Task Effectiveness Analysis inside S.E.S.T.AN.T.E. application

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ABSTRACT: Task Effectiveness Analysis (TEA) is a main component of Total Ship Systems Engineering. In this paper, documentation is given to the implementation of TEA within SESTANTE (Systems Engineering Ship Task ANalysis Toolbox Evaluation) application: a stand alone application, developed by Orizzonte Sistemi Navali (OSN); its goal is the estimation of the military vessel merit (MOE – Measure Of Effectiveness) for each naval task.
To achieve this result, OSN has conduct a modeling and operational naval analysis phase in order to define the models (Operations Research oriented) which allow the evaluation of the effectiveness of the ship (MOE) for the set of tasks.
In particular, this paper describes the S.E.S.T.AN.T.E. functional Diagram and the attention will be done to the description of the mathematical expressions used to represent a measure of the ship's capability to pursue its assigned tasks: Patrol without Helicopter, ESCORT, ASW-Area Search, ASW-channel patrol con BMS and TAS, Naval Surface Fire Support, ASuW.

Keywords: S.E.S.T.AN.T.E., MOE, Naval Task,

1. Introduction

Orizzonte Sistemi Navali (OSN) has the mission of designing and supplying integrated warships, and upgrading existing vessels.
In order to support the OSN Mission, the simulation area is developing a stand alone application, named S.E.S.T.AN.T.E (Systems Engineering Ship Task ANalysis Toolbox Evaluation), to estimate the Measure of Effectiveness (MOE) for each naval task.
Innovative ship design projects often require an extensive concept design phase to allow a wide range of potential solutions to be investigated, identifying which best suits the requirements. In these situations, the majority of ship design tools do not provide the best solution, limiting quick reconfiguration by focusing on detailed definition only.
The output of the S.E.S.T.AN.T.E application allows to make a comparison of alternative ship configurations in term of WholeWarShip(WWS) during the first ship design phase called "Early Stage Design".
For WholeWarShip it intends the WarShip more the performances; the WholeWarShip is composed by platform system integrated with the Combat System and the Combat System functionally integrated (sensors, communications, EWS and weapons).

2. S.E.S.T.AN.T.E. Description

The application allows to evaluate a configuration ship inside a different tasks, defining the following elements: Environment in which the ship operates, Threats, Sensor Ship parameters, weapons ship parameters, ship configuration parameters and mission parameters.

The main goal of the S.E.S.T.AN.T.E application is to evaluate the single MOE which characterizes each naval-task. In order to achieve this goal, the MOE for each naval-task has been defined how an analytic formulation composed by three main factors:

A - *Operational Availability(OA)*: the probability that a configuration ship operates satisfactorily when needed.
B - *Survivability(SUR):* the capability of a surface ship to avoid and/or withstand a man-made hostile environment while performing its mission.
C - *Tasks Effectiveness(TE):* the quantitative term that represents a measure of the ship's capability to pursue its assigned tasks.

The following is presented the expression which characterizes the MOE:

$$\mathbf{MOE = OA * SUR * TE} \qquad (1)$$

In brief, the Measure Of Effectiveness (MOE) for each operational naval-tasks depends directly proportional on "Operational Availability", "Survivability" and "Tasks Effectiveness".
First and second parameters are expressed with a percentage instead the third parameter represents the analytical formulation of the naval-task purpose.

it's important to notice that the formula introduces clearly a top down hierarchy to estimate the operational effectiveness measure in different scenarios. That top down hierarchy starts with the definition of three basis functions of a naval combatant, identified as **OPERATE**, **SURVIVE** and **SUSTAIN**: taking for granted that the SUSTAIN function includes the Operational Availability(OA) factor, likewise the SURVIVE function includes the Survivability factor, and the OPERATE function includes the capability to execute military missions and tasks so it includes Tasks Effectiveness factor.

3. S.E.S.T.AN.T.E. Functional Diagram

This chapter shows a Functional diagram that indicates the principal modules of S.E.S.T.AN.T.E application and the important relationships and interactions among them.

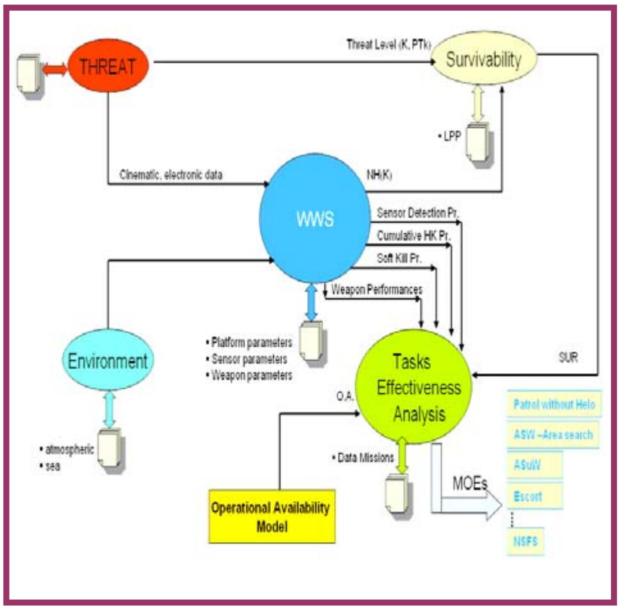

Fig 1: S.E.S.T.AN.T.E Functional Diagram

In detail, it's important to notice that S.E.S.T.AN.T.E. application is composed by five main modules which allows to configure all data used to evaluate the three factors used to compute the MOE for each tasks (see (1)).
The main S.E.S.T.AN.T.E modules are:

1. Environment
2. Threat
3. Survivability
4. WholeWarShip – WWS
5. Tasks Effectiveness Analysis

This paper concentrates the attention to the Tasks Effectiveness (TE).
For more details about others modules see the article proposed by OSN at the MAST Conference 2007.

Relatively to Tasks Effectiveness Analysis (TEA), the first release of the S.E.S.T.AN.T.E application analyses these tasks Patrol without Helicopter, ASW-Channel patrol with BMS and TAS, ASW-Area Search, ASuW and NSFS.

This paper continues detailing the naval-task which the first release of S.E.S.T.AN.T.E allows to analyse. For each task, it is given an analysis in term of "*Description task*" and "*Task analysis*".

3.1 Patrol without Helicopter

Description task: It means to control a defined operational area during a given period of time. The task could be relevant in peacetime, crisis and also during combat operations.

The period of time represents the duration of the mission and it's indicated by TM. The operational area is situated at the distance DA from the refuelling zone.

Task analyisis:

Thanks to the WWS module of S.E.S.T.AN.T.E, it's possible to setup the parameters that characterize the configuration ship in term of Endurance (RP), Cruise speed (VC) e Sensor Detection Range (WS)

Fig. 2: Patrol without Helicopter

Considering these input, it's possible to define the surveyed area as follows:

$$TSA = WS * VC * TS \qquad (2)$$

where TS term represents the time effectively spent by the ship in order to conduct their mission.

$$TS = TM - (INT[NS] + 1) * 2\frac{DA}{VC} \qquad (3)$$

In (3) NS is the number of times in which the ship has to leave the operation area and reach the refuelling zone**,** NS is calculated as follows:

$$NS = \frac{TM * VC}{RP * FUF} \qquad (4)$$

Taking in account also the others two parameters (OA and SUR) which depends on the outputs of the operational availability and the survivability analysis, S.E.S.TAN.T.E. application calculates the MOE for this task.

3.2 ASW - Channel Patrol with BMS and TAS

Description task: The Frigate patrols a barrier that delimits a Stationary Naval Force.

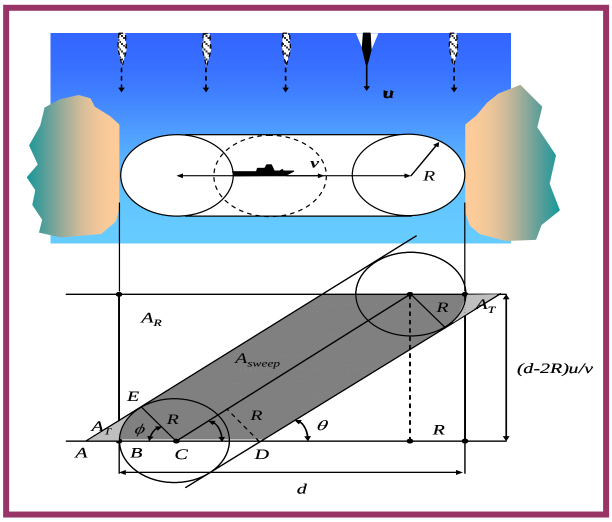

Fig. 3: Geometry of the "Channel Patrol Task" Scenario

Task analysis:

The Model, shown in Fig. 3, evaluates the Probability of detecting a conventional submarine in a well limited channel area (Barrier). The search area is delimited by the radius R that defines the Sonar Detection Range. The evaluation of the task is based on the Linear Patrol Model which evaluates the Detection Probability (P_d) of a submarine trying to cross over the frigate patrolled zone.

In order to describe the MOE for this task, it's necessary to observe the second previous second figure representing the geometry of the task considered: in this case, the task effectiveness (TE) is defined by the detection probability (Pd).

The Detection Probability is calculated as ratio of “Grey Area” and “Yellow Shadow Rectangular Area”

Main data considered for this task are: the extension of the channel (d), the torpedo speed (u), the ship speed (v) and the sensor detection range (R).
With the geometric consideration, the Pd can be expressed as follows indicated:

$$P_d = \frac{2R}{d}\sqrt{1+\frac{v^2}{u^2}} - \frac{R^2}{d(d-2R)}\left(\frac{v}{u}\right)^2 + \frac{R^2\phi}{d(d-2R)}\left(\frac{v}{u}\right) \quad (5)$$

Area total: $$A = \frac{u(d-2R)}{v} * d \quad (6)$$

Area_sweeped: $$A_{swapped} = A_p - 2A_{ext} \quad (7)$$

$$A_p = \frac{2Ru(d-2R)}{vsen\ \theta} = \frac{2Ru(d-2R)}{v}\sqrt{1+\frac{v^2}{u^2}}$$

$$A_{swapped} = \frac{2Ru(d-2R)}{v}\sqrt{1+\frac{v^2}{u^2}} - R^2\left(\frac{v}{u} - \phi\right)$$

3.3 ASW – area search

Description task: It relative to the control of a given area.

Fig. 4: Area Search Mission

Task analysis:
The search area is delimited by the radius R that defines the Sonar Detection Range.
In order to evaluate the MOE for this task, we propose to consider these four data information: Sonar Detection Range (R), Silence Fregate Speed (V), Time Search (T), operational area (A).
These data can be considered inside the Cumulative Search Probability, as following indicated:

$$CDP = 1 - e^{\frac{-2 \cdot R \cdot V \cdot T}{A}} \quad (8)$$

3.4 ASW - Channel Patrol with Helicopter

Description task: It relative to the control of the channel using helicopters.

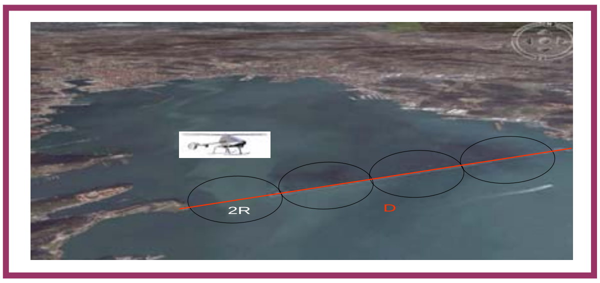

Fig. 5: ASW – Channel Patrol with Helicopter

Task analysis:
The MOE for this task is express how the helicopter search and patrol probability (Pd).
The analysis starts considering the number of cycle generated by the helicopter inside the operational area (shadow area in the figure):

$$n = \frac{d}{2*R} \quad (9)$$

where: *d* indicates the Barrier length

If the analysis is performed studying the relative movement of the submarine, it’s possible to consider the Pd as ratio of “Blue Area” and “Yellow Shadow Rectangular Area”:

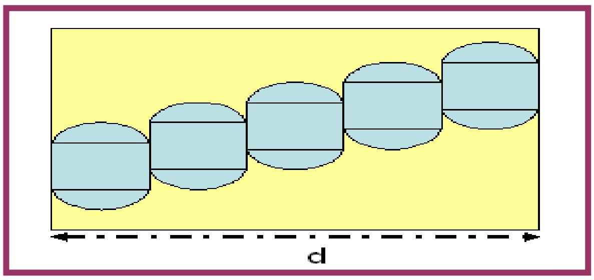

Fig. 6: Geometric Task

$$P_d = \frac{BlueArea}{YellowArea} = \frac{(2R * u * Tdp + \pi R^2) * n}{d * u * (2 * \frac{R}{V} + Tdp) * n} \quad (10)$$

where:

Tdp duration dipping sonar, *u* summarine speed and *V* helicopter s, d channel, *R* tactical search distance for helicopter radar.

3.5 ASuW

Description task: The objective of this task is the denial of surface units to come into a position to inflict damage to the units to be protected. This means in essence the neutralization of threatening surface units if use of own weapons is authorized. Since in most situations combatants must be prepared to fight in a multi-threat environment, this task has also to be coordinated with those of other warfare areas (AAW, ASW).

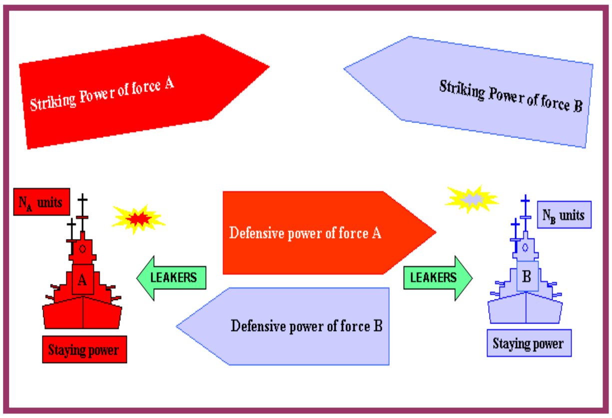

Fig. 7: ASuW Mission

Task analysis:

The model, shown in Fig. 7, deals with the Naval Surface Missilistic Combat between two fleets in open sea and gives an average evaluation of the Fractional Exchange Ratio (FER) i.e. the ratio between the percentage of fleet reduced from both sides considering the offensive/defensive capabilities of the fleets (Hughes, 1994).

A = Number of units in force A
B = Number of units in force B
α = Nr. of well-aimed missiles fired by each A unit
β = Nr. of well-aimed missiles fired by each B unit
a1 = number of hits by B's missiles needed to put one A out of action
b1 = number of hits by A's missiles needed to put one B out of action
a3 = number of well-aimed missiles destroyed by each A
b3 = number of well-aimed missiles destroyed by each B

Using these data defined by user, the analysis starts to define the number of units in force A out action from B's salvo (ΔA) and the number of units in force B out action from A's salvo (ΔB), as indicated:

$$\Delta A = \frac{\beta B - a_3 A}{a_1} \qquad \Delta B = \frac{\alpha A - b_3 B}{b_1} \qquad (9)$$

We proposed to indicate the MOE AsuW with the term called Fractional Exchange Ratio (FER) that can be expressed like:

$$FER = \frac{\Delta B / B}{\Delta A / A} \qquad (10)$$

It compares the fraction of two equal-cost forces destroyed by the other under the supposition that they exchange salvos. When FER is greater than 1, side A has reduced B by a greater fraction than B has reduced A.

First release of the application described in this paper implements that analysis but it could be extended in a stochastic ASuW Model: this model could evaluate the results of one or more salvo exchanges between two naval forces:

1. in the model a discrete number of missiles are fired at each unit. A random distribution is used to determine whether or not the shot will be effective.
2. Effective missiles are randomly assigned to each unit of the opposing force
3. Each opposing unit can counter only a limited number of missiles, each one will a defense effectiveness, which allows a random selection to determine whether or not attacking missile will be neutralized.
4. The unit status is determined by taking the difference between the number of missiles fired at the unit and the number of missiles that the unit can defend against and then dividing that number by the number of missiles that the unit can absorb before becoming out of action.

3.5 NSFS - Naval Surface Fire Support

Description task: This task is an element within the framework of the traditional principal naval mission area power projection. It is a kind of shore bombardment to neutralize those stationary and mobile targets

which are threatening the respective operation.
The objective of this task is the neutralization of land targets and requires long range, level of effort and threat oriented weapons.

Task analysis:
The MOE for this task would be the probability of damaging a target with a number (N) of shots.
In particular, the TE for this task can be indicated as the following indicated:

$$PKnsfnN = 1 - (PKnsfn\_1)^N$$

where PKnsfn_1 represents the probability of damaging with a single shot. As indicated in literature [5] this probability is expressed in terms of

$$PKnsfn\_1 = 1 - e^{\frac{-Rd^2}{2\sigma^2}}$$

inserting the term of the circular error probable (CEP), which is defined to be the radius of the circle, centered on the target, within impact 50% of the rounds, it's possible to obtain:

$$PKnsfn\_1 = 1 - e^{\ln(1/2)\frac{-R^2{}_d}{CEP^2}}$$

4. Conclusions

This approach provides a practical method for the ship designer to calculate all MOE associated to single tasks and to support the Overall Measure of Effectiveness (OMOE) evaluation using the analytical hierarchical process (A.H.P.).

In the next future, essential work is represented by:

- Integrate in S.E.S.T.AN.T.E a completed ship design database.
- Integrate a database of existing product in order to can realize the comparison between a new ship design with a old ship design.
- Insert a geographical map scenario in which the user can decide dynamically own tasks. The optimum could be achieved giving to user the facility modifying the formula to calculate the MOE for the defined mission.
- Insert a geographical map scenario with associated a coherent environment information.
- Extend the description of other tasks in particular the ones classified as MOOTW.

5. Acronyms

AAW	Anti Air Warfare
A.H.P.	Analytical Hierarchical Process
ASW	Anti Submarine Warfare
ASuW	Anti Surface Warfare
BMS	Bow Mounted Sonar
MOE	Measure Of Effectiveness
MOOTW	Military Operation Other Then War
NSFS	Naval Surface Fire Support
OA	Operational Availability
OMOE	Overall Measure of Effectiveness
O.S.N.	Orizzonte Sistemi Navali S.p.A
SAM	Surface Air Missile
TE	Task Effectiveness
WWS	Whole War Ship

6. References

[1]. P. Neri, N. Dazzi, S. Traverso, M. Mangiarotti, M. Cirillo, *Orizzonte Sistemi Navali S.p.A.* - *"Total Ship design Approach"*, INCOSE 2004

[2]. M.Dazzi and M.Mangiarotti, Orizzonte Sistemi Navali S.p.A
G.Caprino and E.Pino CE.TE.NA. S.p.A "*Optimisation of operational performance at the preliminary design stage*", MAST Conference-Nice 2006

[3]. Rains, Dean A. – *"Fleet Mix Mission Effectiveness Analysis"* , Naval Engineers Journal, January 1999

[4]. Knut Rief Armo – *"The relationship between a submarine's maximum speed and its evasive capability"*, Naval Postgraduate School, January 2000

[5]. D. Wagner, C. Mylander, T.Sanders – *"Naval Operations Analysis"*, third edition, Dpt. of Mathematics, U.S. Naval Academy

[6]. F.Perra, N. Dazzi – Orizzonte Sistemi Navali S.p.A – "*System Component Integrated Requirements Evaluation: S.C.I.R.E.*", MAST- Conference, Genoa2007

Author Biographies

NATALINO DAZZI graduated in Electronic Engineering in 1973
His activity mostly in defense industry and related to simulation models of weapons systems ad Operations Research study related to military effectiveness.
He joined Orizzonte Sistemi Navali in 2001 and since then his activity has been related to Total Ship Systems Engineering.

ALDO GUAGNANO graduated in Electronic Engineering in 2002 at the University of Genova, discussing a Degree Thesis entitled "Automatical Speech recognition based on DSP Motorola ".
At present he works for Orizzonte Sistemi Navali S.p.A. – System Simulation Warship Architecture – and he is developing some tasks using HLA.

FRANCESCO PERRA graduated in Electronic Engineering in 1994 at the University of Genoa. He has been working for Orizzonte Sistemi Navali S.p.A since 2001 where he works in simulation group. He has contributed to the developed the VISION Scenario simulator and actually he's defining all specifications for a new tool, named S.E.S.T.AN.T.E (Systems Engineering Ship Task ANalysis Toolbox Evaluation) in order to analyze the ship's task capabilities