Vessel Management Simulation

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ABSTRACT

The present paper deals with the problem of estimating vessel performance during early phase of their development by proposing an innovative methodology. The approach involves the correlation of historical data for getting reference data to be used with hypotheses on new systems by reverse engineering techniques based on Genetic Algorithms, for estimating the new ship component characteristics.
The simulator is used dynamically during this process and for evaluating new scenarios in term of cost and benefits of different design solutions, operative modes or general policies.

INTRODUCTION

Vessels represent a very complex system involving many inter-relations among different objects. Usually, during early phase of ship design, special analysis are carried out by traditional techniques for evaluating efficiency, effectiveness as well as costs and other performance factors.
In fact, the main problem is related to the fact that when a new vessel program starts very few information are available on the performances of its components; at the same the operative profile is often very general and few details concerning the expected scenarios are available. This problem is present in cargo, passenger and military ship, however the impact of these cost analysis is different among different sectors due to the dynamic evolution of the specific area as summarized in table I.

Table I - Critical Issues in Program

	Cargo Ships	Cruise Ships	Military Ships	Aircraft Carriers
Details on Operative Profiles and Scenarios	Good	Good	Average	Average
Systems and Subsystems Details	Good	Average	Low	Low
Number of Units/Class	High	Medium/Low	Low	Very Low
R&D Challenges	Low	High	Very High	Very High

Obviously, these aspects represent for military vessels a big challenge, as well as critical factors. In fact, along the program development these requirements continuously change due to many different reasons, including especially budget availability, international political situation, joint ventures, experience on operative policies and new concepts. For instance, due to this some of factors, in the last years ASW capabilities (Anti-Submarine Warfare capabilities) was often dropped as requirements in favor of Command and Control.
So while the details of the new vessel program are not available, very strategic decisions are required in term of budget allocation on the different ship systems and plants as well as definition of operation modes.
This paper proposes an approach for dealing with these aspects by using simulation as core engine for definition of critical relations and investigation of the new scenarios. In this research, the very challenging case a vessel is used as validation example for the proposed methodology. An aircraft carrier, CV, represents a very particular case of ship, usually produced in very limited number and involving very complex inter relations among the components, not only ship plants/systems and subsystems, but even wing components that have their own operation procedures and requirements.

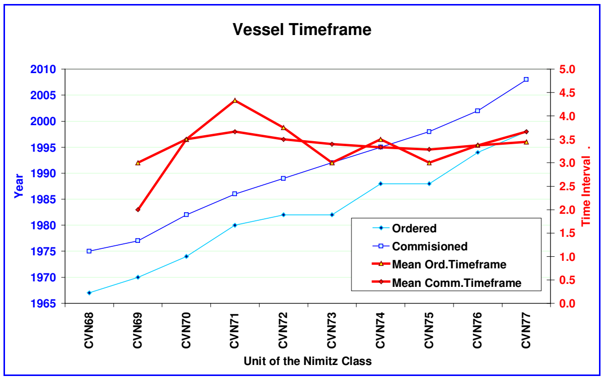

Figure 1 - Delivery of CV Units for a single Class

VESSEL PROGRAM CRITICAL ISSUES

Nowadays, the development of a new vessel requires from the beginning to deal not only with nautical architecture, classical design and acquisition cost, but to move forward to integrate as much as possible the whole ship life cycle analysis in order to guarantee high level of availability and efficiency with convenient costs.
In this paper the authors focused on military ships, using as case study for testing proposed analysis methodologies a program for a new aircraft carrier.
It is important to state that the proposed considerations are often valid also for cargo ships and for many other complex systems as well, while probably some aspects result less critical.
In military context, the proposed CV case is very critical, in fact CVs is usually produced as a single new unique prototype and normally even USA units (the only country currently producing more than one unit/class) have a very high degree of customization, due the long time interval between two deliveries respect technology advances and mission profile evolution. The main critical aspects in this context include:

- Research & Development: most of the ship plants and systems are based on innovation and developments, often including critical systems to be concurrently developed ad hoc for the new vessel (i.e. a new 3D Radar developed for a new destroyer)
- Mission Profile: the mission profile is often the motivation for launching a new vessel, however this profile is rarely detailed and in several cases it continuously evolves, sometime including radical changes
- Overall Performance Expectations: these performances requirements are usually vague from quantitative point of view during early phase of the program
- System Performances: the performances of the different ship systems is pretty unknown in advance, due to the fact that even if the system is not new, usually each new vessel involves strong tailoring and special solutions. In addition normally due to the technology advance, all the strategic components (i.e. engine, radar, weapon systems) are pretty new.
- System Interaction: the overall efficiency and effectiveness strongly depend on combination of different ship plants, systems and subsystems.
- System Reliability and Maintenance Programs: these aspects strongly affect the ship availability and operative efficiency as well as costs.
- Historical Data: usually the data are not easily available for many reasons, including their reliability and not homogenous measurement procedures. Also, the suppliers don't share most of the related information about their system for commercial competitiveness reasons.

In addition to this factors, with the exception of USA, military vessels are normally produced in very limited numbers; even new classes of frigates (NATO multinational programs) usually result to very heavily customized for each country with exception of ship structures.
Moving to Carriers it is common to produce one single unit for each new carrier class over a time period of about 20 years; even USA case demonstrates that for the NIMITZ class CVN (Nuclear Aircraft Carrier) the total number of units (10) is distributed over a timeframe of 30 years (the distribution is summarized in figure 1).
The mean time between two commissioning is 3.5 years, with a minimum value of 3 year and maximum of 6. This context highlights the necessity to have some models to be used for estimating the overall performances as well as the corresponding costs in order to properly design infrastructures, services and operating policies.
Figure 2 presents an analysis carried out by the authors, such an analysis is based on quantitative cost distribution estimation from experts in relation to a Carrier Life Cycle.
It results evident the predominance of operative costs and the necessity to develop analysis models.

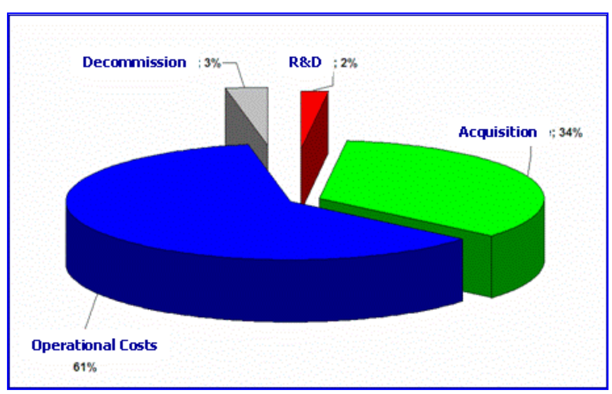

Figure 2 - Carrier Costs over its Life Cycle

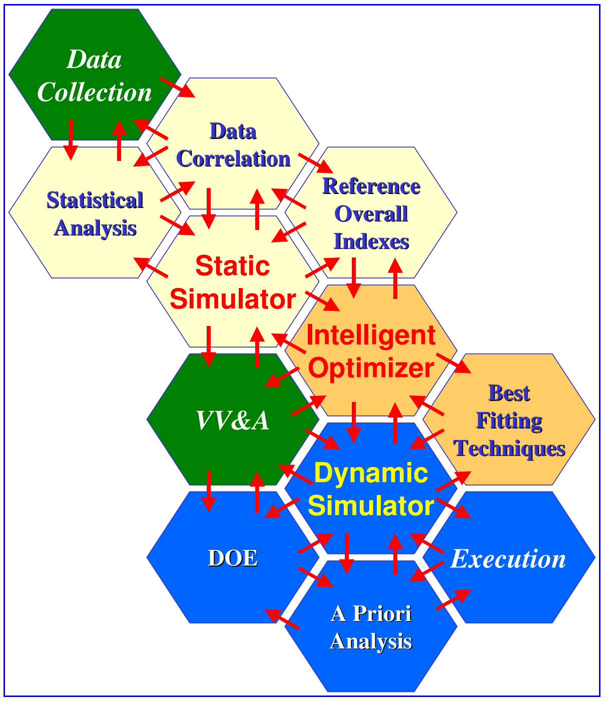

Figure 3 - Methodological Approach

LEAN SIMULATION AS DEVELOPMENT PLATFORM

In this context the innovative M&S (Modeling & Simulation) approach based on Lean Simulation is a very important pillar to succeed; in fact the limited number of reliable data requires to develop models affected by high uncertainty, while the continuously changing of the boundary conditions requires quick and efficient model development times.

In fact, Lean Simulation is devoted to define specific customized techniques for model development and implementation. Traditionally one of main obstacle in optimizing product design is the use of quantitative methods during early development phase, because M&S tools are usually data intensive.

However Lean Simulation expect to use existing expertise in the different fields of M&S in order to develop Compact Simulation Units (CSU); these entities are based on small teams, equipped with specific tools that apply special protocols, tailored on the application area of interest, in order to guarantee a quick and successful development of simulation.

In particular Lean Simulation deals especially with two kind of problems: optimization projects in SME (Small and Medium Enterprises) and ESE (Early Stage Evaluation) in large programs.

The basic idea is that it is possible to develop lean simulators for specific industrial cases that can operate based on a very reduced data set providing at the same time meaningful and reliable results; obviously in this case the data are affected by large confidence band; however a systematic application of DOE (design of experiments) solution tailored for the specific case could guarantee that the result reliability is under control. In this case it is possible to apply techniques that guarantee that they are compliant with the requirements of the new vessel project, even if the simulation estimations result not so precise due to the large uncertainty about the input data.

THE PROPOSED METHODOLOGY

In this case, the proposed approach is modular, in other words is based on a dynamic evolution of the model devoted to reach the proper parameter configuration to complete an a priori analysis as proposed in figure 3.

The idea consider to apply the following conceptual procedure:

- Collection of historical data of ship and systems corresponding to the new vessel design by using a Static Simulator (SS).
- Statistical estimations based on the historical data for identifying conceptual models correlating input and output parameters for each general performance index of the new vessel
- Development of a detailed Dynamic Simulator (DS) based on the conceptual models
- Best fit of the detailed parameters of each ship system/subsystem using the dynamic simulator and an intelligent optimizer in order to converge on the overall performance estimated for the new program
- Extensive validation and testing in order to finalize the dynamic and static simulator settings and properly estimation of the related fidelity levels
- Dynamic Simulation Execution and Experimental Analysis for an a priori evaluation of new scenarios and hypotheses.

The authors had several previous experience in ship design and project management and select this process in order to maximize the possibility to reuse and readapt pre-existing models (i.e. fast ferries, support ship, frigates, destroyers etc.).

In this study, the case of a new Italian aircraft Carrier is proposed; for such a case the authors identified a general architecture to be used for proceeding in the model identification, parameter best fitting and scenario analysis as proposed in figure 4.

Three main components are identified for this case:

- Static Simulator
- Dynamic Simulator
- Intelligent Best Fitting System (IBFS)

Concerning the aircraft carrier, the authors had the opportunity to use different public domain releases derived from solutions developed by DIPTEM, Liophant and DIP (Development of Innovative Project Consortium).

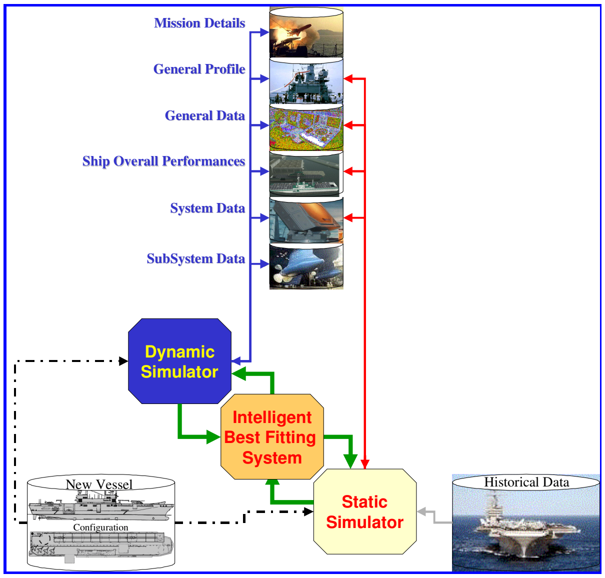

Figure 4 - General Architecture

In fact the two solution sets are based on the following projects:

ACASO
Advanced Carrier Acquisition and Operation cost Simulation & Optimization
ACASO is a system for design new Vessel by simulating their performances in relation to their operative profiles and maintenance policies. The system estimates the unknown characteristics of the new Vessel Systems by applying advanced AI techniques (genetic algorithms) and evaluating different hypotheses and scenarios

CALYPSO
Carrier Life cYcle Period Simulation & Optimization
CALYPSO project investigates methodologies and techniques devoted to analyze the Life Cycle of the New Italian Carrier Cavour. CALYPSO included development of Tools for comparing costs, operations and performances of different Carriers

The authors used these two systems as basis for developing a specific not-classified system to be used for validating the proposed approach on public model and freely available data.
The main goal of this research it is to estimated on different vessel configurations and in correspondence to different scenarios the expected availability level, overall cost and effectiveness; so by this approach it is possible to analyze different alternatives in term of robustness and cost/benefits. Respect traditional SBDVP (Simulation Based Design and Virtual Prototyping) this approach includes a solution for evaluating impact of the operative range and performance parameters related to new systems to be used on the vessel.

THE STATIC SIMULATOR

The statistical model is devoted to investigate historical data for identify models and define a parameter correlation for each overall performance index; some of the identified performance indexes are summarized as follows:

- Vessel Overall Cost
  - Ship Overall Cost
    - Ship R&D Costs
    - Ship Acquisition Costs
    - Ship Operative Costs
      - Fuel Cost
      - Bunker Trading
      - Personnel Cost
      - Training
      - Other Costs
      - Maintenance Costs
    - Ship Decommissioning Costs
  - Wing Component Overall Cost
    - Wing Component Acquisition Costs
    - Wing Component Operative Costs
    - Wing Component Decommissioning Costs

- Vessel Overall Availability

- Vessel Profile
  - Down for Maintenance
    - Planned Maintenance
      - SMP Short Maintenance Plan
      - GM General Maintenance
    - Unplanned Maintenance
  - Operative on Port
  - Operative at Sea
  - Exercise
  - Real Operation

The static simulator correlates different parameters in relation to different vessels for estimating new vessel performance based on modeler hypotheses:

$$TF_{new} = \frac{\sum_{j=1}^{n}\sum_{r=1}^{k} TF_j \cdot \left(\frac{r_{New}}{r_J}\right)^{M_{r,j}} \cdot ia_{r_j} \cdot Cf_{r_j} \cdot Sm(r_j) \cdot DA(TF_j) \cdot DA(r_j)}{\sum_{j=1}^{n}\sum_{r=1}^{k} Sm(r_j) \cdot DA(TF_j) \cdot DA(r_j)}$$

TF_h	H-th target function (i.e. fuel cost or maintenance costs)
new	New vessel characteristic
n	Number of ship data included in the dbase
k	Number of parameters used
r	Parameter be used for the correlation based on modeler evaluation (i.e. sailing duration expressed as miles/year or displacement)

r_j — value of the r-th parameter for -th ship

ia_{rj} — actualization factor for a specific parameter of a specific ship: i.e. for fuel cost correlation between oil cost in timeframe from original historical data and current oil cost for new vessel timeframe

$Sm(r_j)$ — Selection Function (1 for parameters of a ship selected for the correlation and 0 for other ones).

Cf_{rj} — Comparison factor for r-th parameter of j-th ship (i.e. nuclear carrier vs conventional)

DA(H) — Data Availability (1 if the data is available, 0 otherwise) for H-th target functions

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In case of cost estimation it is critical to properly evaluate the ia_r parameter considering the following components:

- Currency Used for conversion in reference currency
- Financial Year values for actualization of Currency
- Reference Material Cost Evolution over year

Considering fuel consumption for instance a relation as the following can be used for actualization

$$ia_{rj} = \int_{to_i}^{to_f} R_{Rcur,Acur}(t)dt \cdot \frac{\int_{ta_i}^{ta_f} RMP(t)dt}{\int_{to_i}^{to_f} RMP(t)dt} \cdot (1+j)^{(ta-to)}$$

$R_{Rcur,Acur}$ — conversion rate between reference currency and currency of the available data at t time

t — time expressed in years

to_i — original initial time of the available data timeframe

to_f — original initial time of the available data timeframe

ta_i — initial time of the new vessel timeframe to be used for actualization

ta_i — final time of the new vessel timeframe to be used for actualization

RMP — raw material price at t time

j — inflation rate

The above mentioned relation is usually simplified operating on average rate available for old years if the historical data can be attributed to a specific year:

$$ia_{rj} = \frac{R_{Rcur,Acur}(to)}{RMP(to)} RMP(ta) \cdot (1+j)^{(ta-to)}$$

Concerning fuel consumption of conventional carrier oil market price can be used as RMP; in fact for this parameter oil could be a significant reference value for correcting the estimation.

Therefore it is very critical to check this aspects and their effective impact for each case by detailed analysis; in our vessel case for instance it resulted that steel market price affects in very low percentage the overall acquisition cost of the ship (even if we refer to large military units).

Obviously for CV this phenomena is justified by the predominance of weapon systems and equipment on acquisition costs.

DYNAMIC SIMULATOR

In order to evaluate more detailed missions as well as influence of vessel systems and sub-systems it becomes necessary to move forward to create a dynamic simulator able to reproduce ship operative profiles as well as ship plants operations.

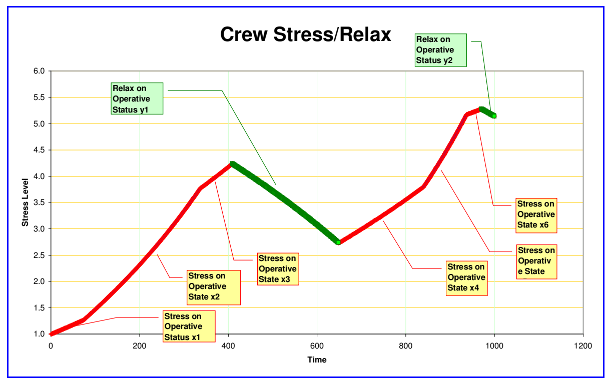

Figure 5 - Psychological Modifier Evolves based on their status, trend and ship operative Condition

The authors developed a stochastic discrete event simulator where ship components are modeled by hierarchical objects; by this approach it is possible to explode each single ship plant (i.e. engine system) in its elements by creating multi-layers corresponding to different detail level.

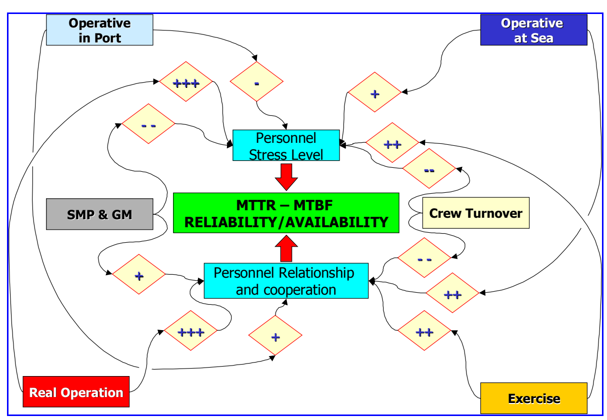

Figure 6 - Dynamic Model involving Human Factors affecting Ship Operations

As stochastic factors affecting the model was identified:

- changes in operative profile
- failures and breakdown both in term of:
    - time intervals
    - impact on the overall efficiency
- duration of maintenance operation
- cost of maintenance operation
- crew behavior

Due to the fact that most of this parameters need to be estimated by experts, beta distribution was extensively used for modeling stochastic entities.

It is interesting to focus on the crew; in fact it represents a very critical component of the ship; in this case the authors were interested in modeling this entity in order to estimate the impact of different operative profiles on the overall ship performance.

For properly simulating the crew in this case it was applied a special methodology developed by the authors for human behavior modeling that highlights the best ratio between cost/benefits by a ranking list. This method data availability, fidelity improvement, impact on target function are key factors; by this approach it resulted critical to emphasize two different psychological modifiers: stress and harmony.

The impact of these two phenomena on the crew has been defined in order to represent the evolution in its capabilities in relation to ship operative status and its history: for instance, as much as the crew is acting in real operations as much its stress level increases; therefore the relation for this increase correspond to a special trend that properly model psychological aspects such habits, limit points, etc.

These trends corresponds to the curves represented in figure 5 including the hysteresis due to the different behavior corresponding to stressing and relaxing the crew.

The psychological modifiers affect the efficiency of the ship in term of operation and maintenance with different impact on sea operation respect port.

In figure 6 it is proposed the dynamic model introduced in the stochastic discrete event simulator for crew psychological modifiers (including the effect of crew turnover).

The other very critical component in this simulation is represented by ship systems and sub-systems and their reliability; in this case the authors paied special attention on modeling their mutual influence on vessel performances as well as their maintenance activities, including planned and unplanned maintenance in different conditions (i.e. at sea, in real operation, at port, during general maintenance at port basin, etc.).

As already anticipated, the critical aspect related to these components it is that in most of the cases they refer to new, not even existing systems, where very few data are available. In this case the initial setting of the parameters is based on similarities with corresponding old equipment and/or expert estimation; for final setting the Intelligent Best Fitting System (IBFS) is used in combination with the simulator.

Therefore, in the present study, for each ship system/subsystem/component it was defined a set of variables including among the others:

- Current status in term of level of efficiency
- Impact factor on each target function
- Mean time between failures (MTBF)
- Mean time to repair (MTTR)
- Equivalent hours of use

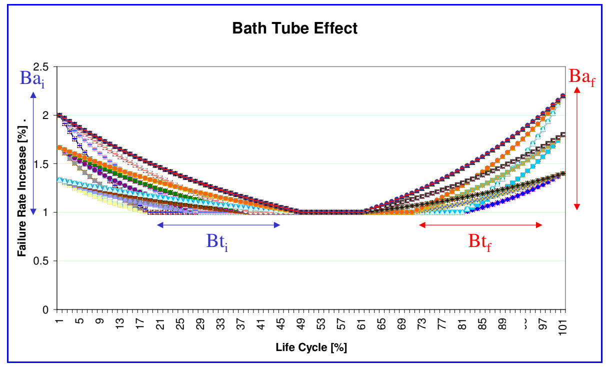

Figure 7 - Bath-tube effect influence on failure rate changing reference parameters for a component

Among the factors affecting the maintenance, it is important to highlight that failure rates over the whole ship lifecycle are subjected an evolution; the authors defined for each of them a reference value, but applied dynamic modifiers affecting by their utilization profile.

In fact, one interesting aspect on failure of complex systems, such as present CV case, is related to the bath tube effect on ship plant components: in fact during early usage failure frequency of each components results higher than usual for initial set-up problems, while at the end many problems emerge due to their extensive use and consumption. In the proposed model it was defined an ad hoc relation devoted to being able to reproduce different component profiles, so the bath tube effect is defined for each component based on the following relations:

$$BE_h(t) = \begin{cases} t < Bt_i & RF_h \cdot \left[1 + Ba_i \cdot \dfrac{\left(e^{\frac{Bt_i - t}{Bt_i}} - 1 \right)}{e - 1} \right] \\ Bt_i \le t \le Bt_f & RF_h \\ Bt_f < t < Bt_Z & RF_h \cdot \left[1 + Ba_f \cdot \dfrac{\left(e^{\frac{t - Bt_f}{Bt_Z - Bt_f}} - 1 \right)}{e - 1} \right] \\ t \ge Bt_Z & RF_h \cdot \mathrm{Ba}_Z \end{cases}$$

Bt_i, Bt_f Represent initial and final reference times for Bath-tube effect
Ba_i, Ba_f Represent initial and final maximum increase of failure rate due to Bath-tube effect
t is current simulation time
Bt_Z represent time corresponding to end-life of the component
Ba_Z represent failure rate increase corresponding to end-life of the component

This relation corresponds to the different curves reported in figure 7 for different parameterizations.

INTELLIGENT BEST FITTING SYSTEM

The Intelligent Best Fitting System (IBFS) is devoted to evaluate the unknown data.
The procedure is defined based on the following main phases:

- Preprocessing
  - ♦ Setting on the static simulator of the preferred hypotheses (reference ships and parameters for correlating general data)
  - ♦ Identification of Reference Baselines by the static simulator on a vessel in order to estimate the new vessel performance and in particular:
    - ◊ Overall Availability
    - ◊ Overall Reliability
    - ◊ Overall Costs
    - ◊ Ship Time Sharing among different states
    - ◊ Critical components performances (i.e. cost of fuel, cost of personnel, availability of radar system, etc.)
- Elaboration
  - ♦ Setting of the best fit general criteria such as:
    - ◊ Optimization Algorithm & Parameters
      - ▪ Algorithm type
      - ▪ Range of Analysis
      - ▪ Resolution in the range of Analysis
      - ▪ Convergence Criteria
      - ▪ Target Function Weights
    - ◊ Simulation General Data
      - ▪ Number of Replication for each new configuration
      - ▪ Duration of simulation runs
      - ▪ Tolerance for target data comparison
  - ♦ Dynamic runs on the DS driven by the IBFS for iterative search of the best input configuration able to converge on reference baselines
  - ♦ Saving of best configurations
- Post-processing
  - ♦ Tests for validating best obtained configuration

It is evident that this optimization process, if successful, converge on DS configurations able to guarantee results consistent with the reference target function provided by the SS. So this process is mostly based on some hypotheses:

1. the SS provides valid results, it means that SS is supposed to be able to properly estimate several target functions based on similarities and correlation with other ships. This idea is acceptable on condition to properly choose the reference baselines; this is correct in case these represent overall ship performances related to not so new phenomena: for instance estimating fuel consumption or even ship availability is probably correct.
2. a phenomena affects this approach: in fact the IBFS identifies an input data set consistent with target, concerning output often in so complex problem there are multiple configuration providing consisting results; for instance an equal value for total availability of a two machine system could be obtained with infinite combination of availability values for its two components; therefore instead considering just a single target function, many target functions are introduced with mutual dependency from same input. The introduction of these “constraints” reduce the number of multiple alternative configurations.

The authors assumed that the target chosen functions guarantee that even if alternative configurations exist, they results equivalent from user point of view; this means that the experts must define a combined target function including all the aspects that are interesting during this phase of the vessel program: in this case few multiple configuration probably can satisfy a so articulated goal, at the same time if two different solutions provide the same results probably they result equivalent from user point of view, being able to cover all desired aspect of the vessel design/operation/management etc.
Therefore in order to increase the robustness of the solution, the authors decided to investigate area optimization approaches; in fact in this case as optimization algorithm it was decided to apply systems avoiding local gradient, due to the high uncertainty, while the used algorithms for the CV example included Genetic Algorithms and Direct Random Search. In fact by these two approach it is possible to collect multiple solutions from different areas in the investigation ranges that provides “good” results, while with gradient method the points usually belong to the same search path.
In both case as configuration input it was decided to introduce new variables able to drive multiple parameters in order to reduce the complexity of the problem.
For CV case the unknown parameters related just to the maintenance included for each component:

- Minimum, Maximum & Most Probable Cost of Repair at Port
- Minimum, Maximum & Most Probable Cost of Repair at Sea
- Minimum, Maximum & Most Probable MTTR at Port
- Minimum, Maximum & Most Probable MTTR at Sea
- Minimum, Maximum & Most Probable MTBF at Port
- Minimum, Maximum & Most Probable MTBF at Sea

So if we stop the analysis at higher level including 12 ship plants (engine, power, radar, sonar, Command & Control, Anti-Air Weapon System, Anti-Sub Weapon System, Anti-Ship Weapon System, Wing Component, HVAC, etc.) and we consider just the investigation on maintenance variables this correspond to 216 variables. For example in a real case for a new Carrier and at this detail level, just 63 values was supposed to be properly estimated by the experts, it means that in this case the configuration is related to 153 variables. Therefore several of these parameters are not-independent due to physical aspects (i.e. failure rate of radar and power systems), to physical similarities (i.e. impact of the 3D radar and of the IFF radar) or logical relation (most probable value is expected to be larger than the minimum and smaller than the maximum).
Based on these aspect it was possible to group general parameters driving the other variables based on the following relation:

$$i \in G_j \Rightarrow V_i = R_i \cdot x_j + C_i$$

i	i-th independent variable
G_j	set of independent variables driven by j-th grouped parameter
V_i	Value of the i-th Independent Variable
R_i	multiplication factor affecting the i-th variable
C_i	constant factor affecting the i-th variable
x_j	value of the j-th grouped parameter

This grouping and setting was based on hypotheses by experts and allowed to reduce the problem complexity for the proposed CV case study to 64 grouped parameters. However another critical aspect is related to the fact that failure rates are variable characterized by very broad possible ranges: i.e. some devices have an MTBF of 1000 hours while other ones overpass 10 years.
In order to face this problem the IBFS was allowed to define the variable range by a logarithmic approach to the resolution, able to investigate with homogenous density different orders of magnitude; in fact each group parameter was modeled by a string of bit, where the length correspond to the resolution desired.
In figure 8 it is presented the difference between two modes of coding: homogeneous respect linear variable (diamonds) and homogeneous respect logarithmic scale (squares). It was decided to have the values distributed homogeneously respect the logarithmic scale for guaranteeing better results in scanning a so wide spectrum of order of magnitudes; the x_j value is computed by the following relation:

$$x_j = e^{\frac{\log\left(10^{Ra_j \frac{\sum_{m=0}^{m_t-1} b_m 2^m}{2^{m_t}}}\right)}{\log(e)}}$$

$$Ps'_j = \frac{2^{m_t}}{\log\left(10^{Ra_j}\right)} = \frac{2^{m_t}}{Ra_j}$$

$$res'_j = \log\left(\frac{2^{m_t}}{Ra_j}\right)$$

m_t	Number of bit used for coding
Ra_j	Order of magnitude for j-th variable
Ps'_j	Average number of points over each order of magnitude with m_t bits and Ra_j orders to be investigated
res'_j	Average number of resolution digits over each order of magnitude with m_t bits and Ra_j orders to be investigated

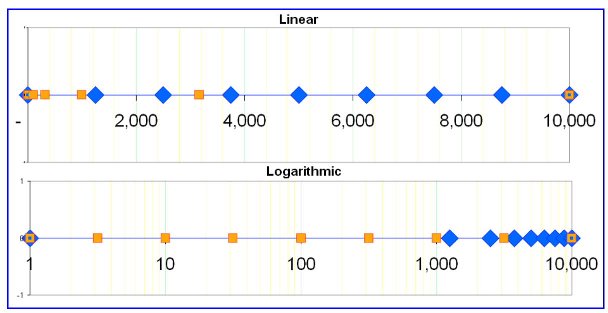

Figure 8 – Homogenous distribution of experimental values respect a linear scale and logarithmic scale

In the proposed CV case the authors tested coding length of 12 and 16 bits with the five order of magnitude corresponding to have an average of 2 and 4 resolution digits; in the availability identification process just the 16 bits was able to properly converge on a general maximum, while 8 bits was unable to investigate properly the problem.

THE SIMULATION IMPLEMENTATION

The different components were implemented in order to run on PC by adapting pre-existing systems; in particular the Static Simulator is integrated in MS Office™ by Visual Basic, while the Dynamic Simulator as well as the IBFS are coded in C++ in order to guarantee best computational efficiency.
The Dynamic Simulator and the IBFS are fully integrated by dynamic data links.

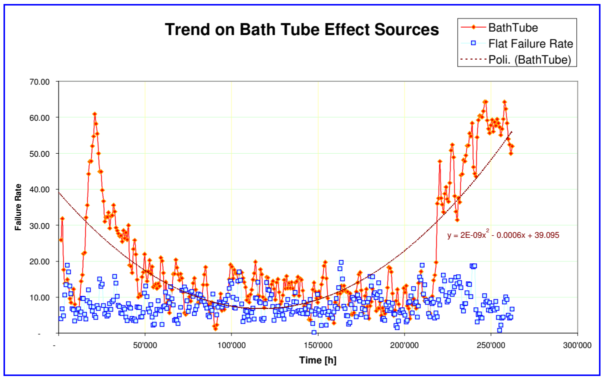

Figure 9 - Instantaneous failures rates during simulation

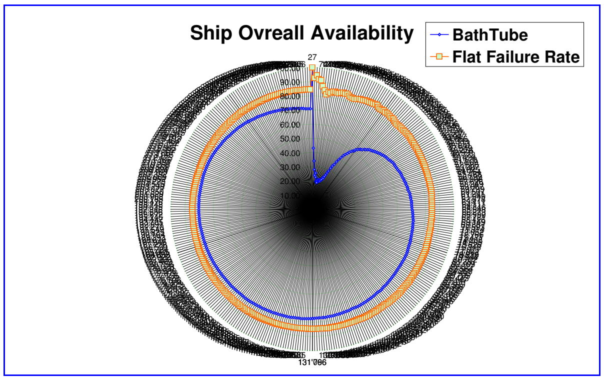

Figure 10 - Ship Availability along its life cycle with with different Hypotheses on Bath-tube effect

The connection with the static simulator requires just access to reference baselines, this it is guaranteed by regular Dbase access; the data management is guaranteed by custom Dbase libraries.

EXPERIMENTAL RESULTS

Validation & Verification represented a critical phase for this initiative, in general it was possible to reuse VV&A (Validation, Verification and Accreditation) results of previous existing model. The two simulation models were tested by applying desktop review as well as dynamic VV&T (Verification, Validation and Testing). In this case DOE (Design of Experiments) and ANOVA (Analysis of Variance) techniques was applied to estimated the confidence band on each target function. The complexity of the models required to choose among the alternatives as many hypotheses as possible before to start the best fitting procedures, this in order to speedup the process. After that, extensive test was completed on different phenomena; for instance the influence of bath-tube on failure rates is summarized in the figure 9, while figure 10 represents the overall ship availability around the lifecycle clock. Based on these results and expert evaluation it was decided to keep active the bath-tube effect during simulation runs. The IBFS was successfully applied in the process and obtained a solution converging on the values proposed by the SS; so the IBFS identified a consistent configuration that was then available for investigating changes in operative scenarios, ship design solutions and/or vessel management philosophies.

CONCLUSIONS

The proposed approach analyzes complex system management and its impact over the whole life cycle demonstrates his efficiency in a couple of case study. In particular, in reference to very innovative vessels to be produced in few units, the approach is able to estimate most of the variable and properly assess the overall ship performance. The case of the aircraft carrier represents in effect a very challenge application, where the IBFS is able to identify a parameter configuration consistent with expert evaluation and similar/historical. The authors currently are working on reusing this methodology in other application areas.

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