Multi-scale performance evaluation in Naval Combat Systems domain

20th Anniversary International INCOSE Symposium
2010, July 14 – Chicago (IL), US

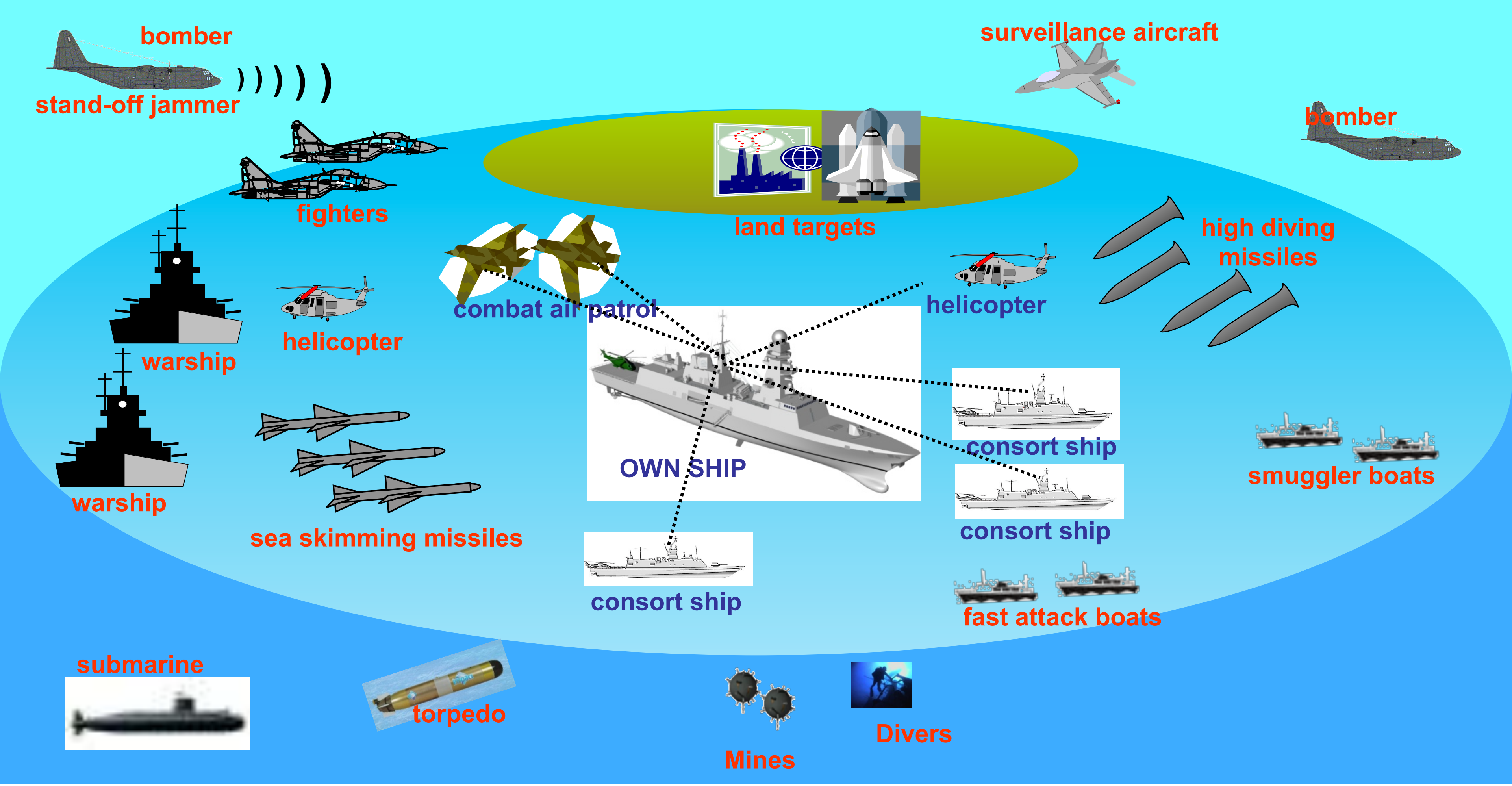
Speaker: Francesco Ciambra

Agenda

- Introduction , context, approach
- Naval Combat Systems performances evaluation
- Case Study: Performance results and system analisys
- Conclusions

Defence Scenario: The big picture….

Naval Scenario an example…

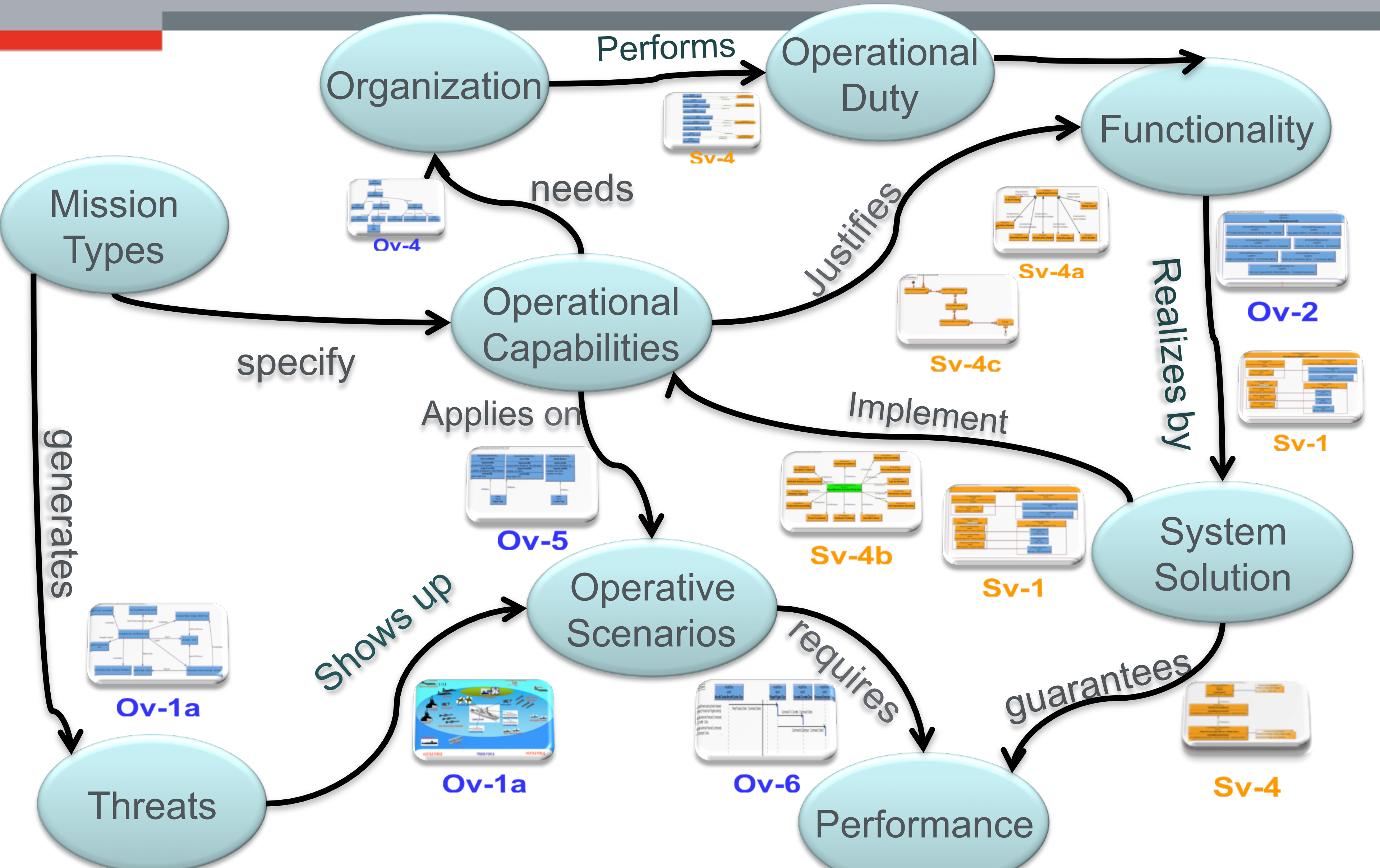


HOSTILE FORCE

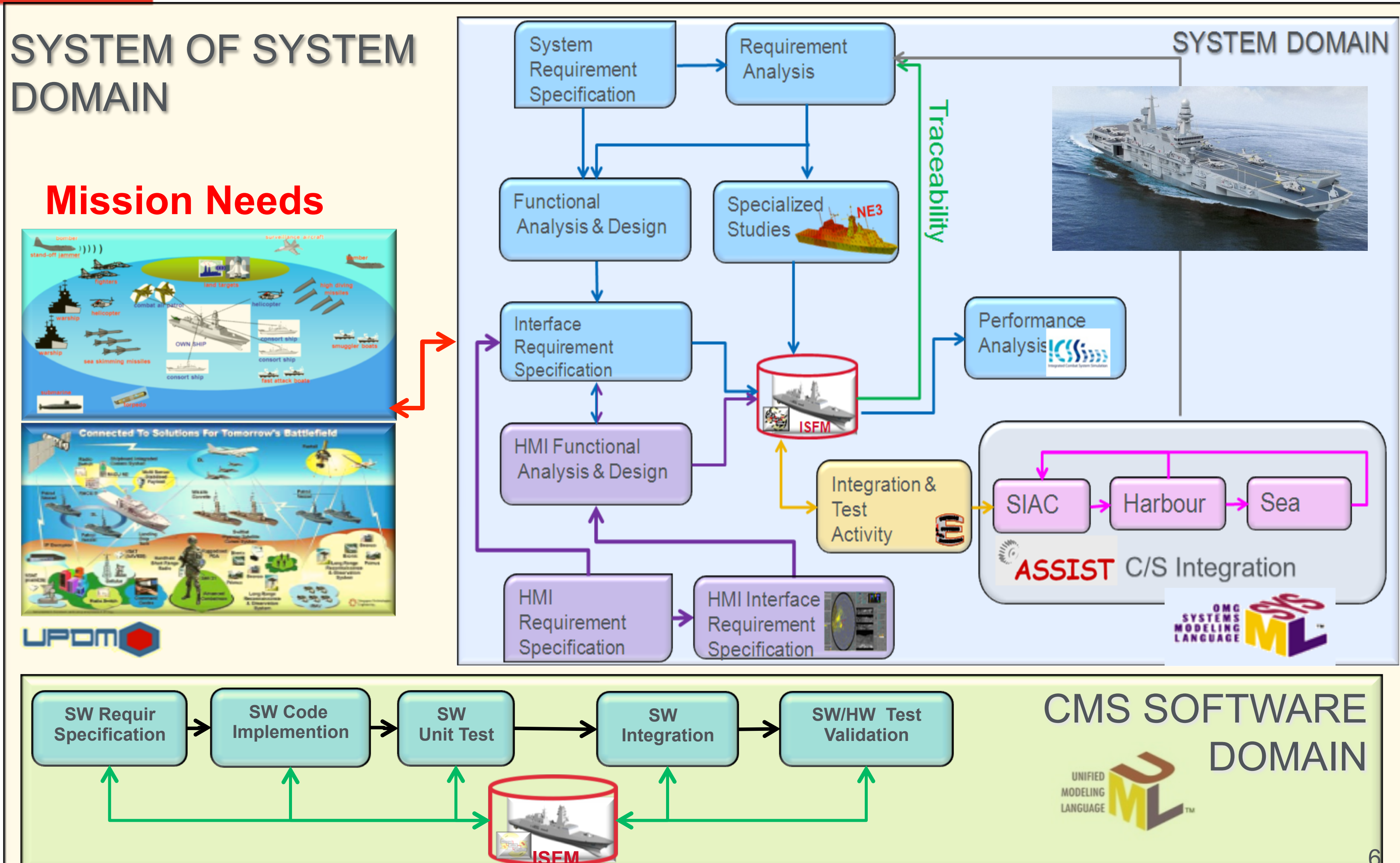
FRIENDLY FORCE

HOSTILE FORCE

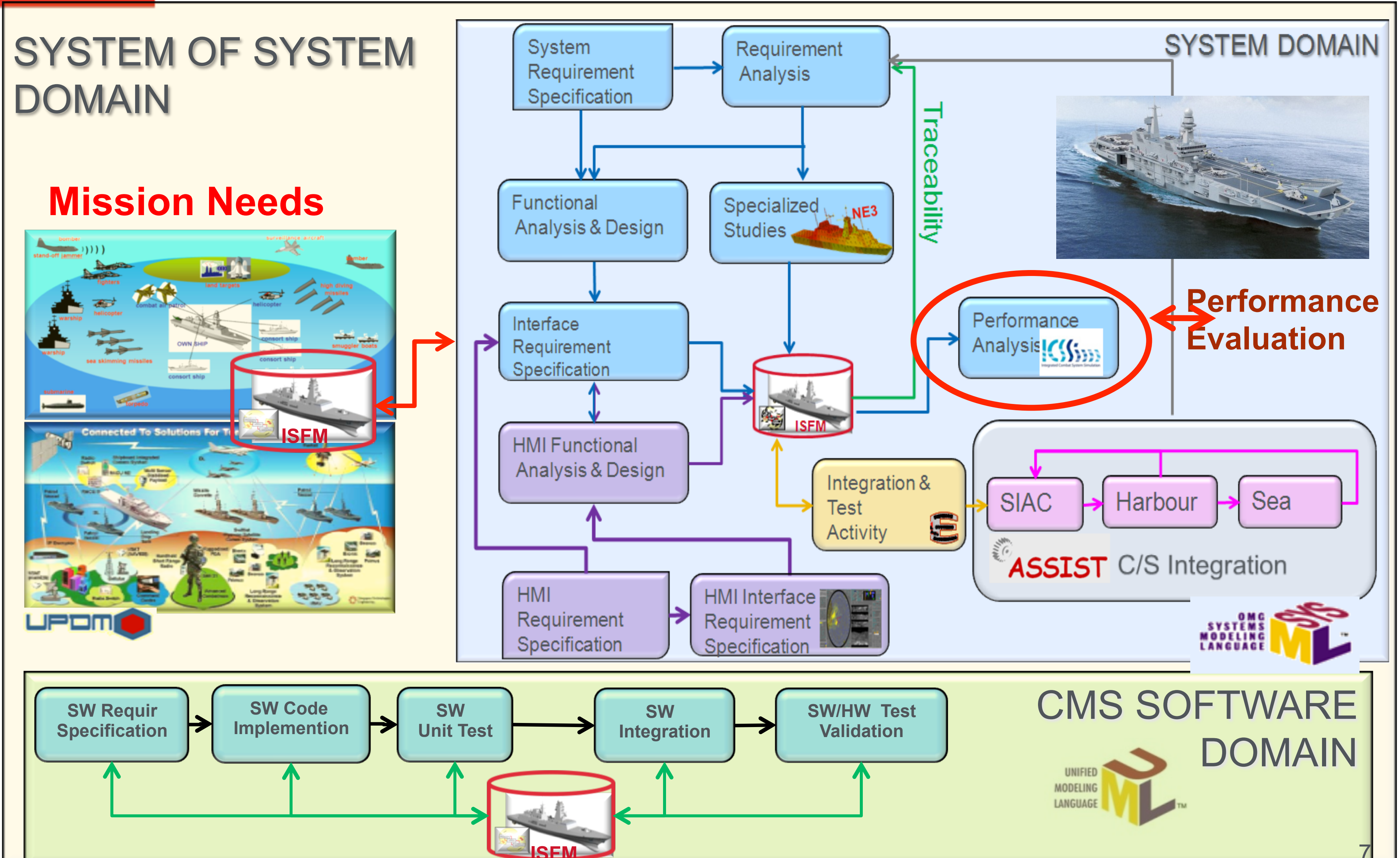
Mission Context: Analysis, Artifacts,Performances



Context: Domain & Process



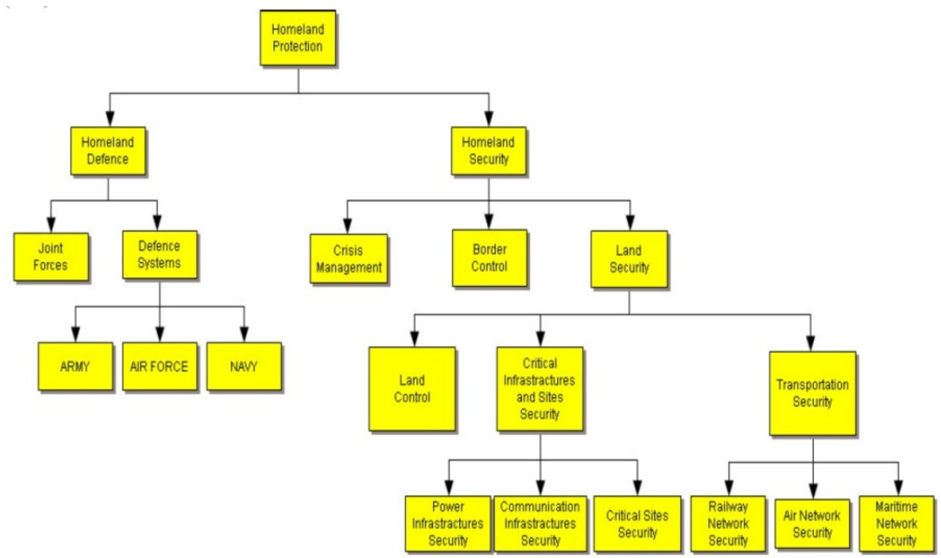
Context: Domain & Process



Multi-Scale method: domain

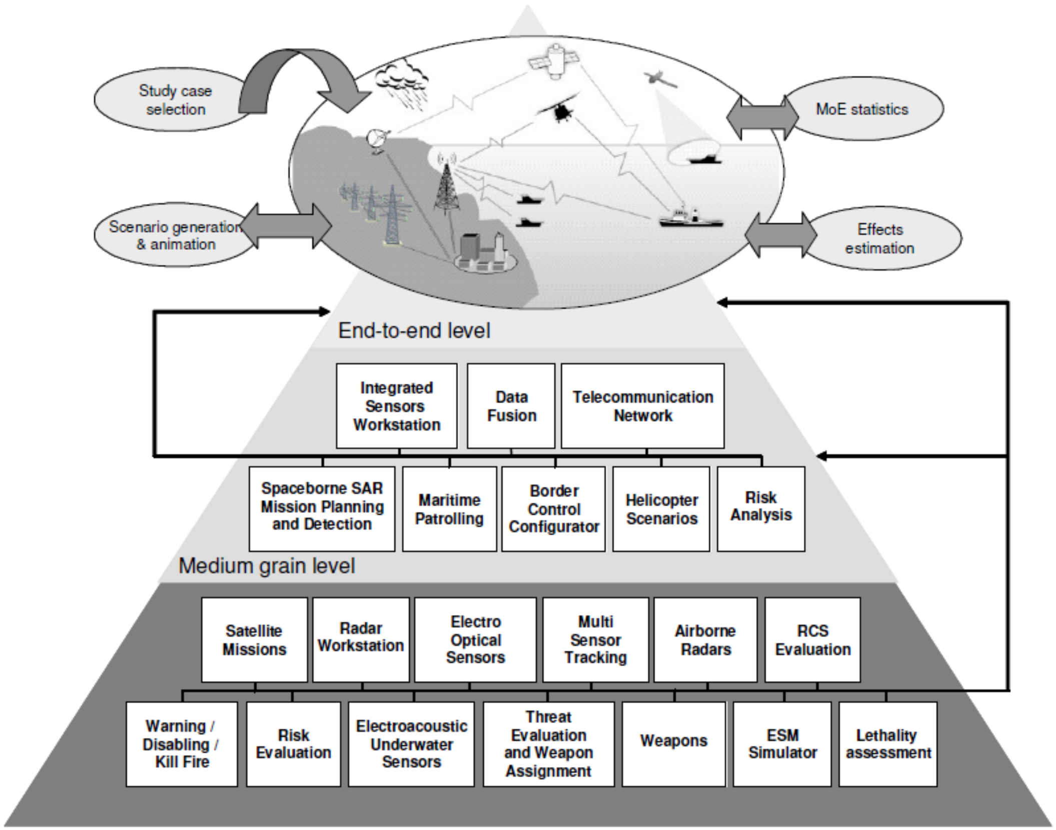
M&S plays an important role in the **analysis of large systems** (e.g. Homeland Defence & Security HD&S systems).

Since from the analysis of the technical literature **no clear indication emerges on the methodology to adopt for the modelling and simulation of large systems**, in the following we introduce a simulator architecture which addresses the issue of system modelling and simulation in a novel **integrated multilayer perspective**.



Multi-Scale method: the way

The aim of this section is to present the general architecture which has been conceived to address the issue of modelling and simulation of an integrated system in a structured and efficient way.



Multi-Scale method: different granularity

The purpose of the **multi-scale architecture** is to integrate **in a single frame** models and tools having **different granularity** and which may refer to a specific function, component or aspect of the system.

The architecture is structured in levels that realize different **trade-offs between field of view and accuracy** of the modelling and simulation.

GLOBAL FIELD OF VIEW	⇨	Is necessary to capture the overall system behaviour
ACCURACY OF MODELS	⇨	Is necessary to analyze in depth each component of the integrated system and to perform sensitivity analysis

Multi-Scale method: the three levels

For this scope, in particular three levels have been identified:

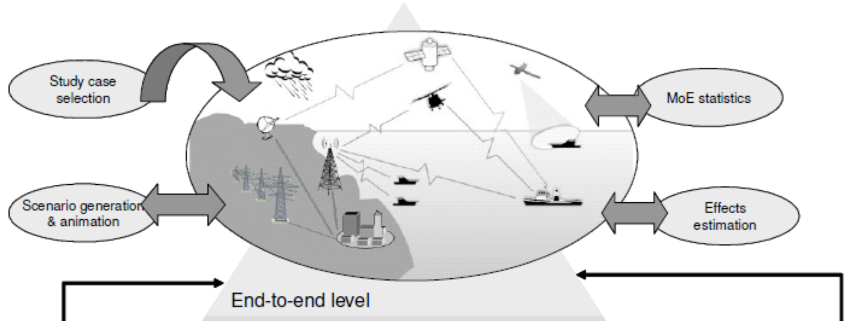
1. The **end-to-end level**, characterized by **global** field of view and **coarse** grain accuracy;

2. The **medium grain level**, characterized by **intermediate** field of view and **medium** grain accuracy;

3. The **fine grain level**, generally characterized by **narrow** field of view and **fine** grain accuracy.

Multi-Scale method: End to End Simulation

Multi-Scale simulations – End-to-end level



The end-to-end level aims to achieve an overall representation and a global view of the system. The end-to-end approach **models the system as a network of system components**, each viewed as an **interacting black box**, and enables to simulate system behaviour in a selected scenario.

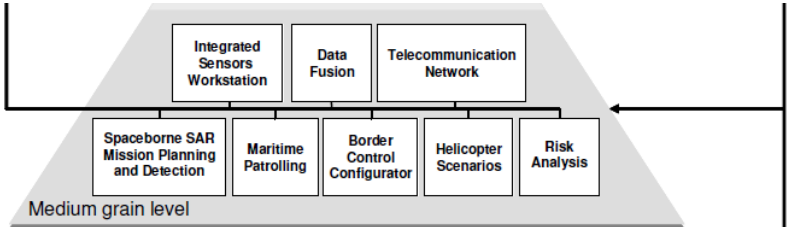
An important aspect of this level is that models are able to **accept input from lower levels**; input is generally obtained off-line, and is used to set-up models to achieve a specific behaviour.

The input of the simulator is a set of parameters for the selected scenario, and the outputs are the systems **Measures of Effectiveness (MoE)** which are evaluated by means of Monte Carlo method over a sufficient number of statistically independent trials.

12

SELEX Sistemi Integrati

Multi-Scale simulations – Medium grain accuracy level

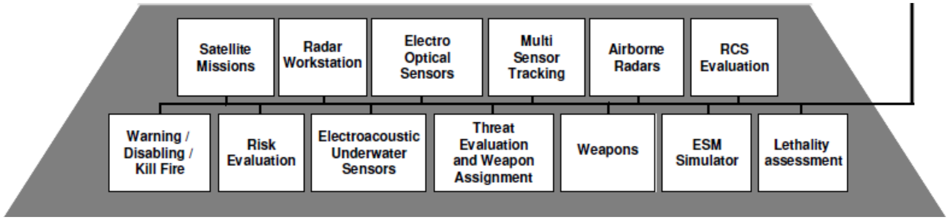


This level includes **models relative to sub-systems or system components** and analysis tools developed to study their behaviour under specific constraints. Models at this level use the same scenarios defined at the end-to-end level to estimate metrics and aspects of interest **and return inputs for the end-to-end simulation**. Exchange of results is also performed horizontally among the tools of this level.

These models bridge the gap between the end-to-end coarse grain and the fine grain levels, because **models at the latter level are often much too complex to be used directly** in the end-to-end simulator; reuse of fine grain models is difficult also because they have often been developed over many years and lack the required portability and customizability.

Multi-Scale method: fine grain accuracy

Multi-Scale simulations – Fine grain accuracy level



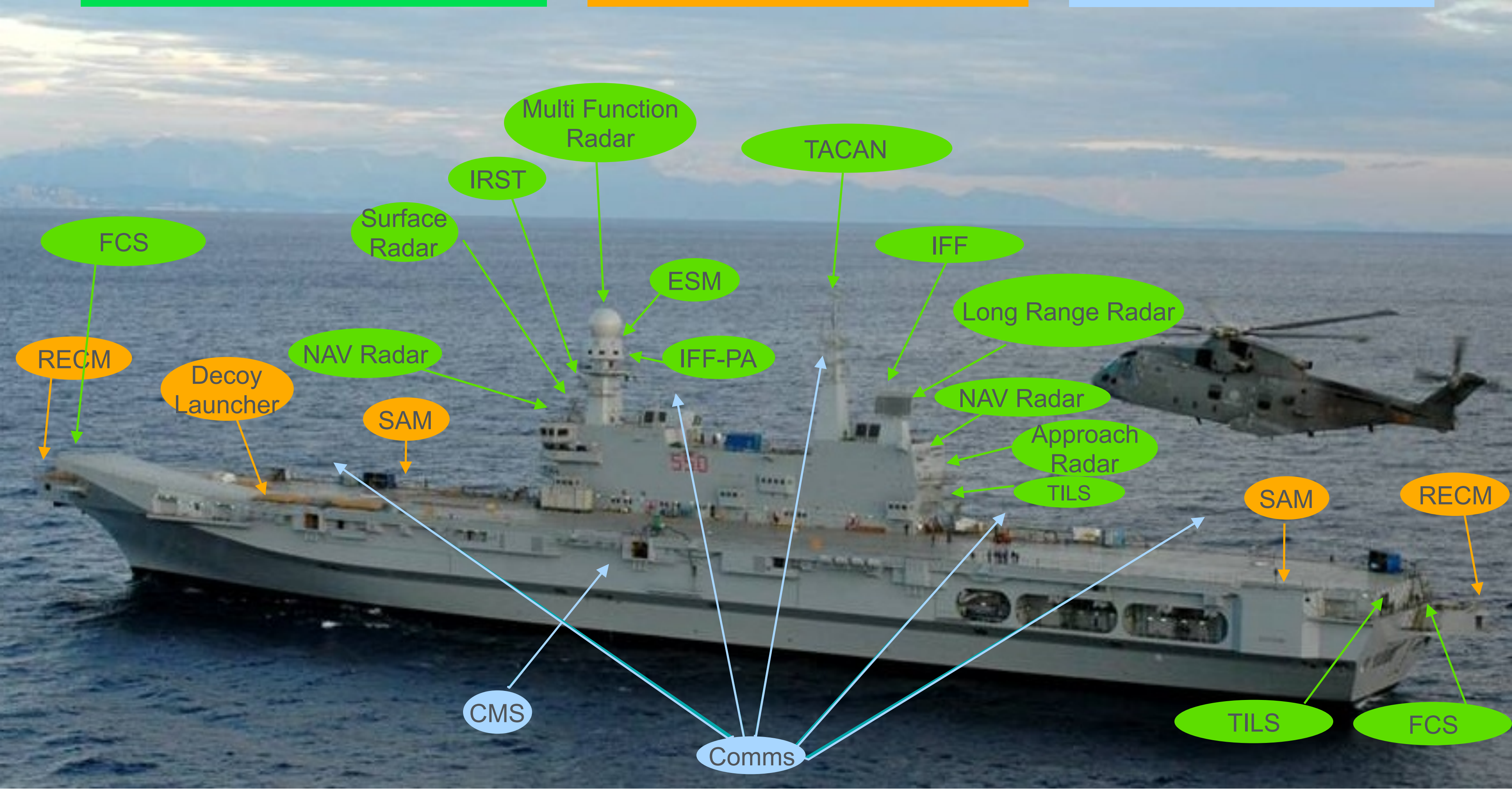
Models and tools at this level are very detailed and accurate, **they are generally confined to components or specific aspects of the system** and are representative of consolidated knowledge and expertise in the field.

They are characterized by a large set of inputs and parameters so that the model is applicable **in a wide set of scenarios**; they may be used to derive performance DataBase which can be fed into the end-to-end models.

Sensitivity analysis is also performed at this level to ascertain which factors significantly affect the performance of the component and therefore it provides valuable feedback in the development of the end-to-end model.

Focus on Naval C/S

SENSORS | WEAPONS | C4I

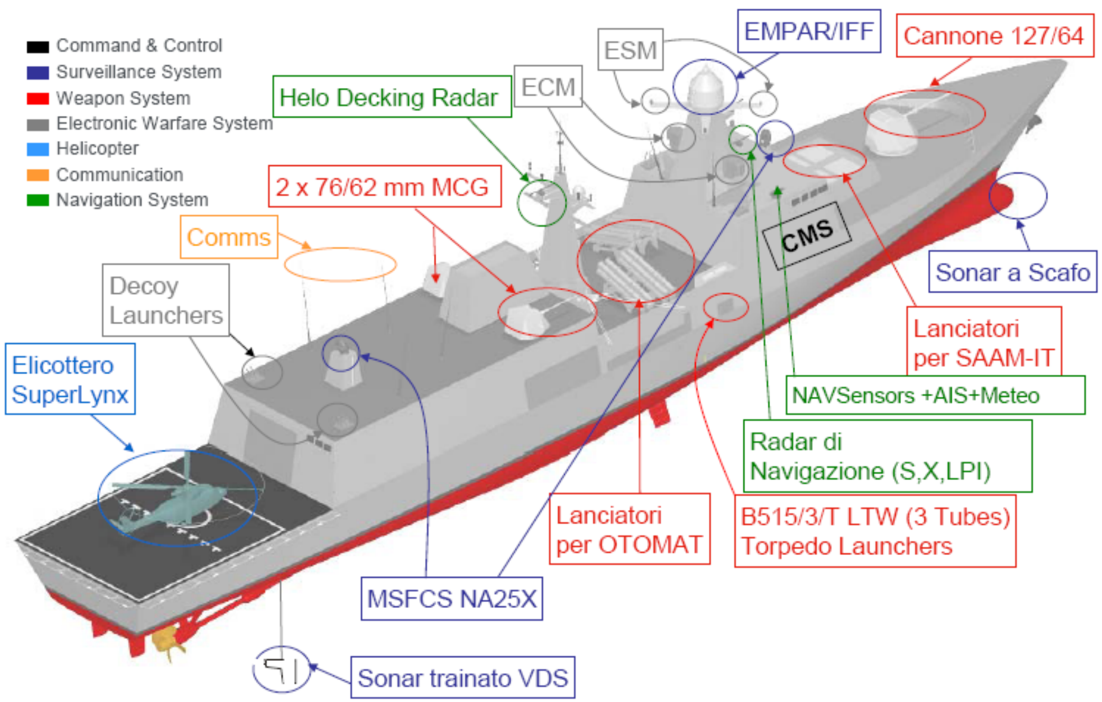


Naval C/S performances evaluation

In naval context, modern combat systems during his operating missions have to perform excellent capability of **Self-Defense** (SD) in addition to a considerable capability to protect other naval platforms which composed a naval fleet or ground assets (LAD: **Local Area Defense**) against eventual structured attacks of missiles, aircrafts, ships, submarine threats, asymmetrical threats and electronic warfare.

These capabilities are realized through a complete and appropriate **equipment of sensors and weapons systems**, and through complex logics of management of this equipment (CMS: Combat Management System).

This kind of performances can be usefully measured with complex instruments of numerical simulation and they cannot prescind from performances of single sub-systems (e.g. surveillance radar, fire control systems, launchers, weapons, CMS).



Naval C/S performances evaluation

Performances evaluation of Naval Combat Systems is made by using a Monte-Carlo numerical simulation software named **ICS-Sim (Integrated Combat Systems Simulation).**

Main goals of ICS-Sim are:

➢**Command and Control (CMS) algorithms definition and validation** for Threat Evaluation and Weapon Assignment (TEWA) function on Anti-Air Warfare (AAW), Anti-Surface Warfare (ASuW) and Anti-Subsurface Warfare (ASW) domain;

➢**Overall Performance Evaluation of entire naval combat systems** through measure-of-performance (MOP) and measure-of-effectiveness (MOE);

➢**Participation at performance evaluation of complex systems of systems** including other defense system in multi-platforms operating scenarios.

Aim of ICS-Sim tool is to provide detailed performance measures for naval combat systems in every project phase (e.g. prototyping, development, qualification), as well as to validate project choices effectuated during systems and sub-systems development and to improve them and optimize.

Naval C/S performances evaluation

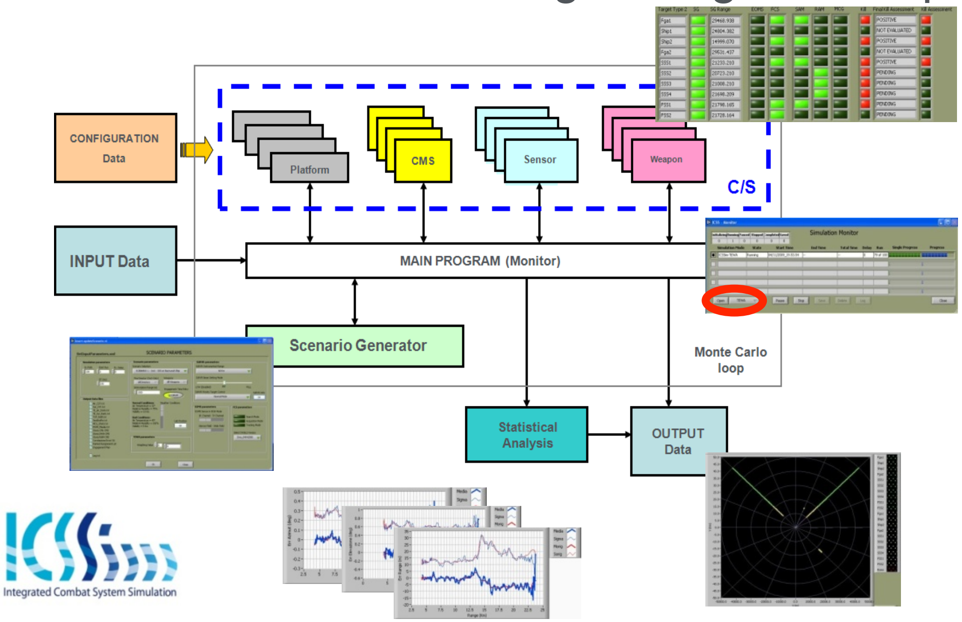
ICS-Sim is a state-of-the-art SELEX-SI tools for C/S performance evaluation.

ICS-Sim structure has conceived to include complex naval combat systems (C/S) modeling with different equipments, through multi-scale modeling of relevant sub-systems (surveillance radar, fire control systems, electro-optical sensors, electro-acoustic underwater sensors, surface-to-surface defense missiles (SSM), surface-to-air defense missiles (SAM), gunnery, torpedoes and electronic warfare each one including multi-scale modeling of its sub-components) and integrated detailed modeling of logic units for control and management of equipments (CMS).

Naval C/S performances evaluation

Functional Architecture: ICS-Sim functioning is managed from a main program (Monitor) which interrogates all components (CSCI: Computer Software Configuration Item) and manages time synchronization and communication between components. Each CSCI is a multi-scale component (sub-system) model of the combat system under analysis.

From the multi-scale point of view, components may be modeled by means of “performances database” obtained through fine grain component simulation.



Naval C/S performances evaluation

ICS-Sim **flexibility** in terms of diversity of naval combat systems that can be analyzed is synthesized from **Configuration Data** function. This feature allows the user to configure the combat system through the choice of its components, each of which may in turn be configured through the selection of its modes of operation or its sub-systems (e.g. selection of a surveillance radar model and selection of its instrumental range).

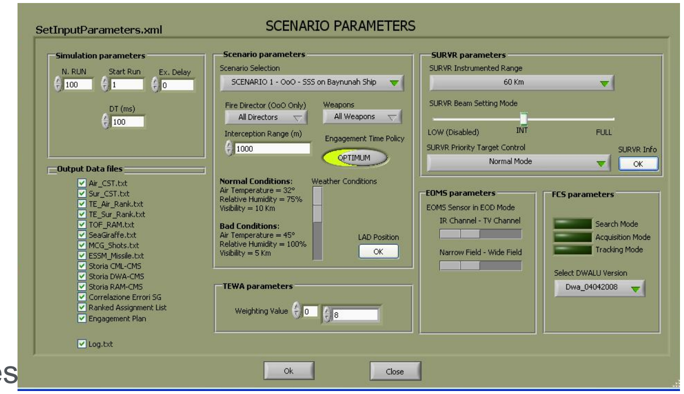
Input data for this simulation tool are the **'simulation control parameters'** (e.g. number of Monte Carlo runs to be executed, order number of start run, simulation 'time-step' and eventual execution delay for code debugging). At input data entry level, user must also select the scenario on which to perform the performance evaluation. ICS-Sim support performance evaluation for One-on-One, Many-on-One or Many-on-Many operating scenarios.

Output data are all performance indicators the user wants to register in order to analyze **combat system effectiveness**. These indicators are in numerical (text files and tables) or graphical (pictures) format and may be related to the **whole system** (e.g. PEH: Probability to Escape a Hit) or one or more of its subsystems (e.g. sensor accuracies, weapon kill probabilities).

Naval C/S performances evaluation

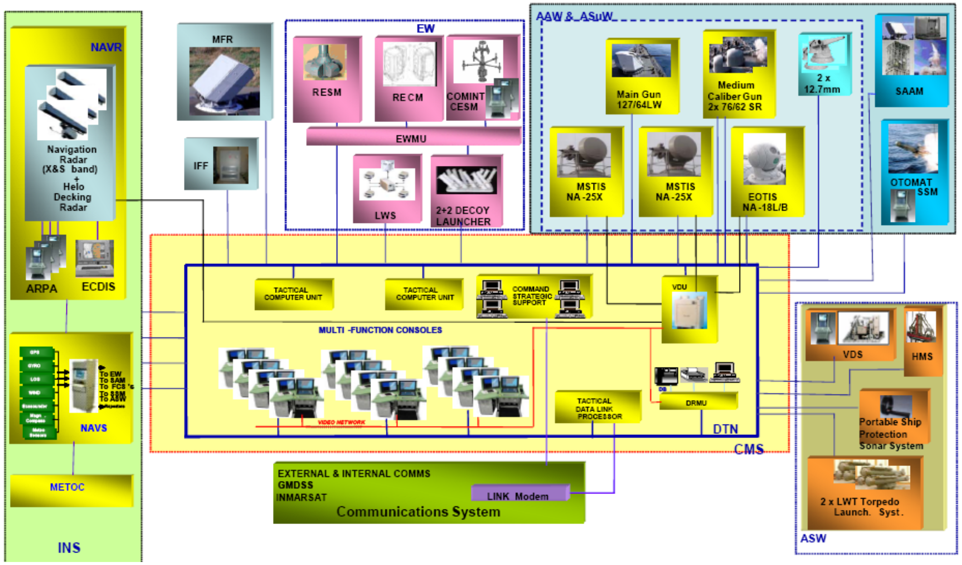
Monitor module is responsible for **management** of numerical simulation tool; it makes calls to all the component modules to achieve the correct sequencing between them; **handles the progress time** with discrete steps (time-step) user selectable; manages the main parameters of **'Simulation Control' ensuring the reproducibility of individual runs;** tests in a dynamic manner the conditions of end-run; allows user to select the 'Output Data' to do performance/algorithmic testing.

Scenario Generator module has the function to generate the characteristic features of user-selected test scenarios. Specifically, scenario generator module summarizes in a shared data area **threat types, threat kinematic and electromagnetic characteristics and environmental condition** (e.g. sea state, rain, visibility, temperature).



Naval C/S performances evaluation

<u>**CMS**</u> modules are the detailed simulation models of combat management systems. Only one of these models can be selected to compose naval combat system to be analyzed. CMS module interact directly with sensor modules and weapon modules through the Monitor module. It includes very detailed modeling of the main functions of Threat Evaluation and Weapon Assignment (TEWA) at platform level and inherent automatic logics.



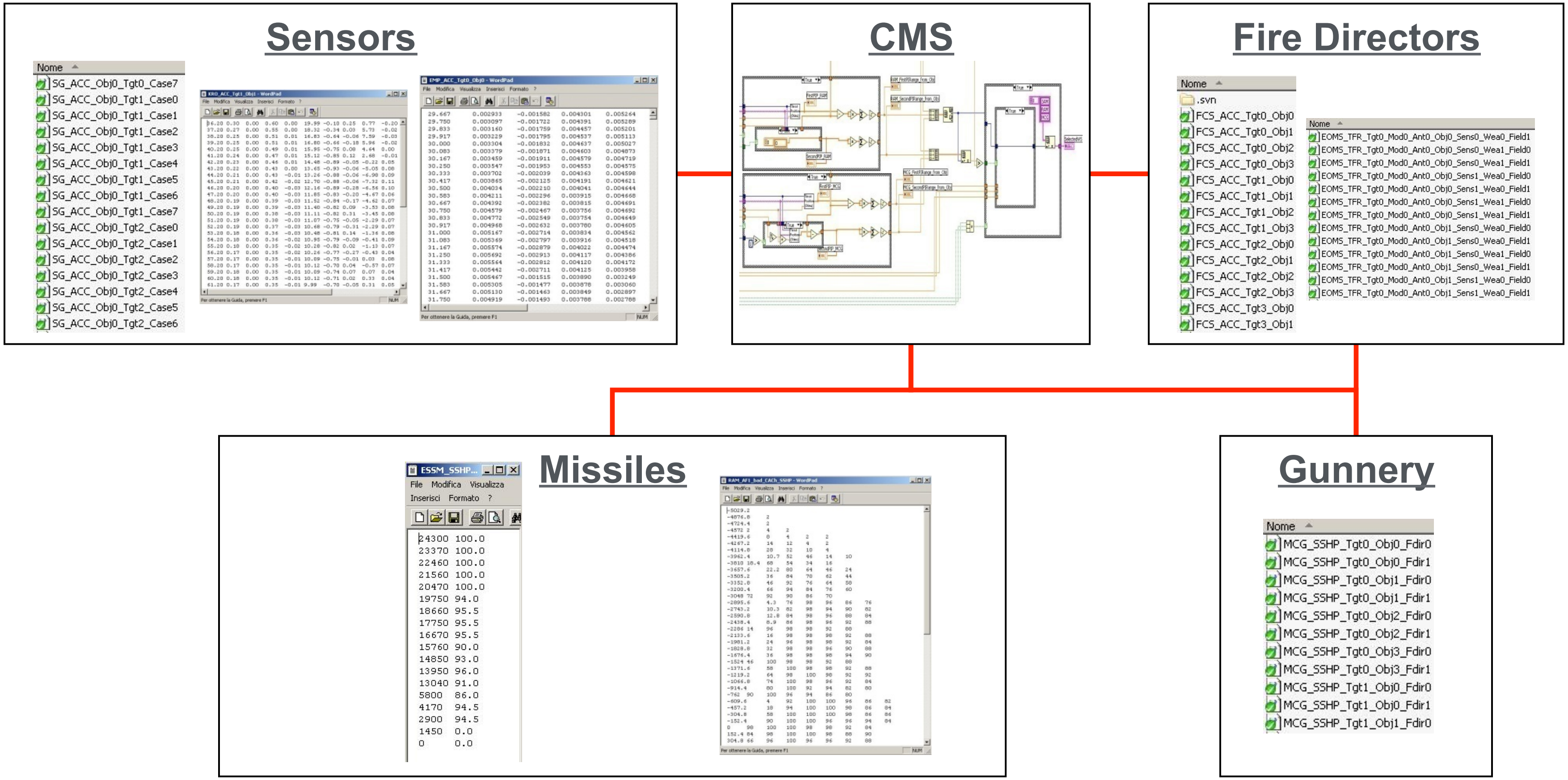
Naval C/S performances evaluation

<u>Sensor</u> modules, considering the multi-scale approach, are detailed through 'performance databases'. These databases are obtained from fine grain simulations directly linked in ICS-Sim. Standard sensor databases consist of following **parameters**: **Track Formation Range** (TFR) probability, angular and **range accuracies**, **speed accuracies and reaction times**, depending on threat characteristics, objective of the attack, weather conditions and their main 'operating modes'.

<u>Weapon</u> modules, in analogy with sensor modules, are detailed through 'performance databases'. They contain the relevant performance data of weapons on threat scenarios to be defined in reference. Standard weapon databases consist of following parameters: **Kill Probability (PK), Single Shot Hit Probability** (SSHP) depending on tracks characteristics, weather conditions and their main 'operating modes'. Several weapon systems include special software needed to determine the conditions for use of the weapons themselves (e.g. track attainability). ICS-Sim manage these special software as weapon sub-systems: if possible (consistent with the hardware requirements and the execution time) integrates SW directly.

Naval C/S performances evaluation

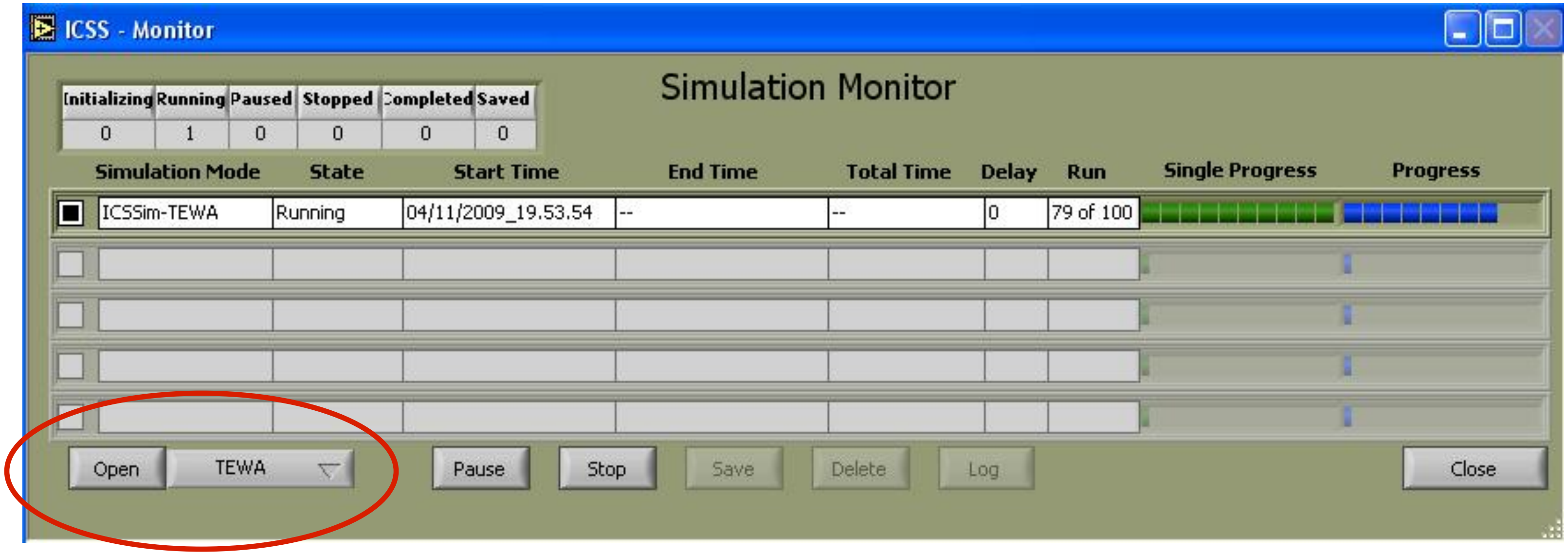
In ICS-Sim sensors and weapons are modeled through performance DB, whereas CMS models are detailed in all TEWA algorithms.



Performances results and system analisys

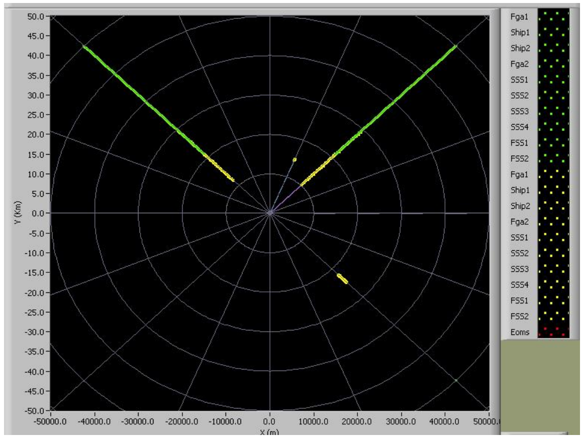
During test executions, ICS-Sim can present to analyzer some dynamical evolutions of operating scenarios. In the following figures some viewers are shown with explanation of analyzer points of interest.

Highlighted section of this panel (see figure) allows to select (dynamically open/close) all available viewers. ICS-Sim offers several points of view for naval combat systems analyst:



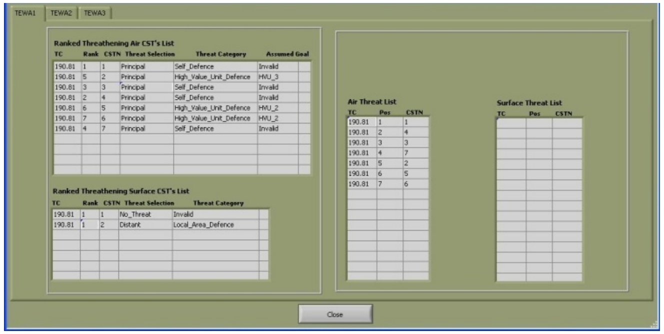
Performances results and system analisys

PPI (Planar position Indicator) dynamic viewer: indicates global tactical situation, showing all threatening targets and weapons in the scenario under test and their associated tracks.



CMS dynamic resources management viewer: indicates current status of each component of the combat system under test managed by the CMS.

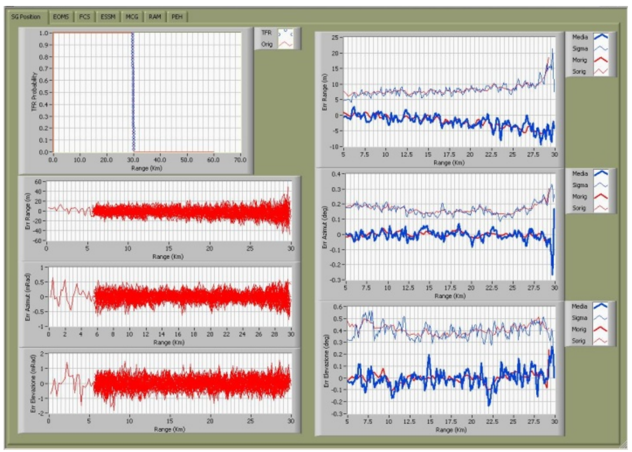
TEWA dynamic viewer: presents some tables related to relevant TEWA functions (e.g. selection and ranking process, tracks attainability computation).



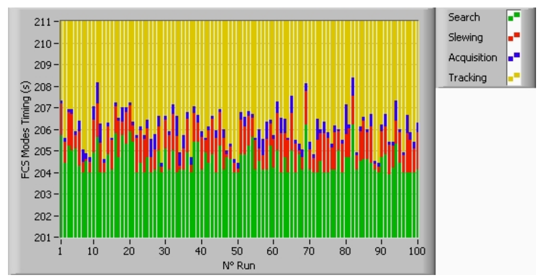
Statistical analisys

At the end of simulation execution, ICS-Sim presents **statistic results**, in numerical or graphical format, related to each system/sub-system component and to global combat system. Statistical analysis is a key capability to characterize naval combat systems and his components. In the following figures we show some typical data result from ICS-Sim statistical analysis features.

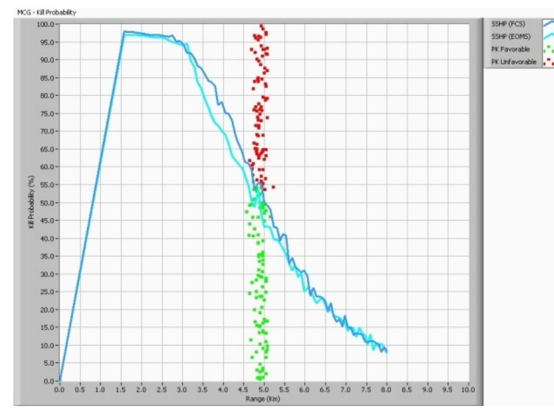
SURVR Performances



FCS Modes timing



Weapon Performances

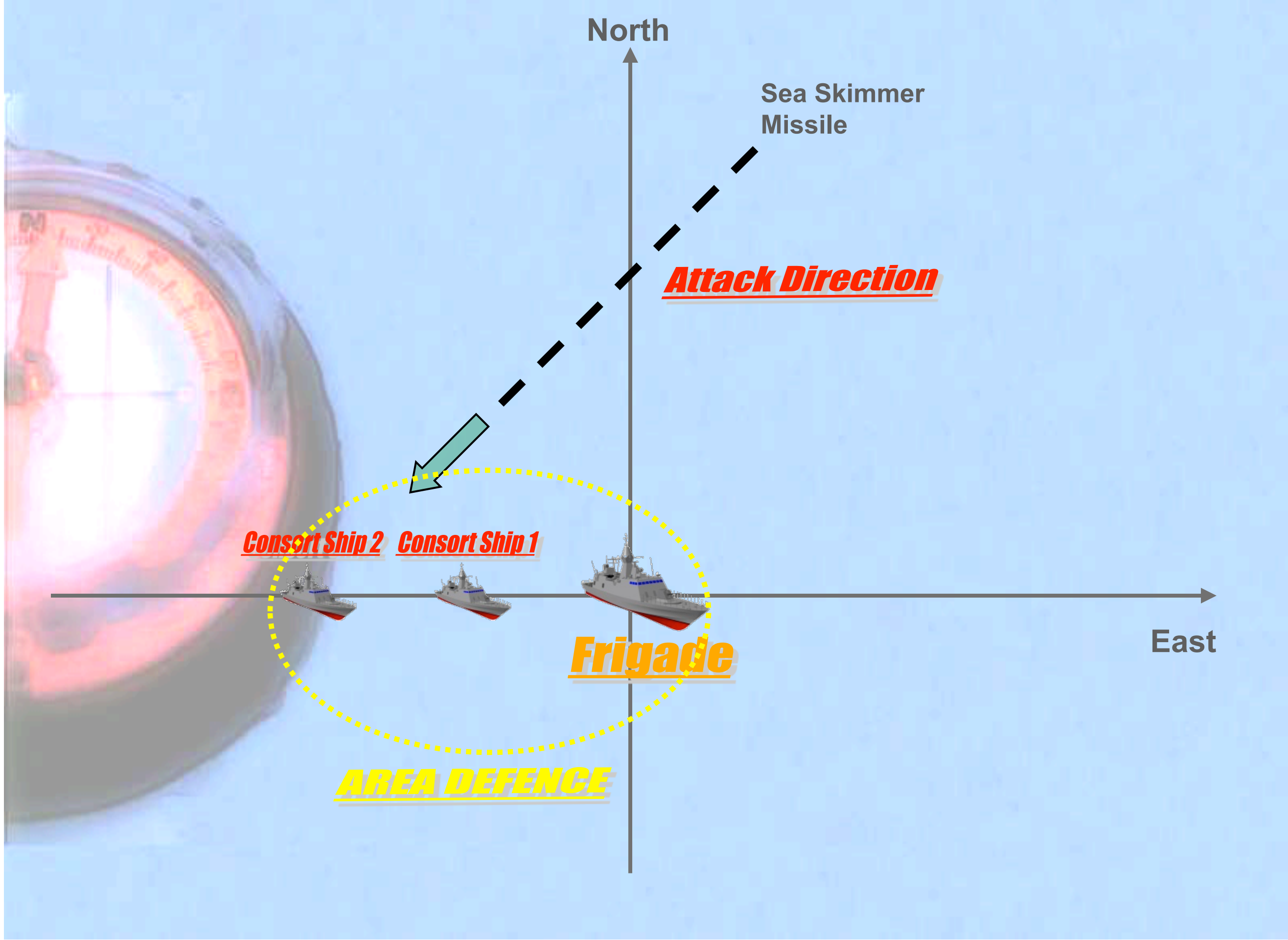


Overall PEH(%) Presentation

	PEH	PEH 1	PEH 2	PEH 3	PEH 4	PEH 5	PEH 6	PEH 7	PEH 8	PEH 9	PEH 10
OS	98.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HVU1	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HVU2	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HVU3	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CASE Study: Scenario

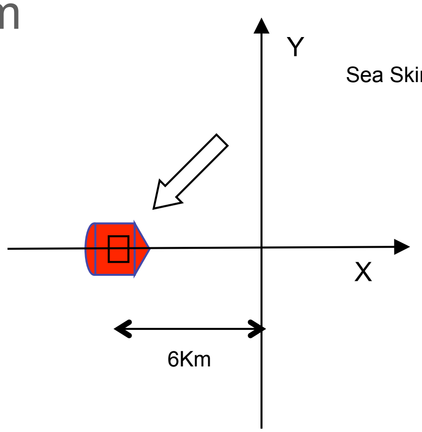
Performance comparison between two different Naval C/S configuration (named CS#1 e CS#2) on a operating LAD scenario:

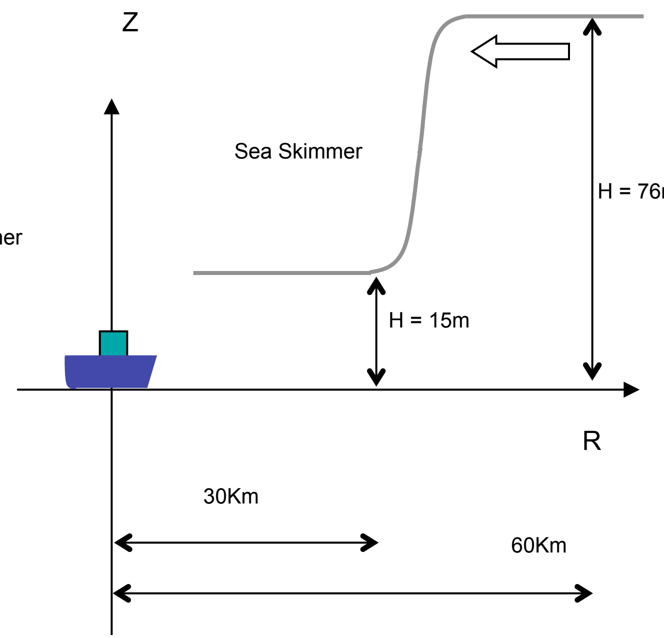


CASE Study: Technical view

Scenario OoO B1.2

Threat category:	Missile
Threat type:	SSS (Subsonic Sea Skimmer)
Objective:	High Value Unit 2 (HVU2)
Speed:	300 m/s
Height (a.s.l.):	76 - 15 m
Acceleration (g):	0
Coming from:	60 Km
RCS:	0.1 m^2
Optical Area:	0.1 m^2
Swerling:	3



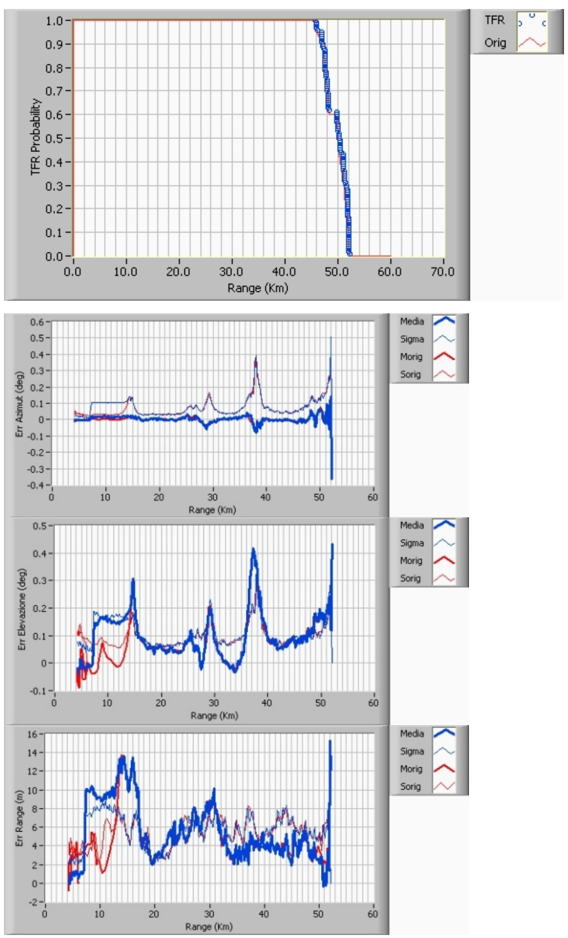


CASE Study: Results

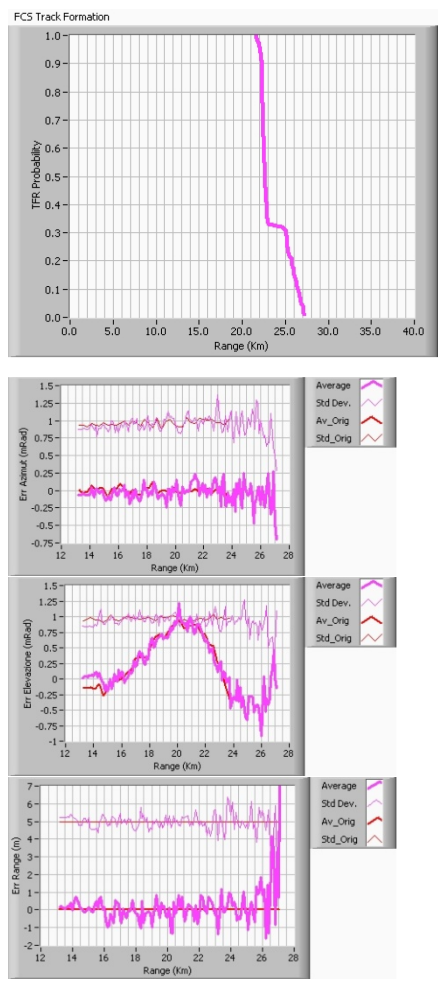
Scenario OoO B1.2 – CS #1

PEH = 61.98 %

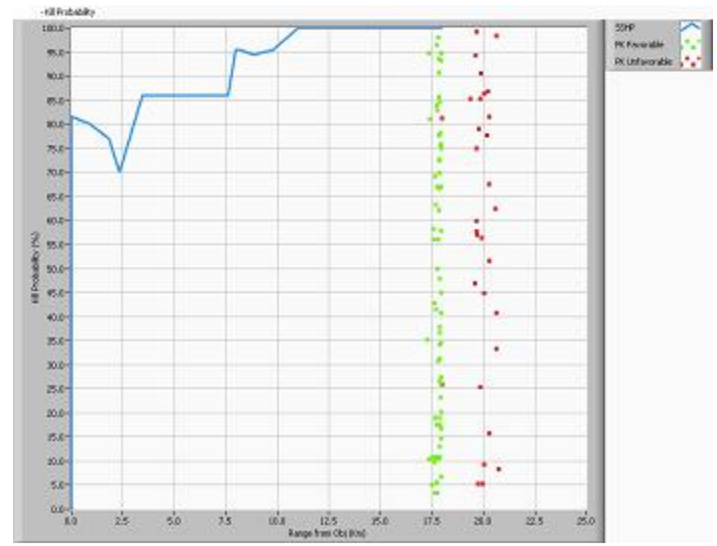
Surveillance Radar (Type1)



Fire Control System (Type1)



Weapon System (Type1)



Interception Range from OS

MAX	MIN	Average
26491.50	13714.92	15194.40

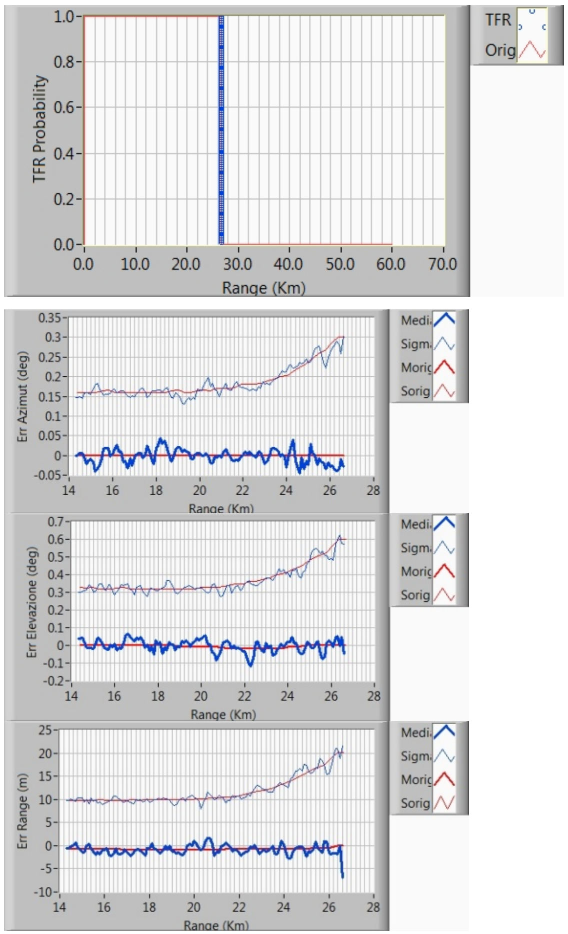
SURVR "Type 1" and CMS TEWA logics and functional chains involving Weapon System 1 cause a 'not enaugh efficient' interception performance.

CASE Study: Results

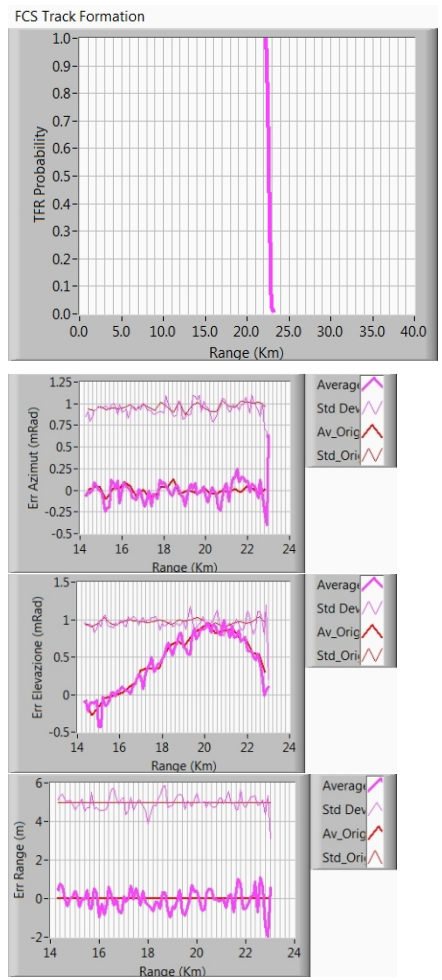
Scenario OoO B1.2 – CS #2

PEH = 94.96 %

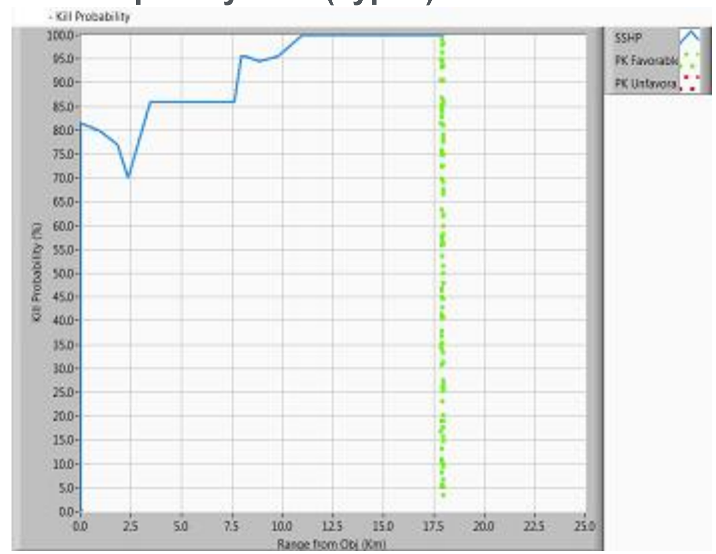
Surveillance Radar (Type2)



Fire Control System (Type1)



Weapon System (Type1)



Interception Range from OS

MAX	MIN	Average
14372.44	14257.86	14320.87

SURVR "Type 2" and CMS TEWA logics and functional chains involving Weapon System 1 allow a more efficient interception performance.

Seven essential ingredients of System Engineering:

- Lyfe Cicles
- Gates
- Requirements
- Perspectives
- Trade-Off Studies
- Modeling and Simulation
- Operational Effectiveness

System thinking: coping with 21st century problems, John Boardman, Brian Sauser, Taylor & Francis, 2008

Conclusions

- Structured Process and System Design Approach is mandatory to deal with SoS complexity;
- The Multi-Scale approach is a key method to determine SoS Measure of Effectiveness and Measure of Perfomance;
- Multi-scale method applied to evaluate naval combat systems performance had produced significant and useful results for industrial programs through the use of ICS-SIM.
- The approach, methods capabilities and tools constitutes an advanced application in systems engineering capabilities evaluation domain.
- Asses, evaluate, validate different System Configuration

Thank You…..

……any Questions?