 4.4 presents the ship bridge simulator focussing on the 3D geometric models and the virtual environments based on the Port of Salerno (Italy). Section 4.5 briefly describes the control tower simulator. Section 4.6 focuses on the HLA federates integration also presenting FOM, SOMs and performance measures definition. Section 4.7 explains how the entire system can be used to create different training scenarios. Finally, section 4.8 summarizes the scientific contribution of the chapter and points out some aspects for future development.

4.2 The sea-keeping problem: the ship motion equations

The ship included as part of the ship bridge simulator is a commercial containership based on the Kriso containership model, whose main particulars are summarized as follows:

- Hull
  - Length between perpendiculars 230.0 m
  - Length water line 232.5 m
  - Breath 32.2 m
  - Depth 19.0 m
  - Displacement 52030 m^3
  - Coefficient block 0.651
- Rudder
  - Type semi-balanced horn rudder
  - Surface of rudder 115 m^2

- Lateral area 54.45 m^2
- Turn rate 2.32 deg/s

- Propeller
  - Number of blades 5
  - Diameter 7.9 m
  - Pitch ratio, P/D (0.7R) 0.997
  - Rotation Right hand

A 6 DOF mathematical model is used to reproduce the ship motion at sea. In particular, for surge, sway and yaw, the Manoeuvring Mathematical Modelling Group model (MMG) has been used (and tuned). Such model takes the name from the Japanese research group that implemented it for the first time between 1976 and 1980. Hence, the MMG group (1985) defined for the first time a prediction method for ship manoeuvrability. Afterwards, Kijima (1999), taking into account the effects of the stern, proposed the approximate formulas for evaluating the hydrodynamic forces acting during manoeuvring motions. As for the hydrodynamic coefficients, empirical formulas are given in Rhee and Kim (1999) and Lee et al. (2003). Moreover, Yoshimura (1986) and Perez et al. (2006) describe how some parameters and dimensions influence manoeuvrability characteristics while Hasegawa et al. (2006) have discussed the course-keeping in windy condition. These findings have been integrated within the MMG model that includes three equations of motion (1, 2, 3) for surge, sway and yaw respectively based on the Newton's second law and according to the reference system depicted in figure 4.1.

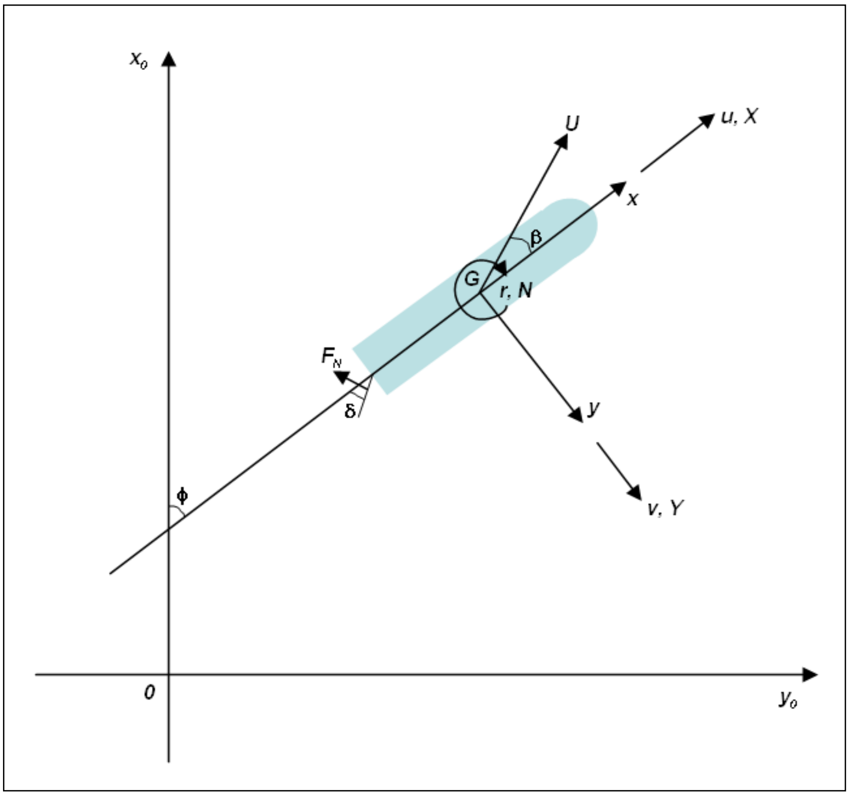

Figure 4.1 – Reference system for ship motion equations (MMG, 1985)

4.2.1 The surge, sway and yaw equations

Equations for surge, sway and yaw are reported in (1), (2) and (3) respectively:

$$(m + m_x)\dot{u} - mvr = X \quad (1)$$

$$(m + m_y)\dot{v} + mur = Y \quad (2)$$

$$(I_{zz} + i_{zz})\dot{r} = N - x_G Y \quad (3)$$

In figure 4.1 and equations 1, 2 and 3:

- m is the mass of the ship;
- m_x and m_y are the added mass in x and y direction respectively;
- I_{zz} is the moment of inertia;
- i_{zz} is the added moment of inertia around z;
- u is the surge speed;
- v is the sway speed;
- U is the ship total speed
- r is the rate of turn;
- G is the center of gravity of the ship
- x_G is the distance from amidship to the centre of gravity of the ship
- X and Y are respectively the total external surge and sway forces;
- N is the yaw moment.
- δ is the rudder angle
- ϕ is the angle between the ship heading and the vertical axis of the reference system
- F_N is the normal force applied to the rudder
- β is the angle between the ship total speed and the ship heading

Added masses and added moment of inertia can be found using the equations proposed by Hooft and Pieffer (1988). In some equations non-dimensional variables are used, they are marked with the prime symbol. The external forces are those produced by the hull, the propeller and the rudder; they are marked with the subscripts H, P and R respectively, therefore surge sway and yaw can be also expressed as shown in equations 4, 5 and 6.

$$X = X_H + X_P + X_R \quad (4)$$

$$Y = Y_H + Y_R \quad (5)$$

$$N = N_H + N_R \quad (6)$$

Since the hull of the ship has a complex shape it is quite difficult to calculate hull forces. To this end, the equations 7, 8 and 9 (proposed in the Proceedings of the 23rd ITTC 2002) have been used.

$$X'_H = -(X'_0 + (X'_{vr} - m'_y)v'r') \quad (7)$$

$$Y'_H = Y'_v v' + (Y'_r + m'_x)r' + Y'_{vvv}v'^3 + Y'_{vvr}v'^2r' + Y'_{vrr}v'r'^2 + Y'_{rrr}r'^3 \quad (8)$$

$$N'_H = N'_v v' + (N'_r + m'_x)r' + N'_{vvv}v'^3 + N'_{vvr}v'^2r' + N'_{vrr}v'r'^2 + N'_{rrr}r'^3 \quad (9)$$

It is worth noticing that the higher order terms have been omitted in the surge force equation because their influence is negligible and an appropriate formula to calculate the coefficients is not available yet. Equations 7, 8 and 9 define a relation between velocities and hull forces with hydrodynamic non-dimensional coefficients. Such coefficients are normally obtained through empirical tests, however a set of semi-empirical equations can be found in Lee et al. (2003). Therefore, the total non-dimensional resistance, X'_0, has been calculated as shown in equation 10 where C_T is the total resistance coefficient (obtained from model resistance tests), S is the wetted surface, L is the length between the perpendiculars, and d is the draft.

$$X'_0 = \frac{C_T S}{Ld} \quad (10)$$

On the other hand, the equations for non-dimensional variables are given in 11, 12, 13, 14 and 15 according to Kijima (1993).

$$m', m'_x, m'_y = m, m_x, m_y / 0.5\rho L^2 d \quad (11)$$

$$X', Y' = X, Y / 0.5\rho L d U^2 \quad (12)$$

$$N' = N/0.5\rho L^2 dU^2 \quad (13)$$

$$r' = \frac{rL}{U} \quad (14)$$

$$v' = \frac{v}{U} \quad (15)$$

In equations 11, 12, 13, 14 and 15, ρ is water density and U is the ship speed that can be calculated according to 16.

$$U = \sqrt{u^2 + v^2} \quad (16)$$

The force generated by the propeller is obtained using the equation 17 from Kijima (1993) where n is the propeller rate expressed in RPM, t is the suction coefficient, D_p is the propeller diameter and K_T is the propeller thrust coefficient.

$$X_P = (1 - t)\rho n^2 {D_p}^4 K_T \quad (17)$$

It is possible to express K_T as a function of the propeller advance coefficient J, as shown in equations 18 and 19.

$$J = (1 - w_P)u/(nD_P) \quad (18)$$

$$K_T = C1 + C2 + C3J^2 \quad (19)$$

In equation 18, w_p is the wake fraction, while in order to identify *C1*, *C2* and *C3*in equation 19 it is necessary to use the least squares method on Wageningen B systematic series for the appropriate propeller. Lastly, the rudder forces are calculated according to equations 20, 21 and 22 taken from Kijima (1993).

$$X'_R = -(1 - t_R)F'_N sin\delta \quad (20)$$

$$Y'_R = -(1 - a_H)F'_N cos\delta \quad (21)$$

$$N'_R = -(x'_R - a_H x'_H)F'_N cos\delta \quad (22)$$

where:

- t_R is the rudder drag coefficient;
- F'_N is the normal force applied to the rudder;
- a_h is a coefficient that expresses the interaction between rudder and hull forces;
- x'_R is the non-dimensional coordinate of the centre of lateral force along the x-axes;
- x'_H is the non-dimensional coordinate of the centre of additional lateral force along the x-axis (such values can be evaluated by using the equations given in Kijima et al., 1993);
- δ is the rudder angle.

4.2.2 Roll, Pitch and Heave Equations

The response of a ship to wave induced loads is quite complex. As a matter of facts complex interactions between the ship dynamics and several hydrodinamic forces have to be considered. Basically, the equations of motion can be derived from the Newton's second law. In particular, recalling the linear theory, acting forces and moments can be divided into excitations and radiations forces/moments. Excitation forces are the forces of the waves acting on a restrained ship while radiation forces are caused by ship motions.

Considering heave, roll and pitch denoted by w, θ, and φ, the related coeffiecients labelled with the subscript *3*, *4* and *5* respectively, the excitation and radiations forces/moments labeled with the subscripts *EX* and *H* respectively, for sinusoidal uncoupled motions the equations are given in 23, 24 and 25 where derivation with respect to time is denoted by a dot (Lewis, 1989).

$$(\Delta + A_{33})\ddot{w} + B_{33}\dot{w} + C_{33}w = |F_{EX3}\cos(\overline{\omega}t + \epsilon_3)| \quad (23)$$

$$(I_{44} + A_{44})\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi = |F_{EX4}\cos(\overline{\omega}t + \epsilon_4)| \quad (24)$$

$$(I_{55} + A_{55})\ddot{\theta} + B_{55}\dot{\theta} + C_{55}\theta = |F_{EX5}\cos(\overline{\omega}t + \epsilon_5)| \quad (25)$$

In equations 23, 24 and 25, the coefficients A_{33}, A_{44}, and A_{55} have the dimension of a mass and are called hydrodynamic masses or added masses, the coefficients B_{33}, B_{44}, B_{55} have the dimension of a mass per unit of time and are called damping coefficients; the coefficients C_{33}, C_{44}, C_{55} are the restoring spring coefficients. Interesting theoretical insights about such coefficients and equation of motions can be found in Lewis (1989). In addition, Δ is the displacement, ω is the wave frequency, $\overline{\omega}$ is the frequency of encounter and I_{44} and I_{55} are the mass moment of inertia for roll and pitch respectively.
Obviously, in order to obtain numerical values for motion amplitudes the coefficient values and exciting forces amplitudes have to be known. The calculation is easy for the C_{33}, C_{44}, C_{55} coefficients that can be derived from stability calculations, but is very difficult for excitation forces, added mass and damping coefficients since a very complex hydrodynamic problem has to be solved. In most practical application the Strip Theory is applied (Ogilvie and Tuck, 1969). However, it has been found out that the implementation of a numerical code based on the strip theory was out of the scope of this study. As a matter of facts the simulator should work real time and therefore a lightweight computation model is needed even for visualization purposes. To this end, past related works such as Chen and Fu (2007), Ueng et al (2008), Sandaruwan et al. (2009), Sandaruwan et al. (2010), Yeo et al. (2012), have been investigated. These works seek to calculate buoy motions arising from waves in order to achieve realistic visualization results and are based on simple dynamic models. However, ship responses are evaluated just in terms of visualization and the numerical results have been accepted even if in some cases they have proven to be far from real empiric data. Under these considerations a more realistic and accurate model has been selected. This model has been proposed by Jensen, (2001) and Jensen et al (2004) and is based on simplified equations for ship motions in regular waves where the coupling terms are neglected and the sectional added mass is equal to the displaced water.

$$2\frac{kT}{\omega^2}\ddot{\omega} + \frac{A^2}{kB\alpha^3\omega}\dot{\omega} + \omega = aFcos(\overline{\omega}t) \quad (26)$$

$$2\frac{kT}{\omega^2}\ddot{\theta} + \frac{A^2}{kB\alpha^3\omega}\dot{\theta} + \theta = aGsin(\overline{\omega}t) \quad (27)$$

$$\left(\frac{T_N}{2\pi}\right)^2 C_{44}\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi = Macos(\overline{\omega}t) \quad (28)$$

The equations 26 and 27 refer to heave and pitch respectively; k is the wave number, B is the ship breadth, T is the ship draught, a is the wave amplitude and A is the sectional hydrodynamic damping that can be evaluated according to Yamamoto et al., (1986). Moreover, F and G are the forcing functions whose values can be worked out according to Jensen et al. (2004). As for roll, the equation is given in 28 where, T_N is the natural period for roll, B_{44} is the ship hydrodynamic damping, C_{44} is the restoring moment coefficient and M is the roll excitation moment.The hydrodynamic damping coefficient, B_{44}, can be found by applying the method described in Jensen et al. (2004), the roll excitation moment M can be derived from the Haskind relation (one of the most outstanding results in the ship oscillations theory), while the restoring moment coefficient C_{44} can be expressed as a linear function of the displacement Δ, the transverse metacentric height GM_T and the acceleration of gravity g (see equation 29).

$$C_{44} = gGM_T\Delta \quad (29)$$

In addition, it is worth noticing that the semi-analytical approach proposed in Jensen et al (2004) is intended to derive frequency response functions of wave-induced motions. Therefore, the model, as it is, is mainly addressed to naval engineering applications. However, the application proposed in this research work is quite new since the model has been solved in the time domain by the Euler's method and is used to provide the simulation and visualization system with real time data.

4.3 Validation of the Ship Motion Equations

The above-discussed mathematical models have been extensively validated before being implemented within the ship simulator. As explained later on, the ship simulator provides the user with a real-time simulation in a 3D Virtual Environment. The validation of the ship motion equations in a such environment is time expensive, each single test would require too much time to be executed (e.g. a simulated circle test executed real-time would require different minutes as happens in a real circle test). To this end, ship motion equations validation has been carried out by using an ad-hoc developed tool (implemented by using Visual Studio 2008 and C++ programming language) equipped with a 2D animation and able to run the simulation fast-time for validation purposes.

This tool allows setting the most important parameters such as the number of iterations to be executed, the time between two iterations, the propeller rate, the initial speed and the rudder angle. In this way, it is possible to execute circle tests, zigzag tests and stop tests according to different configurations as shown in figures 4.2, 4.3, 4.4 and 4.5 and easily carrying equations validation according to experimental data and/or subject matter experts' estimations.

During the execution of such tests, a plot of the ship motion evolution is drawn on the screen and sensible data as speed, drift angle, yaw rate, acceleration, heading, position are recorded on text files. This tool has proved itself as a very useful solution for ship motion equations validation. Since the preliminary tests carried out at the earlier validation stages were not in agreement with the empirical data that have been used as test-bed, the mathematical model has been carefully reviewed and some parameters, such as the dimensionless derivatives, where suitably calibrated based on tentatively approach. Even during calibration, the C++ tool has been used to assess whether the applied adjustments had improved the output results to achieve closer empirical evidence.

Figures 4.2 and 4.3 show the trajectory for two circle tests executed by using the validation tool, moreover they provide a comparison with empirical data (green squares) given by two circle tests executed, in the same conditions of speed and rudder angle. Empirical data are taken from The Specialist Committee on Esso Osaka, Final Report and Recommendations to the 23rd ITTC.

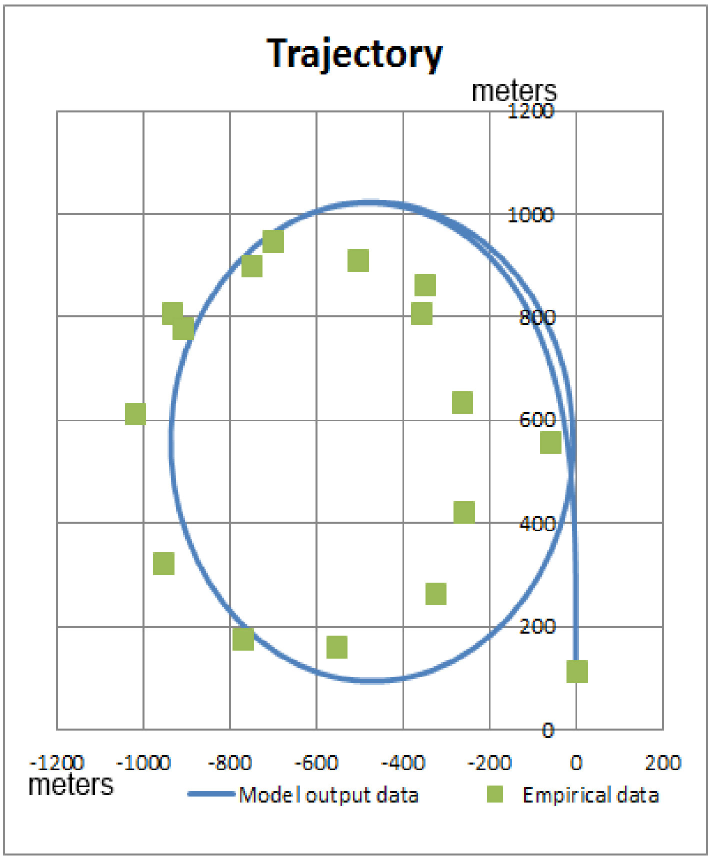

Figure 4.2: Turning trajectory in port side circle test, speed 8kn, rudder angle 35°.

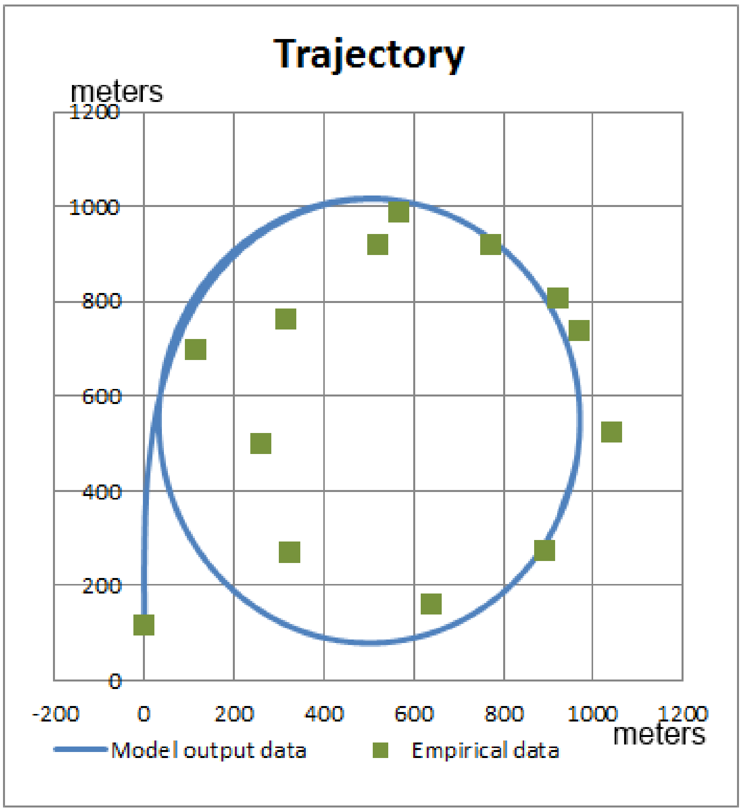

Figure 4.3: Turning trajectory in starboard side circle test, speed 10kn, rudder angle 35°

Figure 4.4 and 4.5 show two zigzag tests. They reflect the empirical data that can be seen on The Specialist Committee on Esso Osaka, Final Report and Recommendations to the 23rd ITTC.

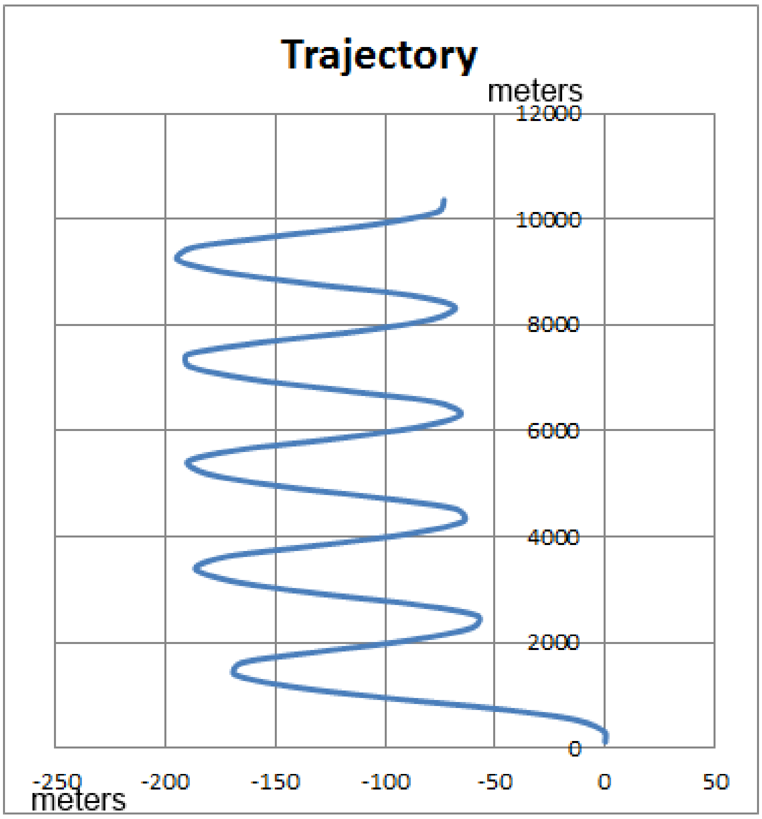

Figure 4.4: Turning trajectory in port side 20/20 zigzag test, speed 5kn

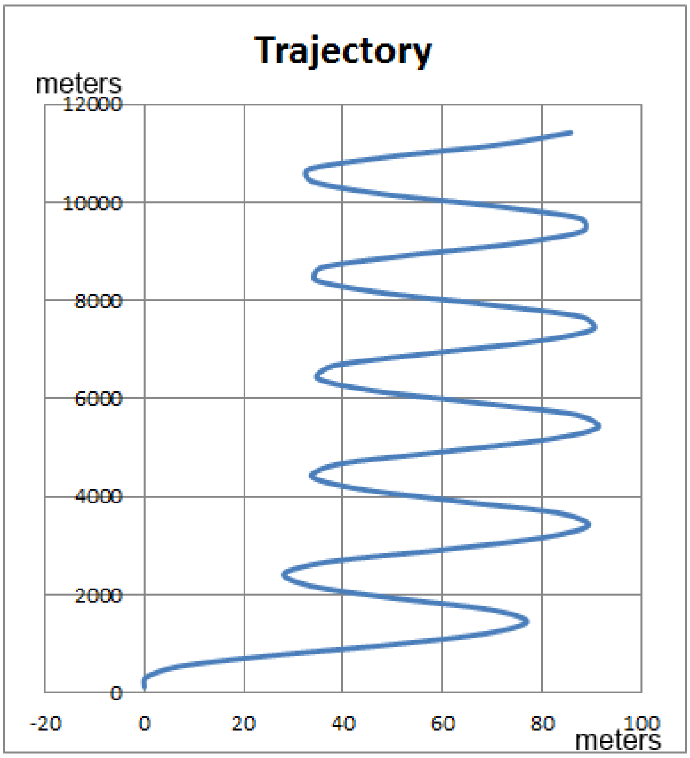

Figure 4.5: Turning trajectory in starboard side 10/10 zigzag test, speed 5kn

4.4 3D geometric models and virtual environments for the Ship Bridge Simulator

The equations described in the previous section rule the 6 DOF motion of the ship at sea; such equations are only a part of the simulation based system; simulators for training are characterized by 3D Virtual Environments able to provide the user with the sensation to be in the real system. Among others, currently the system includes the virtual environments of the port of Salerno (Italy). The port of Salerno, thanks to its central position in the Mediterranean Sea, has a crucial role in the national and international maritime trade. The port area includes the following quays:

- Quay of Ponente , length 563m, dockings n. 22-24;
- Rosso quay, length 226m, dockings n. 20-21;
- Trapezio quay, length 890m, dockings n. 13-19;
- Ligea quay, length 250m, dockings n. 11-12;
- 3 Gennaio quay, length 446m, dockings n. 7-10;

Outside the commercial area, on the east side of the port is located the Manfredi quay (length 380m, dockings n. 1-3) where a Marine Station devoted to cruise ships is being built. An entrance channel (280m large and 13m deep) with a 550 m diameter and 12 m deep evolution area characterizes the port. Moreover the port is served by 4 tugboats (working 24/24 h), 5 expert pilots with 2 equipped pilot-boats and 10 mooring operators with 2 equipped motorboats.

Vessels can pass across the entrance channel only one-by-one: if a boat is entering the port and another one is exiting, the incoming boat will wait until the other has safely completed its manoeuvres. In addition, due to Port Authority restrictions on side thrusters' use and wind conditions (that sometime can reach 40 kn), most of the large ships are obliged to ask the support of (at least) one tugboat during their manoeuvres. The figure 4.6 shows a panoramic view of the Port of Salerno.

Figure 4.6 - Panoramic view of Salerno port

Control and support of ship navigation in the second last/ last mile of navigation are very complex activities. The high number of ships and vessels that usually enter to and exit from a marine port, the adverse visibility and weather conditions that may occur, the type of ship (i.e. container carriers, passengers ships, etc.), the docking times, the loading/unloading times, are examples of factors that slow down the traffic. These factors also increase the risk of collisions during the navigation in the harbour area. In this scenario, the proposed simulators aim at providing a concrete support by leveraging the role of pilots and port traffic controllers training. As a matter of facts, manoeuvring a ship while it is exiting from or entering into a port area is quite difficult and may cause terrible losses. To this end, it is crucial that ship pilots as well as port traffic controllers are well trained and fully aware of the consequences of their actions. Since simulation provides a safe training environment where trainees can gain experience and explore possibilities, simulation-based training has great potentials in this application domain. However, it is worth saying that the effectiveness of simulation based training increases as the trainee's feeling of realism increases. Hence, a great attention has been paid on the 3D geometric models and virtual environments that recreate the port of Salerno. The simulation software Creator and Vega Prime by Presagis have been used for creating highly optimized 3D geometric models and high-fidelity 3D real-time simulations respectively. As a result the simulator gives the possibility to steer a container carrier in the last mile of navigation, as well as offshore, setting the rudder angle, the propeller rate and a number of other parameters dynamically. Figures 4.7 and 4.8 show the 3D geometric models recreating the port of Salerno (Italy), while figures 4.9 to 4.13 show two different views of the containership within the virtual environment of the port of Salerno.

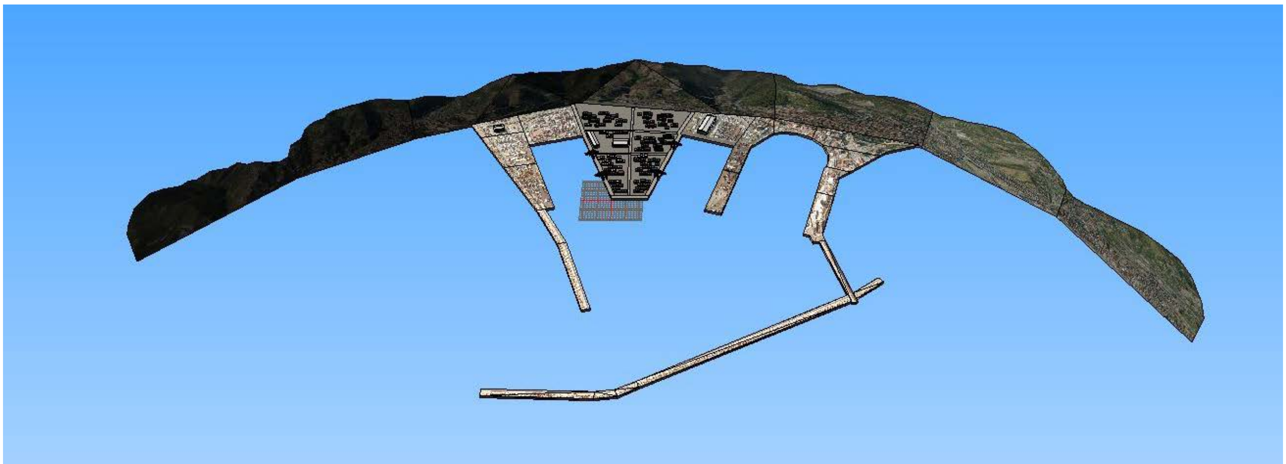

Figure 4.7 – 3D geometric model of the Port of Salerno

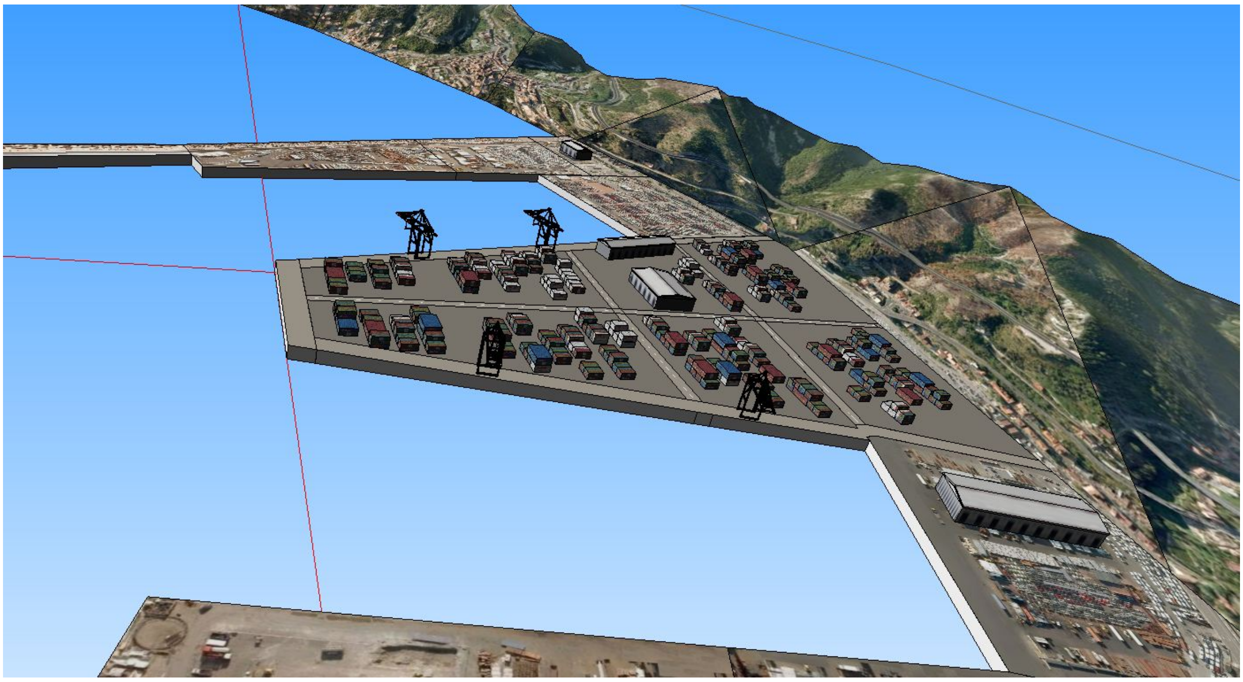

Figure 4.8 – Detailed view of the 3D geometric model of the Port of Salerno

Figure 4.9: View on the Containership in the Virtual Environment of the Port of Salerno

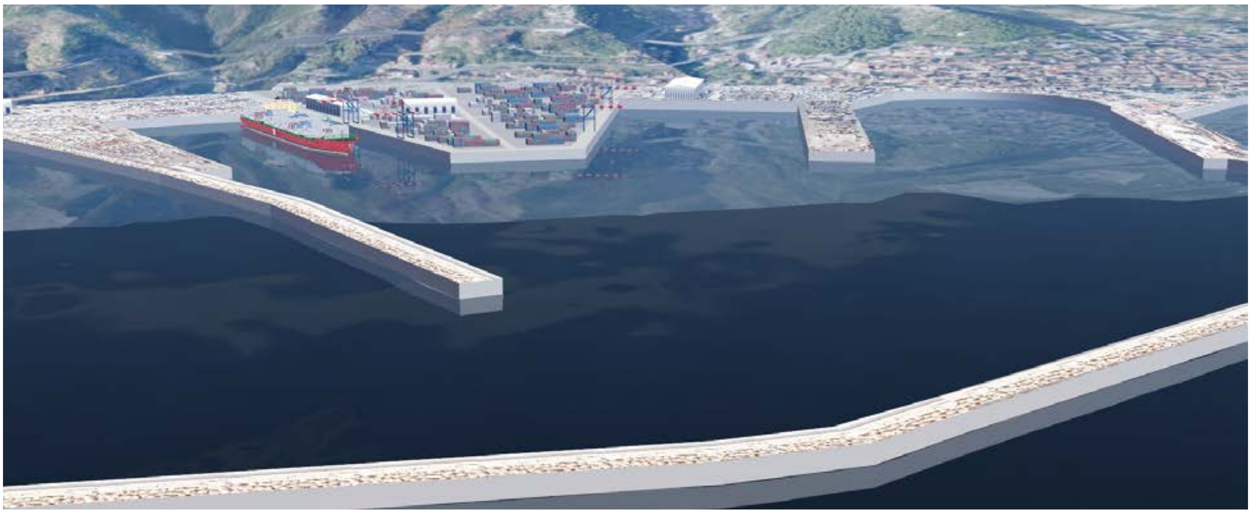

Figure 4.10: Panoramic view of the Virtual Environment of the Port of Salerno

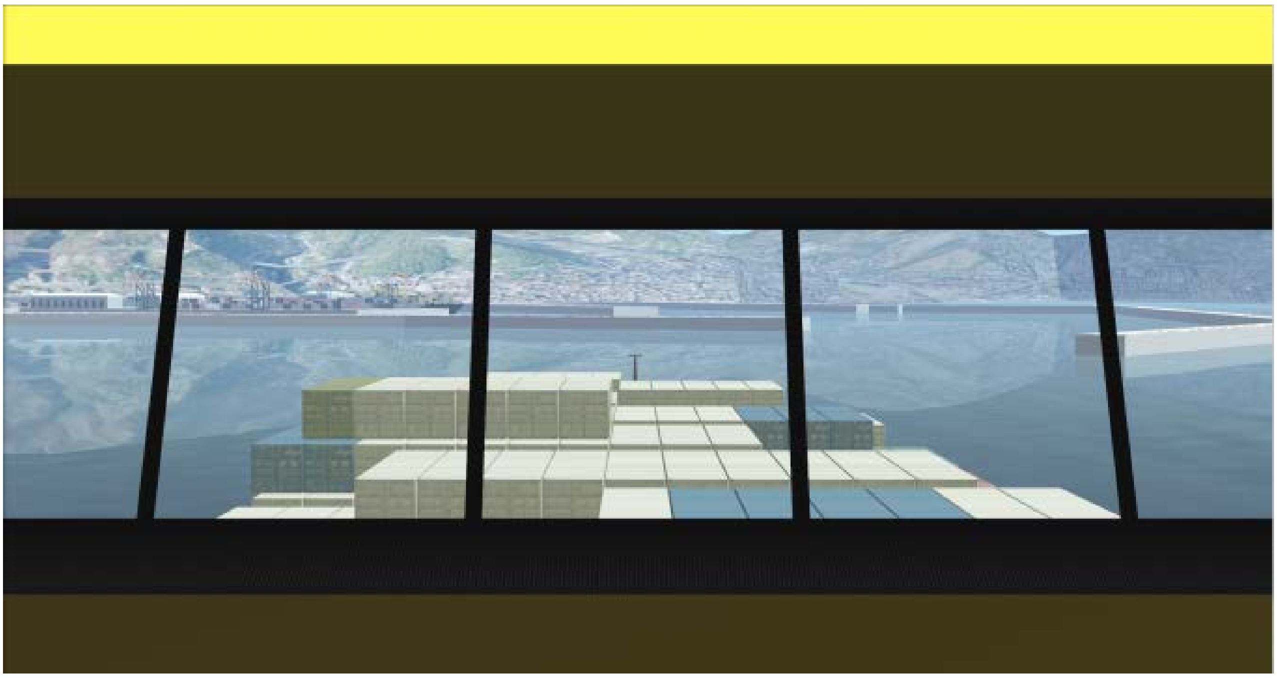

Figure 4.11: View from the containership bridge

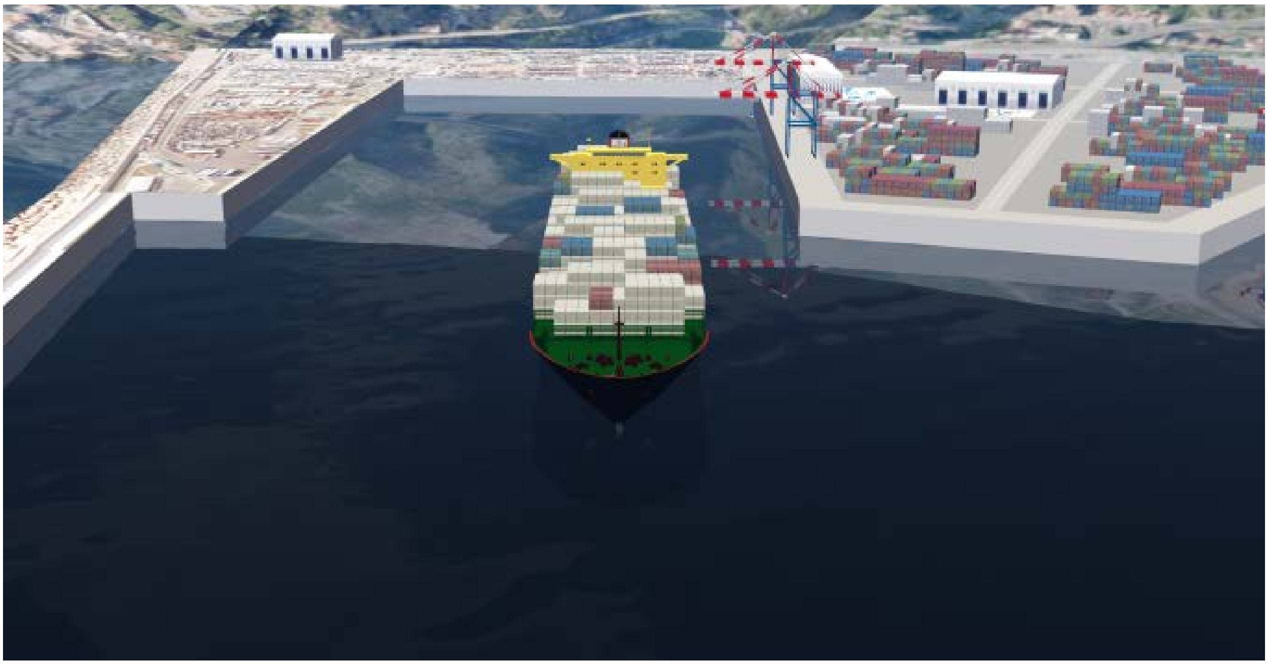

Figure 4.12: Front view of the commercial containership

Figure 4.13: the commercial containership back view (pitch, roll and heave motions)

From previous figures, it is clear that the ship bridge simulator allows the training setting different viewpoints: inside the bridge, outside the ship (therefore it is possible to see the whole ship from different points of view). In addition, as explained later in section 4.7 the ship bridge simulator has been conceived in order to provide the users with a large spectrum of operative scenarios; in fact, the trainer can set weather and marine conditions before the training session starts or even during the execution. Data such us main engine RPM, side thrusters utilization levels, rudder positions, wind intensity and directions, compass, 2D map of the port areas including the other ships (Automatic Identification System – AIS) are always available during the simulation (refer to Chapter 5). Performance measures such as mission time (average and standard deviation values over multiple training sessions), collisions, and wrong manoeuvres are recorded and are available at the end of the simulation.

4.5 The Control Tower Simulator

The control tower simulator tasks involve port monitoring and control. Therefore, the control tower behaviour does not evolve according to a mathematical model but it has to provide ships with operational guidance and real time feedbacks so as to ensure that all the manoeuvres are successfully accomplished. Therefore, the control tower simulator is equipped with communication tools that allow real time interactions with pilots on board of ships. To fulfil its tasks, control tower operators need to have a comprehensive picture of port conditions and therefore it has been equipped with several cameras and several points of views over the port environment. Thus, the control tower has the possibility to monitor in detail the whole port area and verify that each entity behaves correctly. Moreover, a specific teleport function has been implemented. Thanks to this functionality control tower operators may teleport on board of a ship in order to gain a better understanding of the ship perceptions and provide clear indications to drive in a proper way pilots courses of action. Moreover, for the sake of accuracy, the control tower simulator has been equipped with the typical instrumentation that control tower operators avail of. Therefore, even radar and an AIS simulator have been developed and integrated into the control tower federate.

4.6 HLA Integration for cooperative training

As already mentioned, a great attention has been paid on modelling the interactions among the federates (the ship bridge simulator and the control tower simulator). To this end, the simulation architecture has been provided with interoperability capabilities that allow reproducing with satisfactory accuracy the real operational processes taking place in the last mile of navigation. However, it should be noted that, even if the ship bridge simulator has been integrated into a federation of simulators in order to allow the cooperative training of ship pilots and port traffic controllers (and in the extended version also tugboat pilots), the integration via HLA does not prevent the ship bridge simulator from being executed standalone or to be reused in different federations. In this perspective, the proposed architecture ensures a great flexibility because it allows stand-alone as well as cooperative training when necessary. As far as the HLA is concerned, the architecture is based on the IEEE 1516 HLA and the Run Time Infrastructure used is the

MAK 3.3.2. Additional information about the federates, the Federation Object Model, the Simulation Object Models are reported in the following sections.

4.6.1 The Federates and the Federation Object Model

The federation development process has been carried out according to the process described in Chapter 3. The architecture (already presented in Chapter 3) takes into account the needs for training that it should address; indeed such architecture has been designed to provide its user with an advanced training system for ship pilots during their stay on the ship bridge and port traffic controllers. The architecture also provides the instructor with the possibility to collect data and information about the trainees performances and monitor the interactions between ship pilots, captain and port traffic controllers.
Indeed, the federation includes three federates (two of these federates are described as part of this thesis): the ship bridge simulator (SDN federate) and the control tower simulator (SCT federate). The SDN federate allows ship pilots steering the ship selected by the instructor (in this thesis only one type of ship is considered, a containership, the full system includes multiple types of ships), through the replica of a ship bridge including all the hardware, tools and instruments that are usually included in a real ship bridge (levers for controlling power, joysticks, rudder wheels, Radar, AIS system, etc.). By using the SDN the trainees can perform all the maneuvers for entering/exiting to/from the harbor area, mooring operations, interaction with the tugboat, etc. The STC federate (the control tower simulator), as explained in section 4.5, allows port traffic controller to have different views on the harbor area and can also communicate with the pilots on board ships. The STC is also equipped with tools and instruments needed to support vessels operations within the harbor area (2D maps including the vessels traffic, Radar, etc.). In addition, the port traffic controller can be teleported on board each ship moving within the harbor area therefore having the same view of the pilot (bridge view). This tremendously increases the training effectiveness because the port traffic controller can experience the pilots point of view therefore he is able to provide better suggestions for executing safely all the maneuvers and operations. As matter of fact, the SDN federate and the STC federate are two interoperable simulators that, by sharing the same virtual environments, are required to exchange continuously information. All the information exchanged between the SDN and STC federates are included within the HLA Federation Object Model (FOM), described in the following section.

4.6.2 The Federation Object Model and the Simulation Object Models

According to the IEEE 1516 HLA standard, the definition of a Federation Object Model (FOM) is required for each federation as well as the definition of the Simulation Object Model (SOM) is required for each federate. The correct definition of the FOM is: a specification defining the information exchanged at runtime to achieve a given set of federation objectives. This includes object classes, object class attributes, interaction classes, interaction parameters, and other relevant information. Similarly, the definition of the SOM is: a specification of the types of information that an individual federate could provide to High Level Architecture (HLA) federations as well as the information that an individual federate can receive from other federates in HLA federations. The standard format in which SOMs are expressed facilitates determination of the suitability of federates for participation in a federation. According to the IEEE 1516 HLA standards the object classes can be defined as A fundamental element of a conceptual representation for a federate that reflects the real world at levels of abstraction and resolution appropriate for federate interoperability. A template for a set of characteristics that is common to a group of object instances. These characteristics correspond to the class attributes that individual federates may publish and to which other federates may subscribe. An interaction is an explicit action taken by a federate that may have some effect or impact on another federate within a federation execution and the interaction is described by parameters that is a named characteristics of an interaction.
All the information reported in the FOM/SOMs (in terms of objects classes, attributed, interactions and parameters) are usually reported also within the Object Model Template (OMT). As reported in the IEEE HLA 1516.2 standard (Object Model Template Specification), the OMT is an essential component of the HLA for the following reasons:

- it provides a commonly understood mechanism for specifying the exchange of data and general coordination among members of a federation;
- it provides a common, standardized mechanism for describing the capabilities of potential federation members;
- it facilitates the design and application of common tool sets for development of HLA object models.

HLA object models may be used to describe an individual federation member (federate), creating an HLA Simulation Object Model (SOM), or to describe a named set of multiple interacting federates (federation), creating a Federation Object Model (FOM). In either case, the primary objective of the HLA Object Model Template (OMT) is to facilitate interoperability among simulations and reuse of simulation components. All the information reported below apply both to FOM and SOMs unless explicitly stated otherwise.
Among the OMT components, the most important are:

- Object Class Structure Table: to record the namespace of all federate or federation object classes and to describe their class-subclass relationships;
- Attributes Table: to specify features of object attributes in a federate or federation;
- Interaction Class Structure Table: to record the namespace of all federate or federation interaction classes and to describe their class subclass relationships;
- Parameters Table: to specify features of interaction parameters in a federate or federation.

Table 4.1 (the Object Class Structure Table) provides a summary of the main classes that are part of the FOM.

HLA Objects Root	Ships Objects	Main Ship
		Tugboat Ship
		Additional Ship
		Service Ship
	Control Objects	Control Tower
	Subsystem Object	Engine-propeller
		Hull
		Rudder
		Side Thrusters
		Pushing
		Towing
		2D Animation
		3D Animation
		Input-output
		User-interface
		Communication System
	Components Objects	Conning display system
		AIS
		Radar
		Virtual Control Screen
	Environment Objects	Wind
		Rain
		Fog
		Sea State
	Man In the Loop (MIL)	Observer
	Hardware In the Loop (HIL)	Rudder wheel
		Power lever
		Joystick
		Display
		Led system

Table 4.1: Federation Object Model: the Object Class Structure Table reporting the list of all the object classes that are part of the federation

An explanation of the object classes included in table 4.1 is reported below. The ship object includes four main sub-classes:

- the main ship representing the ship currently operated by the ship simulator;
- the tugboat ship representing the tugboat operated by the tugboat simulator;
- the additional ship representing other ships automatically generated to create traffic conditions within the harbour area;
- the service ship representing the pilot boat.

The Control Object includes the Control Tower object part of the Control Tower simulator. The subsystem object class includes the following classes:

- the engine-propeller class used to recreate the behaviour of ship engine and propeller system;
- the hull class used to recreate the shape of the hull and also to manage collisions;
- the rudder class used to recreate the control logic and the behaviour of the rudder;
- the side thrusters class used to recreate the behaviour of stern and bow thrusters;
- the pushing class to recreate the interactions between the ship and the tugboat during a pushing operation;
- the towing class to recreate the interactions between the ship and the tugboat during a towing (through a rope) operation;
- the 2D animation used to recreate a fast-time simulated 2D animation for testing the ship motion equations;
- the 3D animation used to set-up the 3D Virtual Environments (that makes use of the API of the graphic engine);
- the input-output class used to read all the input data (e.g. the ship technical characteristics, the values of the hydrodynamic coefficients, etc.) and to collect and display the output data (e.g. performance measures such as mission time, wrong manoeuvres, wrong positioning, collisions, etc.);
- the user-interface class used to set-up the most critical parameters in the ship motion equations and tune the equations;
- the communication system used to recreate the communications between the ship, the tugboat and the control tower.

The Component Object class includes the following classes:

- the conning display system class is used to display the most important information about the navigation (e.g. compass, wind direction and intensity, GPS position, heading, drift, total speed, propeller pitch, main engine revolution per minute, side thrusters power, rudder position, etc.);
- the AIS class is used to recreate the Automatic Identification System for traffic monitoring and control;
- the Radar class is used to recreate the radar that is usually available on board ships;
- the virtual control screen class manages all the simulators functionalities that come through the touch screen monitors.

The Environment Object class includes the following classes:

- the wind class is used to manage wind intensity and direction and its effect on the ships;
- the rain and fog classes are used to recreate the rain and the fog respectively;
- the sea state class is used to recreate the different sea state levels (according to equations presented in chapter 4).

The Main in the Loop object class includes only the external observer class providing the user with multiple and different points of view (cameras) on the virtual environment. Finally, the Hardware in the Loop class includes the following classes:

- the rudder wheel class to control the rudder, it manages the input values that come through the rudder wheel that is part of the ship bridge replica;
- the power levers class used to control the propeller pitch and the main engine power;
- the joystick class used to control the side thrusters as well as the tugboat direction of motion; it manages all the input values that come through the joysticks that are part of the ship/tugboat bridge replica;
- the display class used to manage output data that the user can read on the displays systems that are part of the ship/tugboat bridge replica;
- the led system class used to manage values that are used to control the led systems that are part of the ship/tugboat bridge replica.

Table 4.2 (Attribute Tables) reports a list of the most important attributes that describes the objects of the SDN federate and SCT federate. It is worth saying that the description of most of these variables is quite intuitive (e.g. position, velocities, accelerations, hydrodynamic coefficients, etc.), however most of them have been already described in previous sections.

SDN		**SCT**	
x y z Φ Ω Ψ v_x v_y v_z ω_x ω_y ω_z a_x a_y a_z	// Ship Position, orientation, velocity and acceleration attributes	x y z Φ Ω Ψ v_x v_y v_z ω_x ω_y ω_z a_x a_y a_z	// Ship Position, orientation, velocity and acceleration attributes as perceived from the control tower
name ID ShipType	// Ship name and ID	Name ID ShipType	// Ship name and ID
L B d Cb m Ct S LCG Dp Pr R_chord R_height R_rate Pitch_rat	// Ship technical Characteristics		
mAd mx mAdx my	//masses, added masses and moment of inertia		

mAdy		
Izz		
izz		
IzzAd		
izzAd		
X0	//Hydrodynamic coefficients (derivatives) used for Hull resistances calculations	
Xvr_my		
Xrr		
Xvv		
Xvvvv		
Yv		
Yr_m		
Yvvv		
Yrrr		
Yvvr		
Yvrr		
Nv		
Nr		
Nvvv		
Nrrr		
Nvvr		
Nvrr		
delCb		
delbl		
delSR		
PCb		
PSR		
Sr		
BPs		
BP07		
Xh		
Yh		
Nh		
xp	// Variables and coefficients used for the Propeller force calculation	
Wp0		
tp0		
Wp		
betP		
C1		
C2		
C3		
Jp		
Ktj		
Xp		

px1 py1 px2 py2 px3 py3 dist_01 dist_py1 dist_py2 dist_py3		
_1_tr ah xh xr Ar ARr Cn Cr CrSx CrDx alfR betR gam Ur2 Fn eps Wr Wr0 ni Kx K s gS P Xru Yru Nru	// Variables and coefficients used for the calculation of the Rudder forces	
CC1 CC2 … CCn CP1 CP2 … CPn	//Interpolation Coefficients for power torque curves	

Table 4.2: List of attributes for the SDN and STC federates

As far as the SDN federate is concerned, table 4.2 includes the attributes used for ship position, orientation, velocity and accelerations; it also includes all the attributes needed to simulate the ship engine and all the forces acting on the ship during its motion at sea (propeller force, rudder forces, and resistance forces).
As far as the STC federate is concerned, table 4.2 includes the attributes used for ship position, orientation, velocity and accelerations in order to provide the port traffic controller with a full picture about each ship moving in the harbor area.
All the actions made by a federate that may an effect on other federates are modelled by using interactions and parameters. Table 4.3 reports the most important interactions and parameters for the SDN and SCT federates.

HLAInteractionRoot	**SDN**	shipCollided	collision incident
		tugBoat	positionReached tugBoatLocked tugBoatWorking tugBoatUnlocked
		speedLimits	limitExceeded
		berthing	shipBerthed anchorDown anchorUp
		lights	lightOn lightOff emergencyLightOn emergencyLightOff horn
		engine	engineOn engineOff propellerRPM
		shipIntersection	type direction outgoingShip
	STC	shipType	AS_SS type
		shipIntersection	type direction outgoingShip
		lights	lightOn lightOff emergencyLightOn emergencyLightOff

Table 4.3: List of interactions and parameters for the SDN and STC federates

As far as the time management is concerned, it is worth mentioning that in order to avoid synchronization problems (e.g. message received in the past, wrong position of an object in the different virtual environments, etc.), the federates (the bridge ship simulator and the control tower simulator) are both time constrained and time regulated. Therefore, federates make use of the time management services provided by the HLA Run Time Infrastructure.

As far as the integration and interoperability tests are concerned, they have been carried out according to the standards IEEE 1516.4-2007 (Recommended Practice for Verification, Validation, and Accreditation of a Federation) and IEEE 1516.3-2003 (Recommended Practice for High Level Architecture. Federation Development and Execution Process, FEDEP). A Federation execution plan has been opportunely defined; all the hardware and software assets have been set-up with the aim of integrating the federates and create the federation. After that, the federation has been opportunely tested even used ad-hoc stress tests to see the behavior of each single federate as well as the behavior of the federation under out-of-range values for the most important input variables.

4.6.3 Federates performance measures definition

Training effectiveness is measured by ad-hoc performance measures that are implemented as part of the SDN federate (ship bridge simulator) and as part of the STC federate (control tower simulator). Table 4.4 reports the definition of the performance measures used within the SDN and the STC.

Federate	Performance Measure
SDN	Number of missions per unit of time Average and maxim mission time Single mission time Wrong positioning Number of extra movements Number of collisions Different types of alarms (out of normal operations limits, security alarms, etc.) Operators stress levels Not giving priority Going off course
STC	Ship collisions Missing communications Wrong communications Dangers detected Different types of alarms (out of normal operations limits, security alarms, etc.) Operators stress levels

Table 4.4 – Performance measures implemented as part of the SDN and STC federates

4.7 Training Scenarios Definition

Before conclusions, it is worthwhile to give a look to figure 4.14. This figure explains how the training system including the ship bridge simulator and the control tower simulator can be used to generate multiple training scenarios for stand-alone and cooperative training (the figure 4.14 also included the tugboat simulator that, as already mentioned, it is part of the training system even if it is not described in this thesis). As clearly depicted in figure 4.14, the training system currently includes three Italian major ports: the port of Salerno, the port of Livorno and the port of Gioia Tauro (as part of this thesis only the Port of Salerno has been presented). Within each port and training scenario it is possible to set-up weather conditions (e.g. rain, fog, etc.), wind intensity and sea state. The ship simulator is able to provide the trainees with different types of ships: a tanker, a containership and a bulk carrier (this thesis presents the containership). The tugboat simulator can interact with ship by pushing or by pulling through a rope (one or two tugboat are available). The control tower simulator may have different views on the port environment, communicate with ships and tugboats, observe the traffic condition even on 2D maps (AIS style) and recreate different ships traffic conditions within the harbour area. Finally, each simulator can be used stand-alone for single operator training or as a federation of simulators for cooperative training. Ship pilots, tugboat pilots and port traffic controllers can become acquainted with procedures, test different types of manoeuvres, experience tugboat-ship interactions. As part of this thesis, the ship bridge simulator and the control tower simulator, their design, development phase and the prototypes (currently available at MSC-LES lab of University of Calabria) are presented.

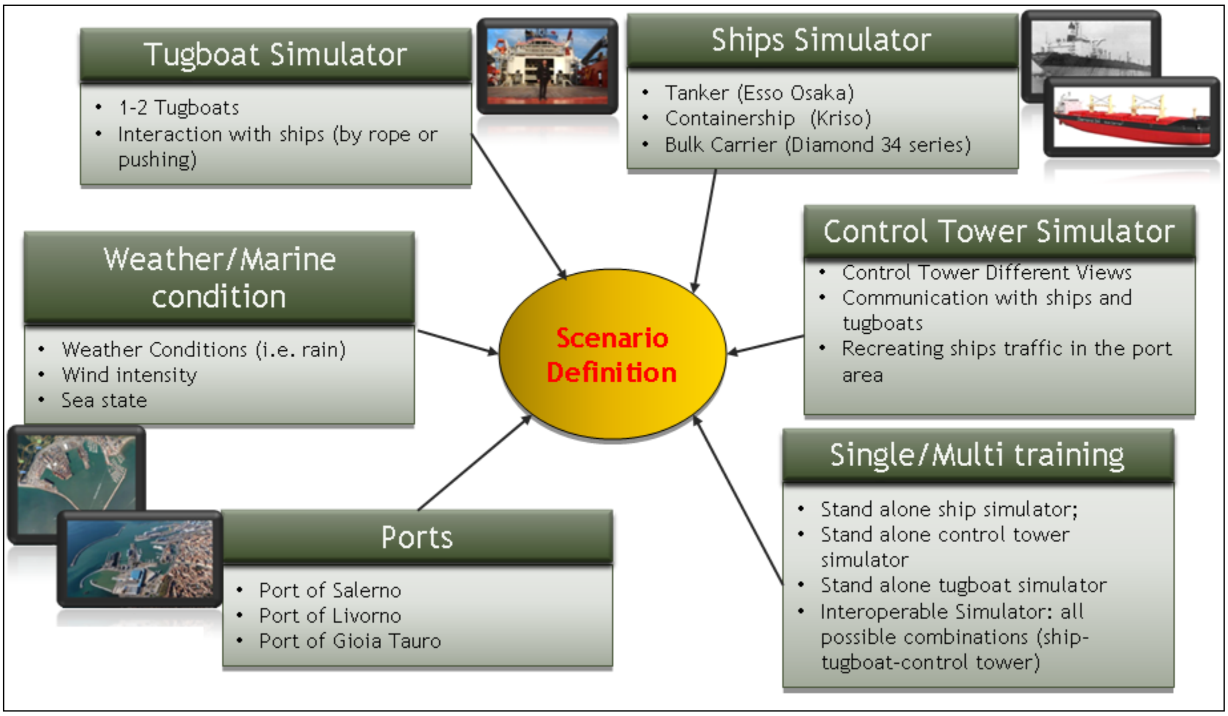

Figure 4.14: Training Scenarios Definition

4.8 Conclusions

This chapter discusses the implementation of the bridge ship simulator, the control tower simulator and their dynamical integration into a federation for cooperative training. Throughout the discussion, the equations that allow recreating the motion of the ship are proposed and commented. Before their implementation within the ship simulator, the equations have been tested by using an ad-hoc tool developed to give the possibility to tune the equations and obtain a realistic behaviour of the ship at sea. The 6 DOF models has been then implemented within the ship simulator with the aim of developing a simulation based training tool for ship pilots involved in the last/second last mile of navigation. To this end, the simulator has been conceived in order to provide the trainees with an experience as much realistic as possible. In this way, the simulation-based approach seeks to maximize training effectiveness, lesson learned and at the same time reduces the need for training on the real system with real equipment. As a matter of facts, the trainee can safely exercise on ship manoeuvring in any desired condition and at any time so that he/she can improve his/her skills and develop the capability of predicting the possible outcomes related to the course of actions he/she undertakes. In addition, the simulator can be used by inexperienced pilots but also by expert's pilots who wish to be acquainted with a never steered kind of ship or simply learn the entry/ exit procedures that are adopted in a specific port.

In fact, it is possible to select different training scenarios including different types of ports and vessels. The ship motion at sea has been recreated by implementing the MMG model for surge, sway and yaw, while simplified differential equations have been solved numerically for evaluating ship response in terms of roll, pitch and heave. The simulator conceptual and operational model has been implemented in Visual Studio 2008 IDE using Vega Prime graphic engine while the virtual environment (Salerno port) and all the geometric models (included the container carrier model) have been made with Creator by Presagis.

Furthermore for VV&A purposes an ad-hoc tool has been developed. This tool allows carrying out manoeuvrability tests such as circle, zigzag and stop tests in any desired ship configuration.

Even though several ship simulators are already on the market few of them offer the possibility of setting up combined and integrated training sessions involving both ship pilots and control tower operators. In fact, the last mile of navigation has not been subject of particular scientific interest until the recent disaster in the port of Genoa.

As for the control tower simulator, considering that its tasks involve port monitoring and control, control tower operators need to have a comprehensive picture of port conditions and therefore the simulator has been equipped with several cameras and several points of views over the port environment. Thus, the control tower has the possibility to monitor in detail the whole port area and verify that each entity behaves correctly. In addition, it is equipped with communication tools that allow real time interactions with pilots on board of ships and a specific teleport function has been implemented. Thanks to this functionality control tower operators may teleport on board of a ship in order to gain a better understanding of the ship perceptions and provide clear indications to drive in a proper way pilots' courses of actions. Moreover, for the sake of accuracy, the control tower simulator has been equipped with the typical instrumentation that control tower operators avail of. Therefore, even radar and AIS simulators have been developed and integrated into the control tower federate.

The ship federate and the control tower federate are integrated into an interoperable simulation framework according to the HLA Standard (IEEE 1516) that has been extensively validated both with a tool specifically designed to the purpose and a team of subject matter experts not involved in the development process.

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5.1 The Ship Bridge Replica Design

As part of this thesis, a ship bridge replica has been designed and recreated including all the on board instrumentations used for ship navigation. The ship bridge that is part of the demonstrator has been designed to be a faithful representation of a real ship bridge. To this end, at the early stage of the design process some real ships were surveyed. In particular, a lot of time was spent on board of two ships: a platform supply vessel that was standing in the port of Crotone and a container carrier that was entered into the port of Salerno. These visits were useful to have a faithful representation of the ship bridge in terms of geometry and technical equipment for ship maneuvering and navigation.
As a result, to the ship bridge replica was designed with a T-shape geometry as illustrated in figure 5.1 where the 3D CAD model is depicted. Moreover, the overall dimensions, as reported in figures 5.2-5.4, have been set in order to easily integrate the hardware needed to control the motion of the ship at sea as well as to host the navigation instrumentations. Moreover, such dimensions have been also defined taking into account the need to comply with ergonomic requirements. Indeed, the trainee while standing in front of the instruments panel must be able to use and access all the control devices comfortably, i.e. the operator must be able to reach easily all the instrumentations available and must be able to look at the Virtual Environment from a suitable distance. As for the material, wood has resulted in a good choice with fairly low costs and good stability. It is worth mentioning that the overall bridge replica design has been carried out in-house while the manufacturing process has been carried out by a woodworker that is a specialist in ships and ship interiors building.

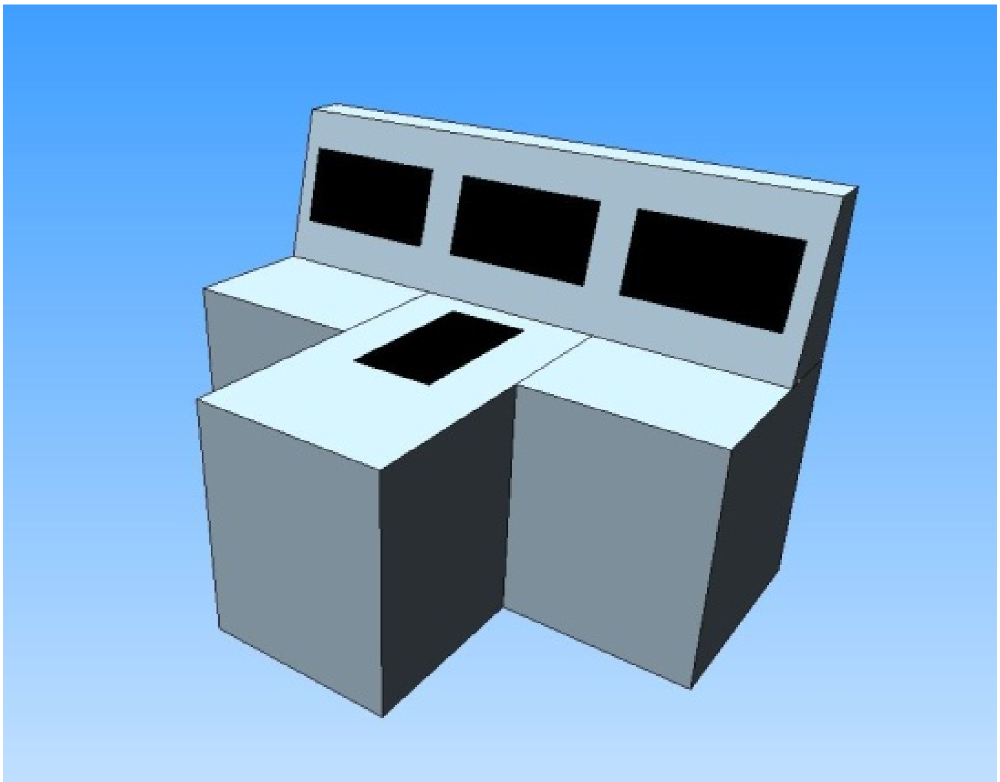

Figure 5.1: Prospective view of the ship bridge replica CAD

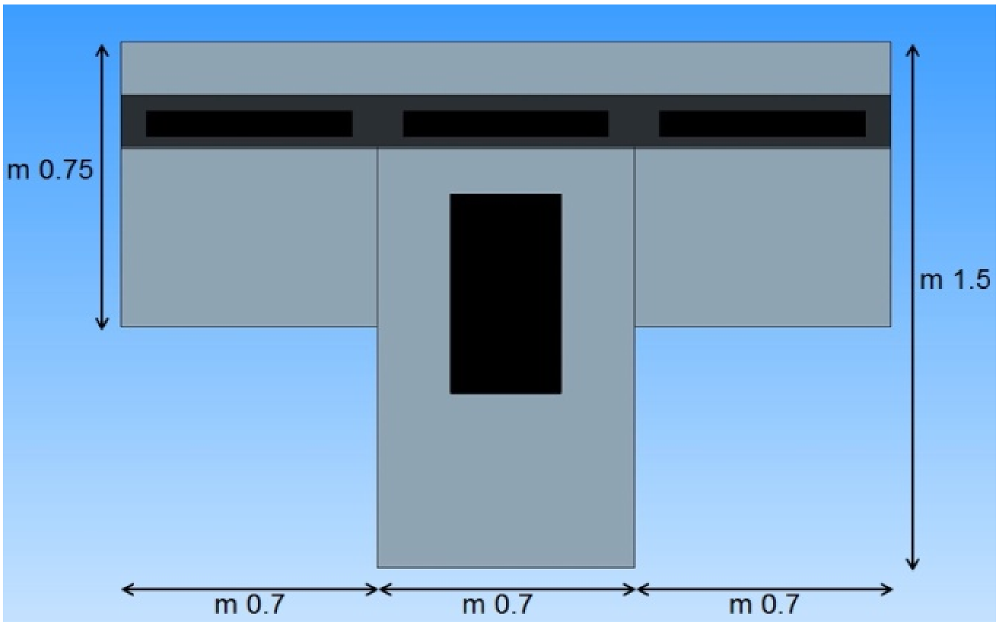

Figure 5.2: Top view and dimensions of the ship bridge replica CAD.

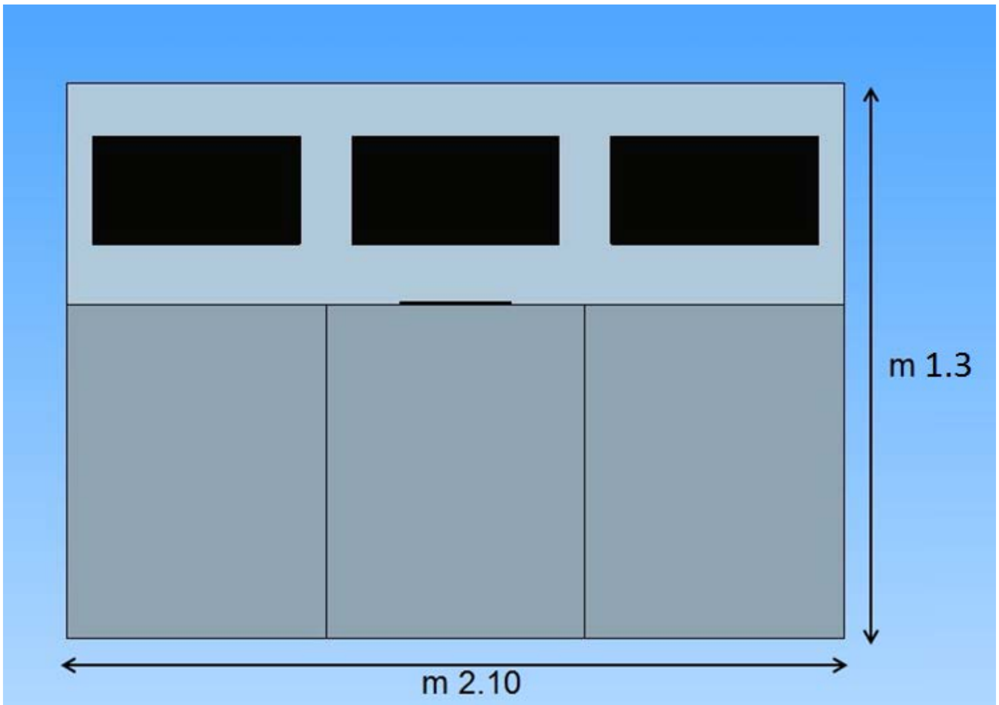

Figure 5.3: Front view of the ship bridge replica CAD

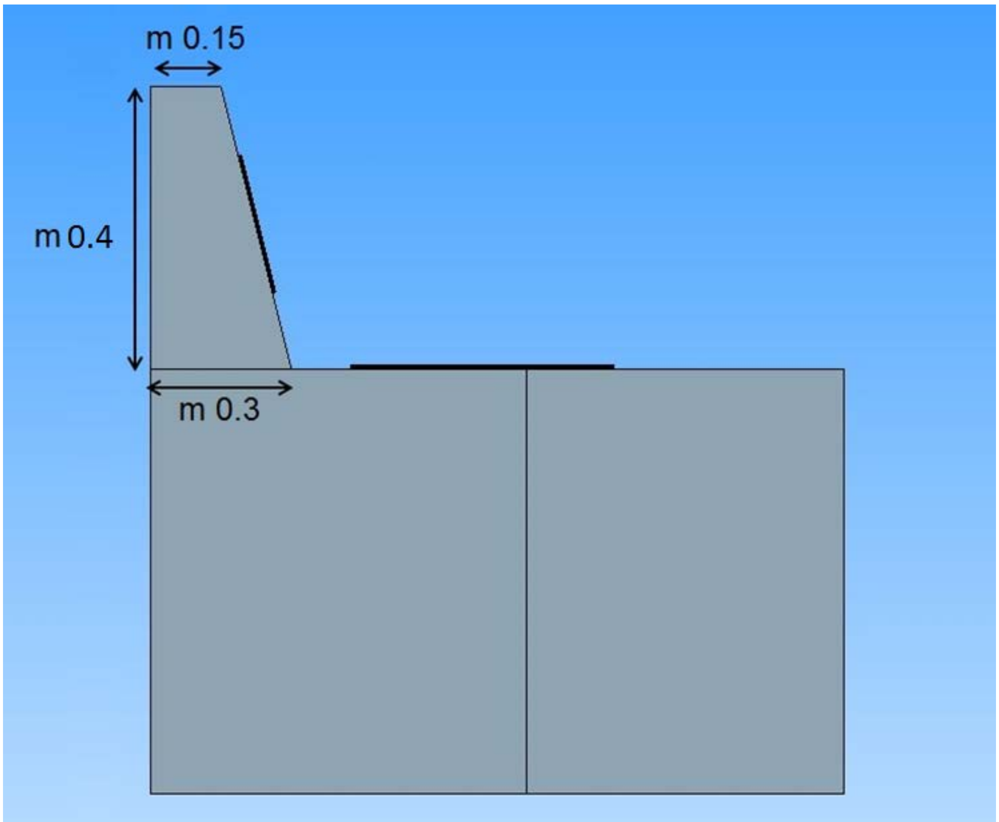

Figure 5.4: Left view of ship bridge replica CAD

The ship bridge replica can host up to three PCs that can be accessed by three doors placed in the rear part. As explained later on in the chapter, currently thanks to a strong modelling effort and computational and graphic load optimization the entire simulation including the ship motion at sea in the virtual environments, the AIS simulator, the Radar simulator and the Conning display are able to run on a single commercial desktop computer. Moreover, in figures 5.1 and 5.2 four black rectangles are depicted. Three of them, placed in the upper part, are the slots for the AIS simulator, the Conning information display, the Radar simulator. The last one hosts a touch screen that allows interacting real-time with the simulation environment and can be used to change the simulator viewpoints, edit the camera of each view, drop/weigh anchor and control the navigation instrumentations. Moreover, the ship bridge replica is also integrated with mechanic and electrical devices that recreate the maneuvering controls: it includes a two-lever system for engine RPM and propeller pitch controls (in order to simulate ships with both fixed and variable pitch propellers), a double joystick for side thrusters control and the wheel for rudder control. It is worth mentioning that all the aforementioned devices have been bought form shops that are specialized in manufacturing and selling spare parts for ships and they have been opportunely adapted and integrated as part of the simulation system. The hardware integration is a very important feature of the training system since it allows the trainee to be acquainted with the same equipment available on real ships and, as a consequence, to benefit from a greater level of immersion during a training session. As a matter of facts, such devices are fully integrated with the simulation environment; in other words the user can have a real time response that is displayed on the visualization system based on the input he/she provides while using ship controls for maneuvering. The interfaces between on board instrumentations and the PC that drives the simulation have been designed and implemented at the MSC-LES lab by using the Arduino technology. Arduino is also used to control multiple LED systems and three small-size displays that are used to show the rudder angle, the main engine RPM, the main propeller pitch and the side thrusters' power. Figures 5.5 and 5.6 show the ship bridge controls and display systems in their current configuration.

Figure 5.5: Ship bridge detail: double lever system and multiple LEDs displays

Figure 5.6: Ship bridge detail: double lever system, joysticks for side thruster control, wheels for rudder control, multiple LEDs displays and small-size displays

Figure 5.7: Ship bridge detail: navigation instruments and visualization area including AIS simulator, Conning display simulator, Radar simulator

5.2 The Visualization System for the Virtual Environments, the Sound System and PCs requirements

The visualization system shows the trainee how the scenario evolves over time as a consequence of the actions he/she undertakes. For the sake of increasing the user's level of immersion, the visualization system includes three large white screens and three projectors (partially visible in figure 5.7). Each screen has 2 x 1.5 m dimensions without external frame; one of the screens is place behind the ship bridge just in front of the trainee's position while the other screens are placed on the left and on the right side respectively. Moreover, the screens are juxtaposed to ensure a seamless visualization and enhance the trainee's feeling of immersion in the simulation (figure 5.7 partially shows how screens are positioned with respect to the ship bridge and the trainee position). In order to increase the flexibility and reusability of the simulation system, dedicated iron frames were designed and manufactured to hold up both screens and projectors. This is resulted in a very flexible and portable solution, since the whole visualization system including screens and projectors, can be easily moved from its current location to another as well as adapted to different configurations in terms of dimensions of the projected area and position (to be used for different virtual simulation based systems).

Both for the screens and the projectors the frames are made of iron in order to ensure solidity and stability while keeping the costs as low as possible. The CAD model of the screens supports and their geometry is depicted in figure 16. Furthermore, as shown in figure 5.8, the iron frame is 2.5 m in height and it lies on two feet (each foot is made up of 0.5 m pieces of square tube).

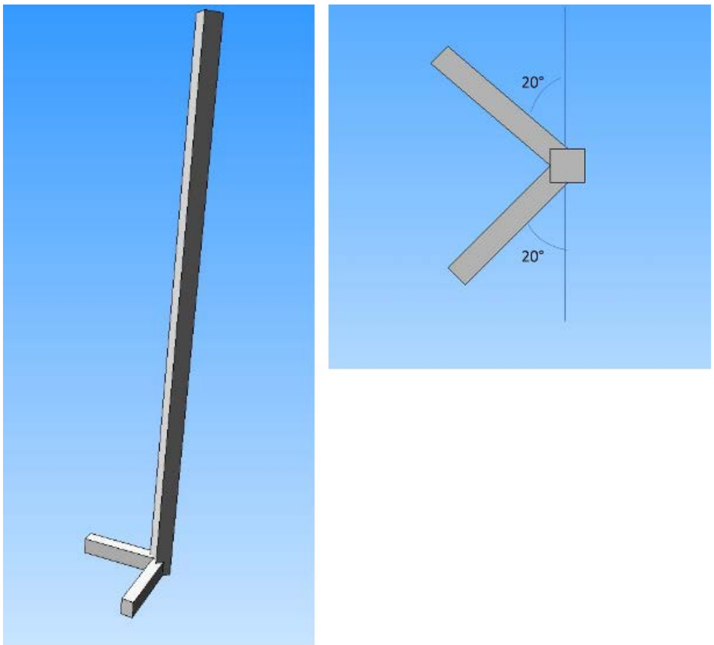

Figure 5.8: Prospective and top view of the foot for screen support CAD

For the projectors (see figure 5.9) the support structure is telescopic for both the width and the height in order to ensure different configurations in terms of dimensions of the projected area and position. The structure is composed of two vertical beams and one crossbeam. The vertical beams are hold up by two square tubes of 0.60 m length. Each vertical beam is actually composed by two square tubes, one with a side section of 5 cm and the other with a 4 cm section in order to create a telescopic system. The two beams can scroll one inside the other and this allows the user to choose the right length of the vertical beam. The same working principle has been adopted for the crossbeam, but, in this case, it is composed by two square tubes with a 5 cm side section and a 4 cm side section. Thanks to this double telescopic solutions (on the height and on the width), it is possible to modify the height of the structure between 2.2 meters and 3.2 meters and the width between 3.5 meters and 5 meters. In addition, all the video and electrical cables can be easily passed within the square tubes. Figure 5.9 shows the prospective view of the CAD of the entire structure. The figure 5.10 shows a view of the projectors installed on the structure.

Figure 5.9: Prospective and top view of the CAD of the structure for projectors

Figure 5.10: View of the projectors installed on the structure

Finally, a 5.1 surround sound system has been added able to reproduce sounds usually audible in the ship cockpit. The 5.1 surround system contributes in increasing the feeling of being inside a real ship.
As far as the PCs requirements are concerned, one of the main goals that was defined at the early stage of the design process was that the architecture of the simulation system had to be light enough and flexible in order to allow the simulation system working with any well-equipped commercial desktop PC. The main requirements of the PC that is currently used inside the bridge ship replica are given below:

- Processor: Intel Core i7 2600k 3.40 Ghz
- RAM: 16 Gb
- GPU: 2 GeForce GTX 680 connected with SLI technology.

The use of two GPU depends on the need to manage 4 monitors and 3 projectors at the same time with one PC.

5.3 The Control Tower Simulator Workstation

As already mentioned the simulation system is devoted to cooperative training of ship pilot and port traffic controllers in the last mile of navigation. This section briefly presents the control tower simulator. Such simulator is connected to the ship simulator through the standard for distributed simulation IEEE High Level Architecture (HLA), therefore the two simulators (ship simulator and control tower simulator) are able to interoperate each other, sharing the same virtual environments and allowing cooperative training of ship pilots and port traffic controllers.
The Control Tower Simulator is equipped with a multi-display system, which displays the virtual environments for monitoring and controlling all the operations in the port area. The port traffic controller may act on the console to change the view (multiple panoramic views are available from different cameras placed in different positions within the virtual environments), to activate communications with the ship pilot,

to display vessels traffic on 2D maps (similar to the AIS system) together with the navigation information of each vessel (e.g. current speed, current route, position, etc.), to activate the radar view.
In addition, the port traffic controller may activate a particular view: the so-called teleportation view. The teleportation view is the same view of the virtual environment perceived by the ship pilot (the view from the ship bridge). Therefore, by activating this view the port traffic controller can be teleported on board each vessel that is currently maneuvering within the port area to observe all the operations from the same view and perspective of the ship pilot. This tremendously increases the effectiveness of the training for both the port traffic controller and the ship pilot because they can exchange information and look at the procedures performed (and related errors) from the same point of view. Finally, the port traffic controller is able to monitor information on weather and sea conditions.
The figure 5.11 shows the control tower simulator workstation with a panoramic view on the Port of Salerno; the control tower simulator workstation is equipped with three monitors that can be used for visualizing the 3D virtual environments as well as to display 2D maps, radar and all the other simulator functionalities.

Figure 5.11 – The Control Tower Simulator

5.4 Rudder and Controllers Integration

To increase the users' level of immersion real ship control devices have been interfaced with the simulator development environment. Starting from commercial components (rudder, joysticks for bow and stern thrusters, ship control levers) an embedded system able to convert mechanical movements into analogical signals that can be sent to the simulator after being digitalized, has been developed. The system core is a 8-bit ATMEL AVR l'ATmega32u4 microcontroller mounted on a ARDUINO prototyping board. Among its features, the ATmega32u4 microcontroller has a GPIO (general purpose input/output) with 12 analogical inputs and 20 digital ports, a 10-bit analog to digital converter (ADC) and an USB integrated communication system. The hardware platform is supported by an Integrated Development Environment (IDE) that provides the tools for writing, testing and debugging a microcontroller using the C/ C++ Wiring library. The Rudder and the control levers have been equipped with three linear potentiometers that can capture the levers rotational movements and the rudder stroke while two switches (one for positive increases and the other for negative increases) have been applied to the BOW and STERN thrusters joysticks. Basically input signals are captured by the GPIO and converted into digital values by the ADC integrated in it so that they can be sent to the simulator through the USB interface. Data acquisition from analogical ports has required some properties to be investigated.

5.4.1 ADC

The ATmega32u4 has a ADC with 8 channels and 10 bit resolution: 8 channels means that there are 8 pin connected to the converter while 10 bit resolution implies that 2^10 digital values are available to discretize the voltage range that in our case is between 0V and 3.3V. Furthermore there are two additional components that cannot be neglected when dealing with the conversion: the Prescaler and the ADC Registers. Indeed, conversion occurs at regular time intervals depending on the clock frequency. In general, the ADC works in a range of frequencies between 50 and 200 kHz but the microcontroller clock frequency is much higher and depends on the oscillator that is characterized by a 16 MHz frequency.
The Prescaler allows splitting the CPU frequency in smaller intervals. In particular, the ATmega328 Prescaler includes 7 factors, namely: 2, 4, 8, 16, 32, 64 and 128. It is worth mentioning that the frequency is referred to the overall conversion unit and therefore the conversion unit of each channel can be obtained dividing by 8. The ADC settings are managed by the user updating particular registers. Such registers are high up in the processor memory hierarchy, they have 8 bit capacity and are the fastest way for data manipulation. As follows they are analyzed in relation to the bits of interest.

5.4.2 Timer Interrupts

In Information Technology, an interrupt call is a signal that calls for particular attention from a peripheral device or a process being executed by the CPU. The ATmega32u4 has three peripheral units called Timer/Counter that are devoted to count up clock cycles. An interrupt call activated by a certain device can execute specific instructions at well-defined time intervals. This is very important because when a C code is written, although instructions are executed according to the sequence they appear, particular events can be hardly timed. Some instructions, indeed, may take more clock cycles than others depending on which Arduino functions and libraries have been used. Interrupts allow breaking the normal sequence of instructions for the time being to execute priority controls and functions and after that the execution goes back to normal.
As already mentioned three Timers are available, two of them are 8 bits and the other is 16 bits. Each timer has a counter that is incremented at every clock cycle, when the counter reaches a certain value that is stored in a particular register called Compare Match Register. Afterwards the counter zeroes and restarts cyclically (Overflow). Therefore selecting the CMR value and assigning the Timer with a certain increment rate allow the frequency of interrupts to be controlled.
Like the ADC, each Timer/Counter has its own Prescaler. In addition, considering that 8 bit and 16 bit values can be stored within the CMR and that the clock microcontroller is 16 MHz, timing is in the order of nanoseconds and milliseconds. Therefore, the Prescaler is useful for further splitting the clock frequency as it happens in the ADC. Once these concepts have been clarified, the code has been compiled. Thanks to the interrupt calls it has been possible to manage data acquisition at the right frequencies and apply algorithms for noise filtering.

5.4.3 Discrete Kalman Filter

Kalman filter is a recursive algorithm aimed at optimally estimating discrete linear systems state when Gaussian white noise affects the system state and its outputs. An optimal estimate means that the error has minimum variance. Recalling that the system state is the set of variables (not directly measurable) affecting the system dynamical behavior while the system outputs include measurable variables under observation, the system taken into account can be deemed known for less than some unknown parameters that have to be estimated.
Although in literature there are many implementations and versions of such filter, for the purposes of the study a classical time-discrete model has been referred to because of its applicability and its low computational burden.
The system state x of a discrete stochastic process is represented in equation 1.

$$x_{i+1} = A_i x_i + B_i u_i + w_i \quad (1)$$

Where the estimate is carried out through measurements *z*, as shown in equation 2.

$$z_i = H_i x_i + v_i \tag{2}$$

In particular, A is the state transition model, B is the control-input model, *w* is the process noise, H is the observation model and *v* is the observation noise which is assumed to be Gaussian white noise and the applies to *w*. Therefore, to understand how the filter works, two estimates of the system state are considered: one of them is based on the system state at the previous point in time (*i-1)* while is based on the *z* measure.
Hereinafter the prime "-" means a priori while "+" a posteriori.

x_i^- *a priori estimate* x_i^+ *a posteriori estimate*

Therefore, the a posteriori estimate can be obtained as a linear combination of the a priori estimate and a weighted mean of *z* and its prediction $H_i x_i^-$

$$x_i^+ = x_i^- + K(z_i - H_i x_i^-) \tag{3}$$

This form is like a mean of recursive measurements where $K(z_i - H_i x_i^-)$ is the innovation whose weigh K, is known as Kalman gain. The determination of this factor, is the main part of the filter and it is evaluated minimizing the error covariance of the a posteriori estimate that is:

$$P_i = E\left(e_i e_i^T\right) \tag{4}$$

Where the error is:

$$e_i = x_i - x_i^+ \tag{5}$$

This minimization is carried out deriving equation 4 respect to K and letting it be zero. Thus K results in equation 6.

$$K_i = \frac{P_i^- H_i^T}{(H_i P_i^- H_i^T + R_i)} \tag{6}$$

The Kalman filter equations can be organized into two sets: time update (or forecasting, equations 7 and 8) equations and measurement update (or correction, equations 9, 10 and 11):

$$x_{i+1}^- = A_i x_i^+ + B_i u_i \tag{7}$$

$$P_{i+1}^- = A_i P_i A_i^T + Q_i \tag{8}$$

$$K_i = \frac{P_i^- H_i^T}{(H_i P_i^- H_i^T + R_i)} \tag{9}$$

$$x_i^+ = x_i^- + K(z_i - H_i x_i^-) \tag{10}$$

$$P_i = (1 - K_i H_i) P_i^- \tag{11}$$

where Q, similarly to *R*, is the process noise covariance of equation 1. The first set of equations (Time Update), given by the initial condition known, can be sees as subsequent to the second one (Measurement Update). The filter or rather the estimator is recursive in nature, and therefore it affects in a recursive way the estimate of the generic time instant as well as those of past time instants. Once the potentiometers measure is filtered, the estimate is sent to the simulator.
Apart from sensors, 79 led have been used. It has required increasing the number of digital outputs using a shift register SIPO (serial in parallel out). Led are placed so as to provide a visual feedback about the instrumentation. In addition, they are not activated by the potentiometers and therefore the response of each

can be programmed based on specific need. They are supposed to provide information on the control instrumentation at any time but delays can set when steady maneuvering conditions are reached.

5.5 The overall prototype system

The simulation based system presented in this thesis has been conceived in order to provide the users with a large spectrum of operative scenarios; in fact, the instructor can set weather and marine conditions before the training session starts or even during the execution. Data such us main engine RPM, side thrusters utilization levels, rudder positions, wind intensity and directions, compass, 2D maps of the port areas including the other ships (Automatic Identification System – AIS) are always available during the simulation. Performance measures such as mission time (average and standard deviation values over multiple training sessions), collisions, and wrong maneuvers are recorded and are available at the end of the simulation. Furthermore, different viewpoints are available during the simulation: inside the bridge, outside the ship (therefore it is possible to see the whole ship from different points of view). In addition, the accuracy and quality of the simulator has been guaranteed by Verification, Validation and Accreditation (VV&A) processes that have been carried out during the entire development period. As mentioned before, the ship dynamic has been verified and an ad-hoc tool has been developed to this purpose. As for the computer simulation model a verification has been carried out by using the debugging technique to ensure high levels of accuracy and quality.
The figure 5.12 shows the ship bridge simulator in use while the containership is entering the port of Salerno (on the bridge ship simulator the camera is showing a rear view of the ship; multiple view are allowed as shown in figure5.13 where the bridge view is displayed).

Figure 5.12: The ship bridge replica and the visualization area

The figure 5.13 shows the full system prototype in use, including two simulators (the ship bridge simulator on the left and the control tower simulator on the right) working together (interoperability mode) and sharing the same virtual environments thanks to the use of the IEEE 1516 HLA standard for distributed simulation. In figure 5.13, a view from the bridge of ship is shown (the view that normally perceived by the pilot while performing maneuvers within the harbor area).

Figure 5.13 – The ship bridge simulator and the control tower simulator working together for cooperative training of ship pilots and port traffic controller (Interoperability use mode and distributed simulation through High Level Architecture)

5.6 Conclusions

The chapter further extends the contents of chapter 4 focusing on the hardware architecture that has been designed and built to develop a fully functional prototype that shows the potentials of the proposed training systems. The prototype is currently installed in the MSC-LES (Modeling and Simulation Center-Laboratory of Enterprise Solutions). Particular attention has been paid on the ship bridge simulator that has been conceived in order to let the user feel the sensation of being inside a real ship. To this end, a ship bridge replica, including maneuvering controls and navigation instruments, has been designed and prototyped. To increase even more the feeling of realism the ship bridge replica has been integrated with an immersive visualization system that includes a wide visualization area thanks to three screens where the scenario is projected and a dedicated sound system.

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CHAPTER 6:
Other related research activities: Simulation for Training in Car Terminals

6.1 Introduction

This chapter is devoted to illustrate an additional research line that has been followed in conjunction with the main research stream illustrated in the previous chapters. Indeed, further research activities have been focused on training in car terminals. A car terminal is a complex system whose complexity relies on two main elements: the nature of inner daily processes and the great number of operators and vehicles (of different types) involved. Therefore, operators' training is critical to preserve operators', vehicles and equipment safety and security, ensure operational efficiency and avoid economic losses. Each operator has his own role and therefore specific training needs. However, within the whole scenario the most critical roles are taken by drivers (both vehicle and taxi drivers) and marshalls (operators assisting drivers during parking operations) whose errors may cause severe human and economic damage. In fact, drivers have to deal with a variety of working conditions including different levels of risk. The main risk factors depend on the configuration of the ship involved in loading/unloading operations; i.e. steep ramps, sharp bends, narrow aisles, slippery floors, etc. Moreover, for optimization purposes, vehicles loading and unloading are concurrent operations therefore it is likely that opposite flows cross each other increasing even more the risk of accidents. Needless to say that only well-trained (both in theory and practice) and highly qualified staff can cope with the complexity of such a working environment and carry out its tasks effectively and safely. As mentioned before, improper behaviors, lack of coordination, incorrect procedures may result in losses of human lives and, from an economic point of view, in increased direct and indirect costs (Bruzzone and Longo, 2013). Traditionally, training activities include frontal classes aimed at illustrating and discussing best practices and operational procedures that should be adopted in standard, unusual and dangerous conditions. Usually, training is not limited to frontal classes but includes also practical training where inexperienced operators are involved in coaching sessions driving in the real system with real vehicles. In particular, drivers and Marshalls courses last between 20 and 40 hours whereas coaching sessions last between 40 and 80 hours. In addition, training does not involve inexperienced operators only; further training is needed to illustrate lessons-learned, successful experiences or even new procedures. Furthermore, training for after action review may be required in case of accidents and vehicles damage. In this case, training activities aim at understanding why the accident occurred identifying which measures and operational modes can prevent the same situations from happening in the future. Hence, operators' training is a crucial and critical activity in car terminals; as a consequence there is a continuous search for tools that allow reducing training costs and maximizing training effectiveness. To this end, Modeling & Simulation (M&S) has proved to be a powerful methodology for dealing with complex systems design, management and even training. As a matter of facts, development and testing real prototypes, even prototype solutions based on simulation, is a relevant training opportunity for its users (i.e. operational testing of weapon systems in the military industry is a clear example). Simulation allows reproducing a real system and its behavior through an artificial system (the simulation model) therefore, operators involved in simulation based training activities, while interacting with the simulated environment (that in most of the cases is a 3D virtual environment) can learn how to interact with the real system and the real equipment. As a result this approach can be advantageous especially when using real equipment in the real system is costly and dangerous as it may be in a car terminal. Indeed, simulation provides a safe training environment (the operator interacts with a virtual word reproducing the real system) where human errors have not economic impacts. In other words, operators can even apply wrong procedures to see the consequences of their actions and learn how to handle vehicles and equipment safely to perform their tasks effectively and efficiently. The main benefits of M&S can be summarized as follows (Cimino et al., 2010):

- practice theoretical concepts and gain awareness of the main consequences related to the undertaken course of action in a very immediate and visual manner;
- provide instructors with a controlled environment where a large amount of data can be recorded and analyzed to evaluate the trainee's evolution and performances;
- avoid hazardous situations that usually occur when inexperienced users manipulate real machines;
- reduce costs associated to training operations;
- provide trainees with the possibility of working in any desired condition (i.e. arbitrary weather conditions).

Figure 6.1: Cars accident during loading/unloading operations in a car terminal

Under these premises, ICO-BLG, the car terminal operator working in the port of Gioia Tauro, and the MSC-LES lab at the University of Calabria, are collaborating (under the umbrella of the Calabrian Pole for Logistics, Transport and Transformation) on a joint research project (CTSIM, Car Terminal SIMulator) which aims at innovating teaching and training approaches in car terminals by using advanced tools based on Modeling and Simulation.

CTSIM is a 3D Virtual and Interoperable System which the operator and the vehicle simulator are part of. Such simulators are intended for parkers and drivers respectively; indeed, parkers and drivers are the main actors in car terminal operational processes and their performance strongly affects those of the whole system. The parker is in charge of giving the drivers all the indications they need to park the vehicles they have been assigned to (e.g. cars). In turn, the driver is responsible for vehicle handling during loading and unloading operations that entail vehicles transfer from the yard to the ship and vice-versa (including parking operations). For this reason, great attention has been paid on the development of the parker simulator (called also operator simulator) and of the driver simulator(called also vehicle simulator). The simulators have been designed to ensure a great flexibility; as a matter of facts they can work in a standalone mode (to allow single operator training), but they can even work in a multiplayer mode and interoperate each other sharing the same virtual 3D environment (for cooperative training). Thus, the CTSIM system can host 4 drivers (e.g. for cars) and 1 parker simultaneously in the same scenario sharing the same 3D virtual environment. This way they can see and interact each other as it happens in a real car terminal.

Each simulator will be presented in the next paragraphs; however it is worth mentioning that, as far as the technologies involved are concerned, the CTSIM project takes advantage of the most innovative technologies such as Microsoft Kinect®, tracking gloves, wheel and pedals, etc., that are integrated into the simulation architecture by dedicated software and hardware (developed at the MSC-LES lab at the University of Calabria). This feature makes the simulators that are part of CTSIM unique compared to other commercial simulators of any kind.

6.2 Related Works

Over the years Modeling & Simulation (M&S) has proved to be a very effective problem solving methodology in different areas including Industry, Logistics and Supply Chains (Piera et al. 2004). As far as the marine ports domain is concerned, many are the cases in which M&S has been used for supporting decision making at strategic, tactical and operative level (Longo 2007, Bruzzone et al., 2000; Bruzzone et al. 2012) also including (above after September 11th 2001) security enhancement (Longo, 2010). However, in the same domain, M&S has been also widely applied for supporting operators training (i.e. container terminals) especially for high-risk and costly activities. There are many examples of works and research projects where simulation is profitably used as a training tool. In the following a general survey on past related works is proposed. In particular, the state of the art allows pointing out that simulation has been used extensively for the training of the operators involved in containers handling processes and loading/unloading operations. As follows a brief description of different types of applications is reported. Many are the examples of simulation systems devoted to train quay cranes operators: Wilson et al. (1998) propose a 3D virtual system devoted to simulate crane operations; such system allows reproducing also the feelings and sensations that can be experienced in a crane cockpit. Huang (2003) presented a method to design an interactive visual simulation mobile crane training. Daqaq (2003) developed a virtual simulation for training of ship-mounted cranes operators. Rouvinen et al. (2005) developed a gantry crane simulator intended for container handling operations between yard and ships. Fernandez et al. (2009) present a training simulator for different kinds of operators, namely quay crane, gantry, rubber tired gantry and reach-stacker operators. The simulator includes an automated system devoted to track and monitor operators' skills. In Elazony et al. (2010), attention is focused on the design and implementation of reusable and interactive simulation-based training systems. Similarly, Lau et al. (2007) present a distributed real-time simulation model for container terminal processes. Furthermore specific research works have been developed to support operators' training and procedures design within container terminals. Moreover, several examples of distributed simulation for operators training in container terminals can be found in Merkuriev et al. (1998), Bruzzone et al. 2010, Bruzzone et al. (2011).

In addition it is worth mentioning that a complete survey on the major projects focusing on simulation systems for training of marine operators is one of the main deliverables of the OPTIMUS (Operational Port Training Models Using Simulators, that is financed by the European Union) project.

A careful analysis of the state of the art shows that the most common simulators for training in the port area include:

- ships bridge simulators:
- engine room simulators;
- handling loads simulators

In these simulators, usually the particular attention is paid on the visualization system that consists of a series of screens where the virtual environment (which recreates the real system) is projected. In addition, these simulators are designed for the training of the following kinds of operators:

- ships pilots;
- forklift operators;
- Reach Stacker operators;
- Straddle Carrier operators;
- Gantry Crane operators (STS, RTG, RMG);
- Offshore Crane operators;
- Tower Crane operators;

Some of the most important commercial simulators include:

- Drilling Systems (http://www.drillingsystems.com) whose simulator KraneSim is an advanced tool for simulating a wide range of quay cranes and vehicles.
- Oryx Simulations AB (http://www.oryx.se/), crane simulators that provide the users with different scenarios and different options in terms of cockpit, motion-based system, real-time graphics, background sounds, etc.
- ARI (http://www.ariworld.com/simulation/default.asp) and Total Soft Bank Ltd. (http://www.tsb.co.kr/) simulators for training on different types of cranes QC (Quay cranes), RTG (Rubber Tyre Gantry), RMG (Rail Mounted Gantry), SG (Ship Gantry), PC (Pedestal cranes), SC (Straddle Carriers)
- MPRI Ship Analytics (http://www.mpri.com/esite/), develops crane simulators for training that can play faithfully the operational characteristics of 12 types of cranes.
- STC Group http://www.stc-group.nl has developed simulators for various types of cranes such as containers cranes, bulk cranes and off-shore cranes.
- Simulation Team http://www.simulationteam.com has developed HLA interoperable simulators of different logistical means including gantry cranes, transtrainers, stackers, trucks, etc. These simulators are used for training, performance analysis and biomedical operators, as well as for virtual prototyping. Such simulators are available also in a full motion, immersive cave and containerized solution that can be easily transported where it is needed.

The studies on the effectiveness of M&S applications have pointed out their usefulness for training applications. In fact, simulators are widely used both for the first contact with machines and equipment and for the skill upgrading experienced operators. The effectiveness of simulation-based training is evaluated according to the transfer of the learned concepts to the real world during scheduled sessions where the operator acts in the real world under the supervision of an experienced instructor (Morrison et al 2000).
However, while many research works can be found for container terminals, there are really few works for car terminals. Indeed, in the area of container terminals, simulation is used not only for training by using 3D Virtual Simulation (Ballis and Abacoumkin, 1996; Bruzzone et al. 2010, Bruzzone et al. 2011; Bruzzone et al. 2012; Bruzzone and Longo, 2013; Massei et al. 2013; Longo et al. 2013) but also for decision making (Merkuryev et al., 1998; Henesey et al. 2006; Hadjiconstantinou et al. 2009; Macías and De La Parte, 2004; Latorre-Biel et al., 2014).As for serious games and 3D virtual simulation, many works can be cited, i.e. a meaningful example can be found in Bijl and Boer, 2011. However, a survey of the state of the art clearly shows that there is a lack of research in the field of training in car terminals by using 3D virtual, distributed and interoperable simulation (Longo et al. 2013). In fact, further analysis of the state of the art shows that existing research works on car terminals are focused on transshipment operations using multi-agent systems (Fischer et al 2004), on operations management (Mattfeld et al 2002) and on business processes definition. In addition, the role of such logistic nodes in the supply chain of the automotive sector has been analyzed by Dias et al. 2007. However, the issues related to training and exercise of various professionals using advanced approaches based on M&S and 3D immersive virtual environments, are unexplored yet.
To this end, the proposed research work seeks to fill the gap thanks to a simulation architecture, CTSIM, indented to support training activities in car terminals. In particular, the paper contribution to the current state of the art can be summarized as follows:

- a training system for drivers of small, medium and large cars operating in car terminals;
- a training system for bus drivers operating in car terminals;
- a training system able to offer multiple scenarios (only the yard, only the ship, ship-yard, etc.), with at least two types of ships (a big ro-ro ship and a feeder ship);
- a training system for carrying out cooperative training of drivers of different vehicles (i.e. cars and buses);
- definition of appropriate performance metrics for evaluating trainees;
- a virtual advanced environment that can be used for performance evaluation also in case of structural lay-out changes in the terminal area;
- development of a business model easily exportable between different car terminals.

6.3 Main processes and activities in a car terminal

In this section the main processes and activities that usually take place in a car terminal are described. One of these processes includes vehicles unloading and their placement into the yard. This process occurs after each ship entering the port is towed and moored. However, before unloading operations can start, some preliminary validation activities and macroscopic controls are carried out; in particular during these activities the staff verifies the compliance of each group of vehicles with the information reported in the informative systems and checks whether there are damaged vehicles. In addition, after that, the optimal vehicle unloading sequence is defined and the yard position assigned to each vehicle is established. At this stage, unloading operations can start.
In the next step, each vehicle is placed in the previously assigned location and a further quality check is performed to ensure that the vehicle has not been damaged neither to the interiors nor to the bodies. In case of damage a damage report is drawn up.
Another typical process that is carried out in a car terminal includes vehicles transfer from the yard area to a service area devoted to pre-delivery inspection (PDI) activities and a subsequent transfer to the loading area.
As far as the loading process is concerned, it should be noted that some of the vehicles are loaded on trains or trucks while other vehicles are loaded again onto ships. Before the loading operation, further controls are carried out and if damaged vehicles are found, they have to return to the PDI buffer area (to be repaired before leaving the terminal area). The vehicles that have to be loaded on ships are driven from the yard to the boarding ramps and, after an integrity check, are driven to the assigned spot on board.
Even in this case, it is possible that after inspections a damage report is drawn up and is attached to the involved vehicle. The main actors responsible for the aforementioned processes are:

- Drivers: they are in charge of vehicles handling (from the ship to the yard and vice versa) during loading/unloading operations and in the yard during shifting operations. Moreover, drivers have to cooperate with quality checkers and marshalls (parkers) in order to avoid incidents and errors while executing particular manoeuvres.
- Taxi Drivers: they pick drivers up from the yard and move them onto the ship (or vice-versa) during loading/unloading processes. In addition, they work in cooperation with quality checkers and marshalls, to ensure the correct loading/unloading sequence.
- Quality checkers: they verify that operators' behaviours are compliant with the instructions and procedures they must adhere (in particular they execute severe controls at dangerous points and during the vehicles inspections). On the other hand, coordination functions include those activities that are carried out in collaboration with taxi drivers and parkers to choose and communicate the assigned position (on the yard or on board the ship) and to ensure that the established loading/unloading sequence is respected.
- Service persons. The service persons are responsible for the viability on board and on the ramps; moreover, they assign bar codes and they are the first responders in case of accidents.
- Tally Men. The tally men is in charge of bar codes scanning (to get Vehicle Identification Numbers, VINs), of assigning a destination to the vehicles of each row/parking area; particular attention has to be paid in order to avoid scanning (wrongly placed) vehicles with a destination different from the one assigned to the same row.
- Marshall (Parker). The marhsalls or parkers have to ensure that vehicles are parked according to the required instructions (such as distances between adjacent vehicles, parking on the line, checking handbrake / first gear, etc).

6.4 CTSIM General Architecture

As already mentioned the aim is to develop a simulation framework devoted to car terminals operators training. An overview of the CTSIM architecture is given in Figure 2 where the main simulation components are highlighted. Basically, the main components of the architecture are three different interoperable simulators: the vehicle simulator, the ship simulator and the operator simulator.

Usually, a car terminal can host different types of ships with different layouts and ramps therefore the ship configuration plays a crucial role in car terminal processes and is a key element of the training scenario. For this reason, particular attention has been paid on the ship simulator development. The ship simulator allows simulating two types of vessels devoted to transport cars and buses: a ro-ro car/truck carrier for long transport routes (international and/or intercontinental) and a ro-ro feeder. Both ships include side and stern ramps and allow for different configurations in terms of bridges layout, lanes, ramps, etc. In addition the ship simulator provides the users with the opportunity to select climatic conditions such as wind, visibility, rain and sea state so as to offer the possibility to train over a wide variety of operating scenarios. Being part of an interoperable architecture for cooperative training of different operators (i.e. parkers and drivers), the Sip Simulator has been equipped with an advanced visualizations system that allows changing the viewpoint and let each operator involved in the training session see the ship interiors from different perspectives as it really happens during on board operations.

Furthermore the feeling or realism has been given special attention due to the need of making the training experience as much engaging as possible. For this reason, dedicated Man in the Loop (MIL) solutions have been integrated into the simulator; for instance basic parameters such as operators' viewpoints, type of display etc are controlled by a computerized console and some hardware devices.

Figure 6.3 shows the cars parked inside a ro-ro ship as they appear within the Ship Simulator.

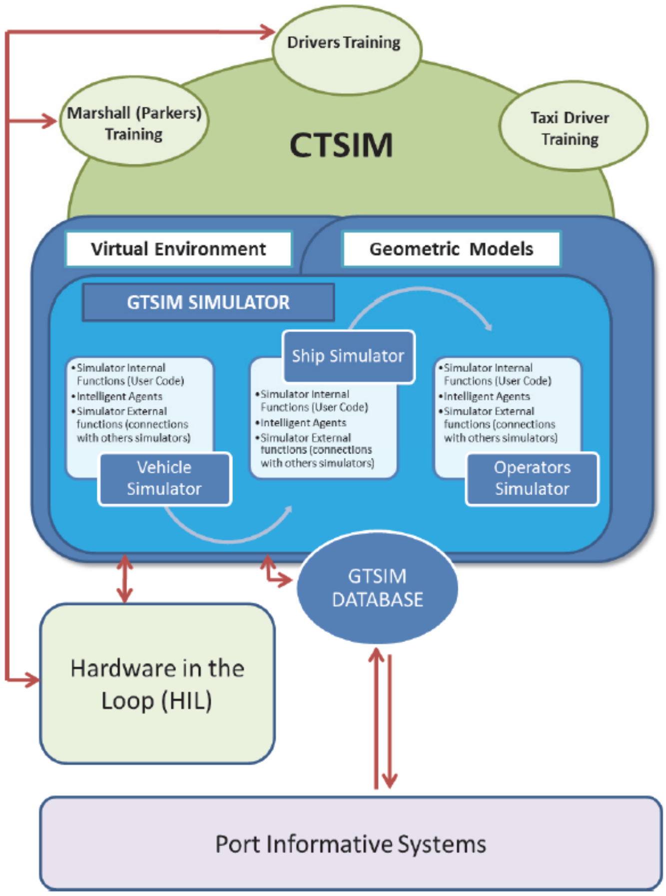

Figure 6.2: General architecture of CTSIM

On the other hand, the Operator Simulator is aimed at recreating the main tasks of marshalls, tally men and quality checkers. The scope of this simulator is twofold: it can be used to train operators different from drivers and it can also be used to train drivers in being acquainted with the meaning of parkers' gestures (or in general to interact correctly with other operators). Particular attention has been paid on the role of the parker because his job presupposes high levels of coordination and cooperation with drivers affecting both the efficiency and the economic outcome of the car terminal. Indeed, the Operator Simulator is an avatar driven simulator that can be controlled by the parker to perform training operations. It is equipped with a gesture recognition system that is able to track both body and fingers movements. In particular the Kinect has been used for body gestures recognition while a tracking glove has been developed for fingers gestures. As a matter of facts the tracking precision of the Kinect turned out to be not enough accurate to recognize fingers movements and therefore an ad hoc, low cost solution has been developed from scratch at the MSC-LES lab.
As for the avatar movements within the virtual scenario, they are controlled by a joystick that allows the parker to move from one place to another in the parking area (on the yard or on board the ship), in order to provide the drivers with the right indications while parking operations occur.
As in the ship simulator, operators have the possibility to change their point of view based on the needs that arise from the contingent situation they are dealing with. In this way, they can act as it happens in the real system and can provide the drivers with accurate instructions. Moreover, even in this case, user interfaces are based on advanced hardware and MIL solutions (i.e. the avatar of the operator in the virtual environment can be controlled through motion controllers, the virtual environment can be seen through head mounted display). Figure 4 shows the view of an avatar while interacting with a car that is approaching the ship, while figure 5 depicts the real operator controlling the avatar through a motion controller and seeing the virtual environment through a mounted head display.

Figure 6.3: Cars parked in a Ro-Ro ship

Figure 6.4: Avatar interacting with vehicles

As clearly shown when dealing with car terminal inner processes, drivers have a very important role: their job entails complex tasks with high levels of risk for people and equipments. Therefore, the car simulator has been designed and developed as part of the CTSIM architecture to address drivers' specific training needs. To provide the users with a realistic experience and enhance the training effectiveness of the simulation system the dynamical behaviour of the vehicle has been carefully recreated. Thus a great deal of details, namely the vehicles physics, the engine physics, the gear, and the wheels friction with the asphalt have been considered. Furthermore the car simulator implements a collision engine devoted to simulate both the collisions and the related damages so that drivers may be immediately aware of the consequences of their action.

Since in a real car terminal there are different kinds of vehicles, the car simulator includes not only a medium car, but also a truck simulator (with tractor and trailer). In this case, all the differences like weight, steering angle, engine behaviour, brakes, velocity, acceleration, etc. are considered.

The vehicle simulator, the operator simulator and the ship simulator are able to run on different computers (distributed simulation) and to interact each other (interoperable simulation) by sharing the same virtual environment as well as different objects, attributes, interactions and parameters. Therefore each simulator is able to run standalone or combined with other simulators. In addition, multiple instances of the same simulator can run and interact each other, e.g. four car simulators and one parker simulator; this configuration can be used to train (at the same time) four drivers and one parker. The CTSIM network architecture is modular, as explained before. It uses a TCP/UDP connection among the simulators with Unity 3D communication protocols and messages. Moreover it shares only the 3D models that each player is using so the information (e.g., positions, rotations and other useful information) needed to recreate the same 3D visualization in all the simulators sharing the same 3D scene is sent out. The network must be characterized by a low communication latency even considering the high number of entities within each simulator and the complexity of the 3D models. For this reason, the 3D models of the environment (ship, parking area, static objects) are pre-loaded in each client; what the network shares during the simulation are only the 3D models of the cars and the parker, and all the dynamic objects.

Figure 6.5: Operator controls the avatar through a motion capture system

6.5 Performance Measures Description

The main objective of any training simulator is to raise the level of personnel qualification as a function of the time that elapses from the moment the training is started. One of the main problems in car terminals is related to the time required for an operator to be considered an "expert operator". The main recommendation coming from the navigation lines in ro-ro sector and from the automobile manufacturers suggest 1 year of work as estimated average time to reach an acceptable level of qualification. Indeed the estimated time for an operator to experience at least two times all the possible driving scenarios in a car terminal is 2 years. As already highlighted, complex driving situations are characterized by:

- Concurrent operations involving multiple ships and simultaneous loading/unloading operations;
- Simultaneity of operations on ships, trains and yard;
- Simultaneity of operations on the same ship (concurrent vehicles embarkation and disembarkation);
- Operations during the night or during adverse weather conditions.

Therefore, a higher level of qualification obtained in a shorter time would have a direct impact on the following performance measures

- increase of the operators productivity in terms of number of handled vehicles per day;
- reduction of the risk of accident
- reduction of the number of collisions;
- reduction of total number of major damage (total loss) and micro damage with consequent reduction of all direct costs;
- reduction of insurance costs;
- optimization of human resources in terms of operators flexibility in carrying out different types of operations.

6.6 The Vehicle Simulator

The Car Simulator recreates the standard operations of various types of vehicles to be loaded/unloaded onto/from ships.

In particular, the Vehicle Simulator includes three different types of cars (small, medium and large) and a generic model of bus. Figure 6.6 shows developing and testing activities at the MSC-LES lab, University of Calabria.

All the movements of the vehicle are recorded, and it is possible to evaluate the accuracy of each operation at runtime during the simulation.

As described in Longo at al. (2013), the Car Simulator can be controlled by specific hardware interfaces (eg. Steering wheel, pedals, dashboard, etc.) and it could be equipped with a 6 Degree of Freedom motion platform. Moreover MIL and HIL interfaces allow vehicle handling according to the driver inputs.

Currently a real car cockpit including steering wheel, pedals, gear and all the other commands that can be usually seen in a real car, is under preparation. The integration of the real car cockpit with the Car Simulator will be done by using Arduino platform, stepper motors as well as other low-cost dedicated hardware.

The main goal is to have (at the end of the CTSIM project) a real car cockpit fully integrated with the Car Simulator and multiple secondary workstations equipped with game controls (steering wheel, pedals, joysticks, etc.). This way it will be possible to carry out cooperative training sessions involving several drivers (one driver using the real car cockpit simulator and the others using secondary workstations). To enhance the feeling of realism, each workstation (as well as the real car cockpit), is integrated with an immersive visualization system made up of multiple screens and an integrated sound system. In addition multiple views allow trainees to visualize their vehicles from multiple perspectives when moving within the port area.

Figure 6.8 shows an internal view from the car while approaching the ramp for entering the ship (note the presence of the avatar controlled by the real operator through the Operator Simulator).

As far as the collisions engine is concerned, each vehicle has a mesh that is sensible to any kind of collision. Depending on the collision strength, the engine is able to provide real time feedbacks about the damage; as a matter of facts the vehicle 3d model is updated showing the visual aspect of the damage (as shown in figure 6.9)and a damage report is also produced. Indeed, the collision engine implements internal functions to evaluate the level of cars damages including direct and indirect costs related to accidents. Thus the collision engine contributes to improve the trainees' awareness of the consequences of improper behaviours while executing their tasks. In this respect, the Car Simulator, is also equipped with a performance evaluation module responsible for recording all the procedures and activities carried out by a driver during the game. Data recorded during the training sessions jointly with replay functionalities are an indispensable support for de-briefing sessions where trainees have the opportunity to see, in a 3D Virtual Environment, their errors and understand the training gaps that should be filled in. Therefore, it becomes possible to correct mistakes, understand wrong and dangerous behaviours, calculate parking accuracy, keep under control the vehicles velocity and also check if all the security protocols are correctly applied.

In order to optimize the work of the CPU and GPU, because of the high number of vehicles in a car terminal (a panoramic view of the car terminal is given in Figure 6.7), the Car Simulator loads only one geometric model for each vehicle and it replicates this model to render all the vehicles displayed in the virtual scene. This approach allows the trainer to set the parking conditions easily and, at the same time, allows the optimization of the GPU workload since only one vehicle is loaded on GPU RAM while the others are rendered as a replication of this one.

Figure 6.6: developing and testing the vehicle simulator at MSC-LES, University of Calabria

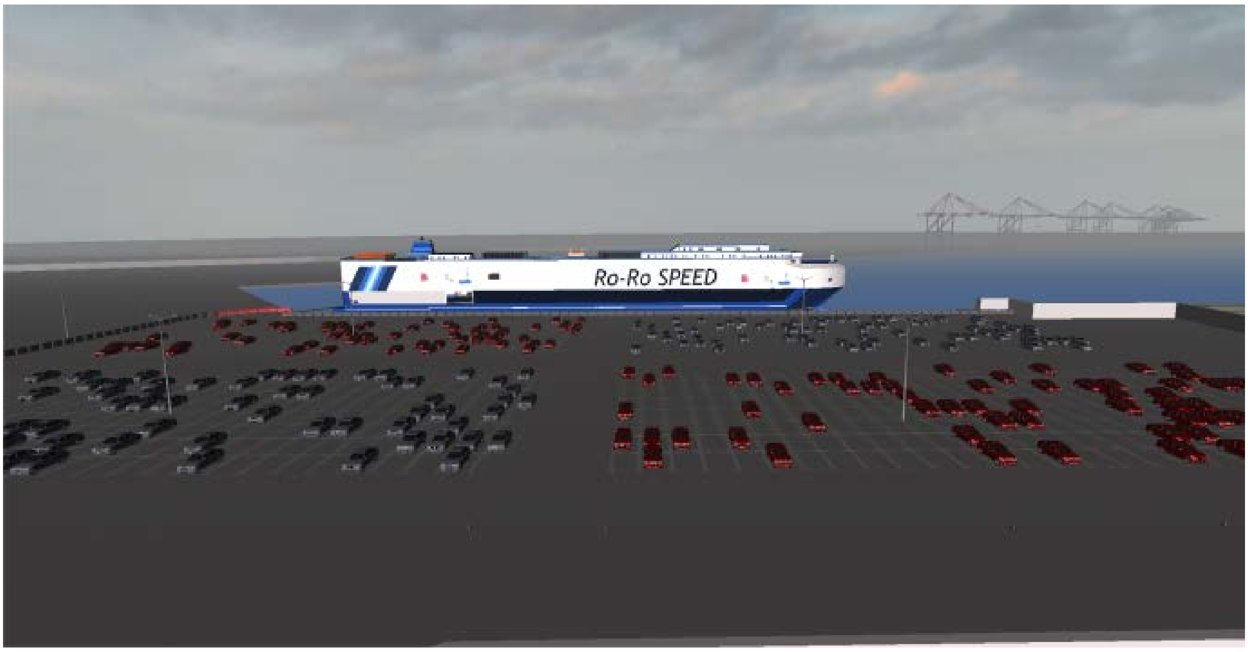

Figure 6.7: Panoramic view of the car terminal

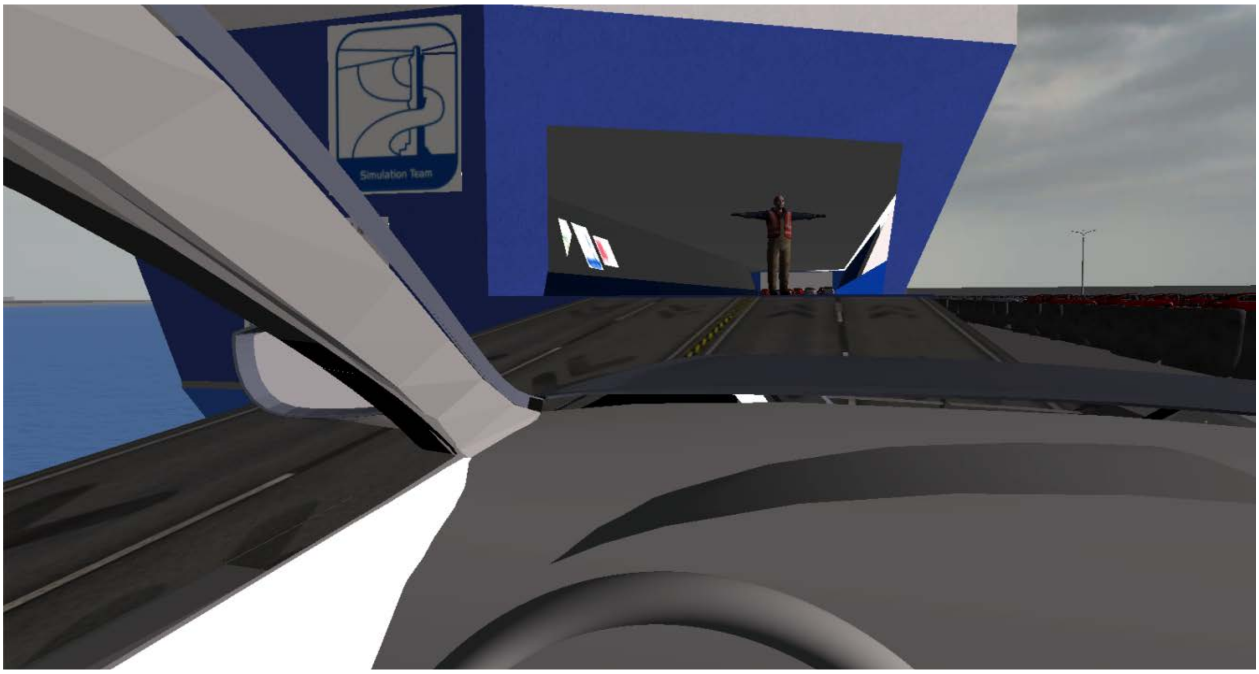

Figure 6.8: internal view from the car while approaching the ramp for entering the ship


Figure 6.9: vehicle simulator – inside view after a collision

6.7 The Operator Simulator

The Operator Simulator development is a really complex work that merges different types of technologies to reach a good level of accuracy for movement tracking and movement reproduction in a 3D Virtual Environment by using an avatar. Although the Microsoft Kinect® has already been used in several research works for gestures recognition and training (see Guyon et al.; 2012, Fothergill et al.; 2012), a considerable effort has been required to adjust this technology and make it compliant with the CTSIM requirements. As a matter of facts, for the main bones tracking, the Microsoft Kinect v2 has been used and a connection to the Unity 3D simulation environment has been set up. Thus the Kinect collects data through cameras and IR

sensors and sends all these data to Unity 3D that updates the position of the avatar 3D model. This applies to the main bones only because the Kinect is not enough accurate to capture the fingers movements as well as those of little parties of the body. In this regard, due to the importance of fingers movements for the parker's task, a Tracking Glove created and developed "in-house" at MSC-LES lab has been used.
The tracking glove allows recognizing the different gestures of a parker and evaluating their accuracy (and example of the avatar hand gesture is depicted in figure 6.10 after cars collision). Even in this case, different studies were already carried out and as a result different types of gloves are available (e.g. Wang and Popović, 2009) as well as other motion capture technologies (Utsumi et al., 1999). However, in most cases these solutions are very expensive while the main goal of the Tracking Glove developed as part of the CTSIM project is specifically designed for Parkers gestures and is a low-cost solution (less than 500.00 €).
Besides, due to the nature of the parker tasks (for a real parker it becomes critical to move around, look at the distances between vehicles and understand gestures that have to be done for supporting drivers operations) the avatar 3D model can walk and move in the car terminal. This functionality has been implemented thanks to the integration of a joystick that allows the user to walk freely both in the yard area and on board of ships to reach each any desired position.
To sum up, from a technical point of view the parker simulator hallmark is the joint and combined use of 3 different technologies (the Kinect, the tracking glove and the joystick) devoted to let the intended user practice the tasks and the activities that are usually undertaken by car terminal parkers. In particular the strength of the proposed solution is the trade-off between costs and accuracy. As a matter of facts even if low-cost hardware has been used, the overall motion capture system is enough accurate and therefore well suited for the purpose it is meant for.

Figure 6.10: Operator Simulator, example of hand gestures

6.8 Conclusions

The chapter presents the general architecture of the CTSIM framework that is an advanced solution for cooperative training of car terminal operators. This chapter is mostly focused on the vehicle simulator and on the operator simulator that are mainly addressed to drivers and parkers operators. Indeed, the analysis of car terminals operational processes has clearly shown that their performance has a direct influence upon the overall system performances. Before going into the substance of the CTSIM design and development, a preliminary study of the state of art has been carried out. The literature review has confirmed that Modeling & Simulation has been profitably used for operators training in port environments. Indeed, many simulators are currently available for training of different operators, namely ships pilots, forklift operators, Reach Stacker operators, Straddle Carrier operators, Gantry Crane operators, Offshore Crane operators, Tower Crane operators, etc. However, there is a lack of research in the field of 3D Virtual Simulators for operators working in car terminals.

Moreover the analysis of the current procedures used in car terminals has further validated the research idea CTSIM relies on confirming the potential benefits of Modeling & Simulation in such a dynamic and complex environment.
In such a context, the high number of procedures that each person has to learn and how workers interact each other are relevant, therefore CTSIM is a modular simulators system composed by three interoperable simulators: an Operator Simulator, a Ship Simulator and a Vehicle Simulator.
The Vehicle Simulator is able to simulate a medium car, a truck (tractor and trailer) and all the procedures performed by a driver in a car terminal while the Operator Simulator simulates with a high accuracy all the movements and gestures of a parker thanks to a technical solution which the Kinect, a tracking glove and a joystick are part of. The simulators that are part of CTSIM are integrated according to the paradigms of distributed simulation so as to be able to interact each other sharing the same virtual environment. The connection is guaranteed by a TCP/UDP protocol also able to work on separated computers; this way it is possible to have more than one Vehicle Simulator and more than one Operator Simulator for cooperative training.

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