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# Performance-Based Logistics and Technology Refreshment Programs: Bridging the Operational-Life Performance Capability Gap in the Spanish F-100 Frigates

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## ABSTRACT

Many large and complex systems have extended operational lives. Examples of such systems include the oil and gas drilling systems, defense systems, and air traffic control systems. A growing concern for many users is the difference between actual and intended system performance during the operational life. An understanding of the root causes of that gap, known as performance capability gap, is required if appropriate measures are to be taken. This paper explores the main reasons for the existence of the performance capability gap and suggests the combination of performance-based logistics and technology refreshment programs as a very effective and efficient remedial strategy. The paper examines the Spanish F-100 frigate to illustrate actual application of these strategies. © 2012 Wiley Periodicals, Inc. Syst Eng 15:

Key words: performance; logistics; technology; refreshment; capabilities; gap; life cycle

## 1. INTRODUCTION: THE PERFORMANCE CAPABILITY GAP

Systems are designed to fulfill actual or perceived needs. The identification of a need, a functional deficiency, triggers the definition of the need in the form of high-level requirements, enabling the identification of potential design concepts, which results in the selection of a preferred solution. The definition of a selected design concept is accomplished through detailed requirements, and subsequent design and development of the system which satisfies those requirements effectively and efficiently throughout the intended in-service life. The design and development process can easily span a number of years. This may result in evolved or depreciated requirements by the time that the systems is commissioned and enters into service, and the system may no longer satisfy in full the current need. Even if the system fully satisfies the user needs, the operational life of the system will inevitably result in a degradation in performance. No matter the effort deployed in maintenance programs and even in reliability growth programs, eventually reliability (whether the system has been in active use or even in a stand-by mode) takes a toll in system performance. Long gone are the days in which failure rates were assumed to be constant [Wong, 1981; McLinn, 1989]; increasing failure rates imply, among other things, less operational availability and thus lower perform-

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ance. Additionally, during the system life, the needs of the user may continue to evolve into more advanced and challenging requirements. Exceptions will arise, but is a common occurrence that systems are replaced with new generations because of the growing capability gap which eventually renders the system of insufficient value to its customer. This gap prompts its system replacement with a new and improved system which better meets the current need of the customer. The most obvious example of this is the personal computer industry. If the performance gap did not drive upgrades, most personal computer owners would still be using an 8086-based chipset. The delta between these two trends (additional requirements and degraded performance) represents a capability gap, as depicted in Figure 1.

Many complex systems in large industrial sectors are designed to have very long operational lives. The transportation sector, and more specifically the rail sector, lay track with the expectation of it being there for decades. The same can be observed for the trains and cars that travel those tracks. Within the Naval Systems sector, it is common knowledge that planned operational lives of 25–40 years are the common situation rather than the exception (Table I). It is not unusual that the scarcity of resources faced by most institutions results in extending the already-long operational lives of the systems, as they lack the financial means to replace them. This extension in the operational lives further complicates the problem, and the capabilities gap increases, mainly due to higher difficulty of sustaining systems in satisfactory operational condition as time elapses.

There are several reasons that may explain the capabilities gap experienced by many systems users. One may be the inefficiencies in the management of the required logistics support, in spite of the higher attention paid to it and the significant improvements made in the last decades. If the logistics support resources required by the systems were perfectly managed, the system would retain throughout its useful life its performance characteristics as delivered the first day of operation. However, management is far from perfect, and the inevitable consequence is a loss in system availability and degradation in the way in which many missions or operational profiles are accomplished. Moreover, all functional and market obsolescence problems that occur at any of the suppliers of the system integrator will eventually hit the system integrator and the end user, unless they are rapidly identified and satisfactorily managed, as the authors have repeatedly seen throughout many years of industry experience in several fields.

**Table I. Average Ages for Relevant Combat Ships and Leading Operators of Offshore Oil and Gas Drilling Rigs, Not Taking Upgrades into Account**

| *Platform* | *Average Age (years)* |
|---|---|
| Transocean (RIG.N) | 25 |
| Ensco/Pride (ESV.N)(PDE.N) | 22 |
| Noble Corp (NE.N) | 29 |
| Hercules (HERO.O) | 31 |
| Frigate F-100 | 30 |
| Australiam LHD | 40 |
| Principe de Asturias Class (CV) | 40 |
| Santa Maria Class (FFG-HM) | 35 |

Another reason may be that new needs or requirements from users will, in general, not be satisfied by the system in the current configuration. The technological obsolescence suffered by the system will further enlarge the capabilities gap. The decomposition of the gap in its main drivers is depicted in Figure 2.

Aware of this gap, many users are starting to specify that the delivered systems must perform throughout the operational lives, in relative terms, as when they were first put into service. The likelihood of this becoming a reality will depend, to a large extent, on actions and decisions taken during the early phases of the life cycle, envisioning the need for measures that will eventually diminish to the extent technically and economically feasible the said capabilities gap.

The authors will examine the reasons for the capabilities gap in the remainder of this paper. Each will be explored in more depth, as well as the main mitigation strategies to be deployed to keep the gap as short as possible during the entire

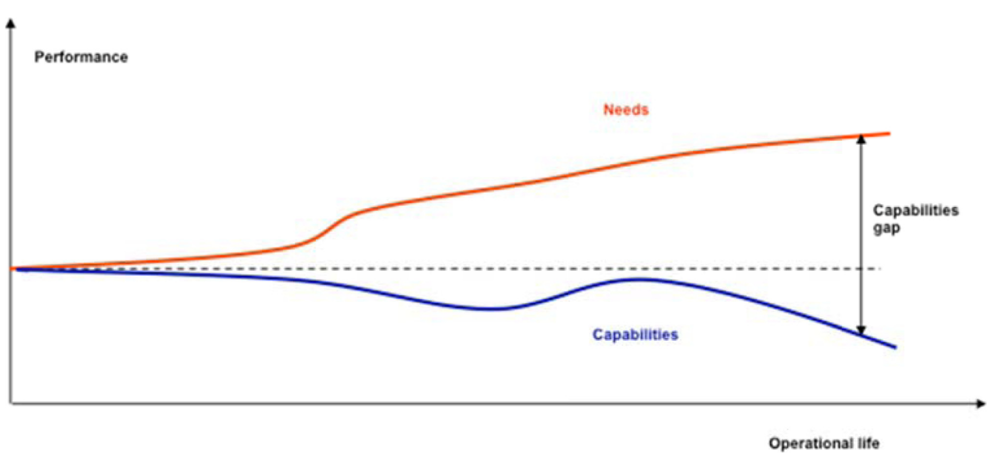


**Figure 1.** The capabilities gap. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

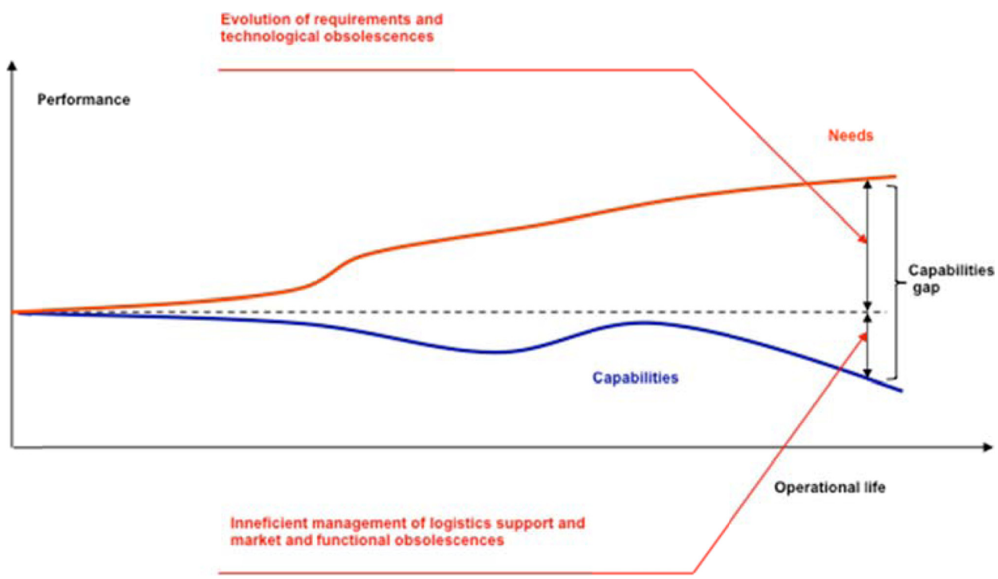


**Figure 2.** Decomposition of the capabilities gap. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

operational life of the system. Finally, a case study of the Spanish Navy F-100 frigate will be presented. Discussion will be presented on how the ship was conceived by the Spanish Navy with a true life-cycle perspective in mind, and were accordingly designed by Navantia, the system integrator, who has adopted a Life Cycle Support strategy to support the Navy in maintaining the frigates. It should be noted that when the F-100 program was initiated, Navantia was called Bazán, and subsequently became IZAR as a result of the merging of the public civil and the military shipyards in Spain. Later, they both reverted to their initial names as both sectors split again; for ease of language, the company will be referred to as Navantia throughout this paper, regardless of the actual name it had on different phases of the life cycle of the program.

## 2. BRIDGING THE GAP: PERFORMANCE-BASED LOGISTICS AND TECHNOLOGY REFRESHMENT PROGRAMS

The first step towards solving an unsatisfactory condition or situation is an appropriate diagnosis. Only after the root cause(s) of a problem have been identified can the adequate corrective actions be defined and implemented.

The "lower" part of the performance capability gap, which represents the breach between actual performance and the one the system had when it entered into operation, is mainly due to the following reasons:

1. *An ineffective and inefficient logistics support of the system.* Although great progress has been made in the logistics area since the advent of the integrated logistics support philosophy, many systems still suffer operational deficiencies that stem from problems with the logistics support elements, whether lack of spares when and where needed, documentation of poor quality or that does not reflect actual system configuration, lack of skilled and trained users and/or maintainers, unreliable test equipment, facilities not duly equipped, and the like.
2. *Market obsolescence.* The supply chain of most system integrators are comprised of a huge number of companies, and the operational lives of many systems are very large. More often than desired those companies in the supply chain face situations such as mergings, decisions for abandoning a line of production, planned obsolescence, bankruptcy, and the like, which eventually imply lack of support of logistics support resources that surface at the system integrator level, hurting the end customer. Those market obsolescence may take the form of spares no longer supplied, repair actions no longer possible (or if done, at least at a much higher than usual turn-around-time and cost), lack of qualified personnel to process in a timely manner engineering change proposals, etc. Several authors have addressed the problem of market obsolescence [Solomon and Sandborn, 2000; Singh and Sandborn, 2006; Sandborn, 2007].

The "upper" part of the performance capability gap, which represents the breach between the performance the system had when it entered into operation and the one that would be currently needed, is mainly due to the following reasons:

1. *Technological obsolescence.* While some elements or equipment continue to function (and can still be supported), the advent of new technologies may render them functionally obsolete. One example is the storage device for computer systems. In the 1980s tapes were widely used, to be replaced in the 1990s by external

hard drives. In less than 15 years we have gone from an expensive, external hard disk of 1 MB of the size of a washing machine, to a flash drive with no moving parts which fits in a small pocket and can store hundreds of GB of data. The new capability results in far less weight, far less volume, and far more reliability, at far less cost. Continuing to use certain devices or technologies, although still operational and supportable, would render the system functionally obsolete in relative terms.

2. *New requirements.* The long design and development cycles usually implies that by the time the system is commissioned and enters into service, the need that drove the systems engineering process has evolved. Even if when commissioned the system still met the initial requirements and fully satisfied the initial need, over the years that need will continue to evolve. Continuing the example from above, while the initial capability may have been for single frame pictures, the new requirement is for streaming video. The old storage device is not capable of storing that much date, but for less volume, higher reliability, and lower cost, storage devices today can satisfy the new requirement. Thus, to the extent that the system stays as initially designed, those new requirements into which the evolving need materializes will not be met and satisfied, suffering thus the user a performance capability lack.

Different ailments call for different remedies. Thus, after identifying the potential causes of the undesired performance capability gap experienced by many systems throughout their operational lives, remedial actions can be put into action. Even better, knowledge of the nature of these potential situations allows for actions in the early stages of the life cycle. There are two main mitigation strategies that help users cope effectively and efficiently with the mentioned performance capability gap, reducing it throughout the system operational live to acceptable levels. These two strategies are performance-based logistics (PBL) and technology refreshment programs (TRP).

## 2.1. Performance-Based Logistics

In the 1990s the International Society of Logistics (SOLE) established the base of the so-called Performance-Based Supportability (PBS). The name originated from the recognition that supportability was considered to be a critical element concerning system performance. The goal was to organize the best practices available in industry and to do it in a systematic manner in order to facilitate its application to civil and military products. The origin in the defense sector of the migration of the logistics support strategy to PBL was the work conducted in the United States by the end of the 1990s by the Office of the Secretary of State for Defense, the three armed services, the Joint Staff, and the Logistics Defense Agency [Rogers, 1997; Kratz, 2001]. PBL represents a change of paradigm, moving from contracting and paying for devoted resources to contracting and paying for results achieved. Instead of telling the contractor what to do and how to do it, the customer tells him what he wants to achieve and then relies on the experience, capabilities, and motivation of the contractor to achieve it. Thus, PBL represents a fundamental change of paradigm in which contractors are told what to achieve, and not what to do, being rewarded as a function of the actual level or degree of achievement of the sought objectives.

Logistics support activities have always been outsourced, but the change introduced by PBL in the externalization is no longer of resources, but of results instead. PBL has been successfully in a number of sectors, defense among them, over the last years. PBL calls for a closer relationship between users and industry, working together to achieve the goals that motivated the design and development of the system in the first place.

There are three main barriers to the successful implementation of PBL contracts:

a. *Technical-economical.* If reward is to be linked to performance, the first hurdle to clear is the objective definition of system performance. That requires the selection of the appropriate array of effectiveness or performance metrics, which should be objectively defined, together with the setting of objectives based on historical data or sound predictions, and with the time scales for achieving them. The second hurdle in this barrier is the definition of the geometry of the reward function that will determine the reward to which the contractor is entitled as a result of the actual level of performance or effectiveness exhibited by the system.

b. *Cultural-organizational.* A substantial change in the way logistics support is externalized will demand changes in the organizations of both users and contractors. Inevitably there will be resistance to change, in part due to the feeling that there will be losers and winners under the new scheme; those believing that in relative terms they will lose in the new scenario will in general not favor it.

c. *Contractual-political.* Even if both parties are interested in entering into a PBL contract, the applicable legislation has to support it. Furthermore, it is essential to consider issues such as intellectual property rights or the redistribution of funds within the organization of the user.

Being aware of these barriers or difficulties, and taking the appropriate steps to overcome them, is a *sine qua non* condition for implementing a sound PBL contract.

## 2.2. Technology Refreshment Programs

The last couple of decades have witnessed the dawn of the technology refreshment programs (TRP) [Neubert et al., 2000; Verma and Plunkett, 2000; Haines, 2001; Boland, 2009]. The only way a system can retain its capabilities during the operational life is through a TRP. Technology refreshment activities may be updates, improvements, and/or insertions of technology. The end goal is to reduce the performance capability gap by taking advantage of new technologies to either cope with new requirements (insertions) or to avoid functional or technological obsolescence (updates or improvements). As many opportunities will arise during the operational life of a system and the resources (human, financial, and material) are limited, the key to a successful TRP is to align opportunities with system's goals. A careful assessment in terms of implication in effectiveness and life-cycle cost will dictate the opportunities that should be materialized. The use of open-system architectures (OSAs), the appropriate handling of COTS elements, and a sound management of technologies based on their maturity, will facilitate the successful implementation of TRPs. The consideration of architecture options has also been recognized as a sound design strategy thinking in terms of the eventual supportability during the operational life [Engel and Browning, 2008]. The insertion of new technologies is seen as inevitable in order to maintain the initial operational capabilities of many complex systems [Burley, 1999; Haines, 2001; Kerr et al., 2008].

## 3. THE CASE OF NAVANTIA AND THE SPANISH NAVY F-100 FRIGATE

The Spanish Navy initiated in the 1990s the so-called F-100 program, after the NFR-90 program was cancelled. The authors have participated in the F-100 program in three key player entities: Navantia (the designer and shipbuilder), Lockheed Martin (designer and supplier of the AEGIS combat system), and Isdefe, the MoD-owned systems engineering firm, which support the Navy in several project phases. The information presented in this paper relative to the F-100 frigates comes mainly from own sources.

One major life cycle objective of the F-100s Frigates (see Fig. 3) is to maintain and evolve its operational performance and capabilities throughout the operational life of the vessel. According to Admiral Beltran (Spanish Navy Chief of Logistic Support, 2007):

> The Spanish Navy's goal is to keep the F-100 Frigate performing for the next 30 years, in relative terms, as it performs today.

The goal of the Spanish Navy, as extraordinarily captured and synthesized in the above quote, is to maintain the operational capabilities of the frigates during their operational lives, which is the same as maintaining updated or refreshed their initial technical capabilities. Simply maintaining the initial technical capabilities will gradually render the frigates in floating museums.

**Figure 3.** The four Spanish F-100 frigates commissioned to date.

### 3.1. F-100 Frigate Background

From its inception, the F-100 project posed a challenge. It was to have the most powerful shipboard Combat System fitted into the smallest platform possible (close to 6000 tons displacement).The F-100 was the first frigate to be equipped with the Aegis Combat System (ACS). To this point, the ACS had only been installed on US Navy destroyers and cruisers and on Japanese Navy destroyers—all of which had displacements larger than 8500 tons.

The F-100 is a multipurpose frigate built by the Spanish shipbuilder, Navantia. The keel for the leading ship of its class, F-101, was laid in October 2000. The ship was commissioned in September 2002 at the Ferrol Arsenal. The final ship of its class, F-105, will be commissioned in November 2012.

The F-100 program engineering began in 1983 when Spain (both Navy and Navantia) was taking part in the Feasibility and Project Definition phases of an international program for the development of the NFR-90 Frigate. Following the cancellation of this program at the beginning of 1990, the Spanish Navy decided to make another attempt with its own program.

After assessing the results of the previous phase, the F-100 Project Definition phase began in 1993 and, at the same time, Spain signed a trilateral collaboration program with Germany and Holland with the purpose of developing new frigates and—despite the differences among these ships' platforms—the intention of taking advantage of the synergy for any possible combined placing of purchase orders, as well as of the installation of an Anti-Air Warfare (AAW) segment around the new design European radar for the Combat System.

In July 1995, with the F-100 Project Definition Phase completed, the Spanish Navy decided in favor of the AAW solution based on the Lockheed Martin's AEGIS system—widely proven in real operations—and against the risks new development programs such as European radar may present.

This decision resulted in the beginning of a new design phase named Transition Phase in which the platform was adjusted to the requirements of the AEGIS Combat System installation around the SPY-1D radar. The architecture of the AEGIS Combat System is depicted in Figure 4. Being integrated by many sensors, processors, and weapons, technology insertion is a must to maintain its capabilities updated over time, as new threats unfold and new technologies become available.

The F-100 acquisition strategy included:

- —A Construction Contract with Navantia for the construction of the ships, which comprises the Project Development, the ships' construction and installation and tests of their equipment including the Combat System, as well as the Integrated Logistic Support Plan (ILSP) and industrial training.
- —A separate Contract to be charged to R&D funds of the Spanish Ministry of Defence to enable Navantia to

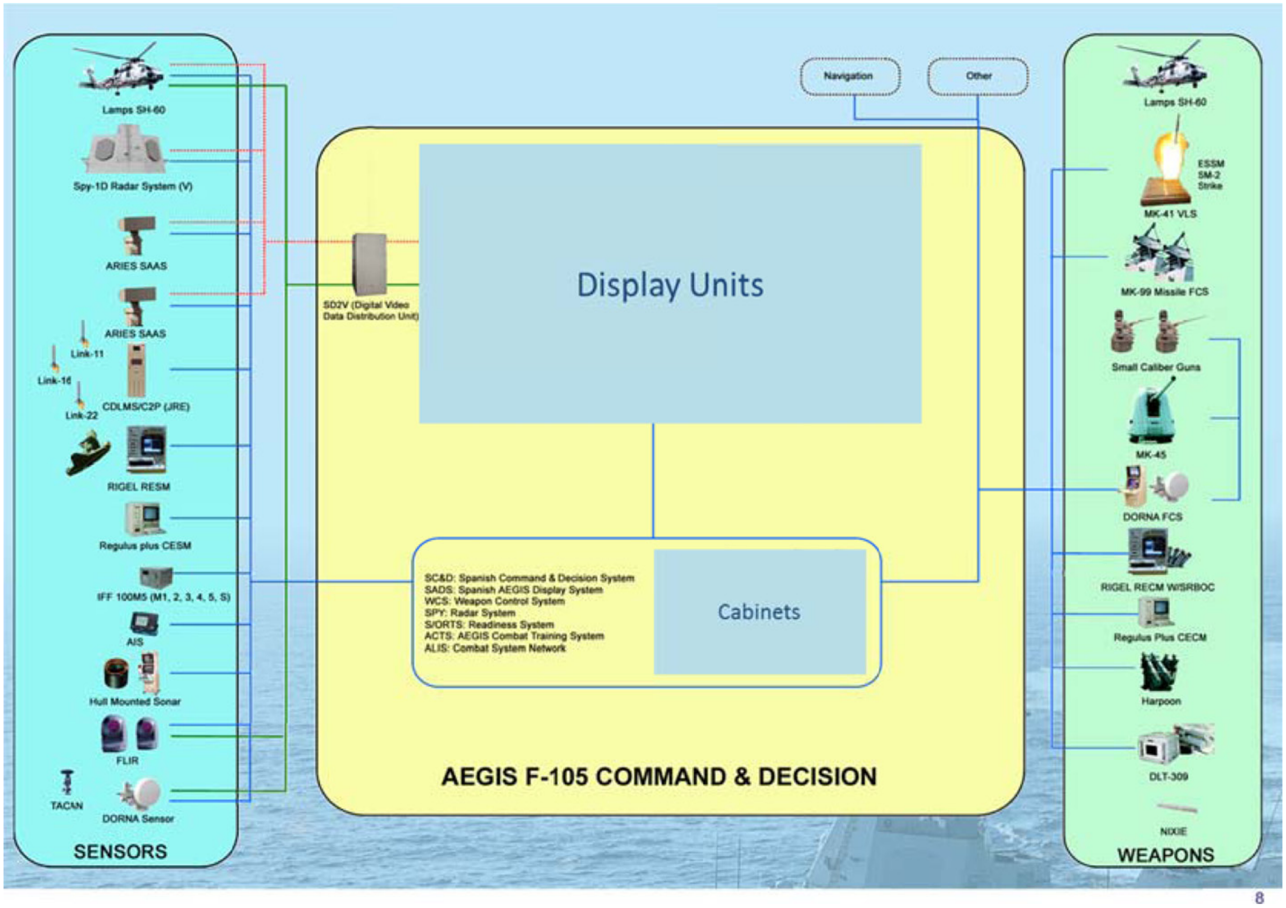


**Figure 4.** Architecture of the AEGIS Combat System for the 5th F-100 frigate. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

develop a Command and Control System (CDS) for domestic manufactured weapons and sensors.

—An FMS (COA SP-P-LFG) Contract for the purchase of the AEGIS System and other equipment/components of the Combat System.

## 3.2. F-100 Combat System through the Life Support Approach

The F-100 frigate combat system is a complex system. This system is developed around the Aegis system, providing it with significant anti-air capability. Subsystems include the AN/SPY-1D radar, the MK-41 missile launcher, two fire directors, and the associated command and control (ACS—Aegis Combat System). The antisubmarine warfare, surface, and electronic warfare capabilities are organized around the Domestic Sensors and Weapons, in which the Spanish Industry is largely present, and controlled by the Command and Control System (CDS) developed by Navantia under the framework of an R&D program of the Spanish Ministry of Defence. It is integrated with the ACS and provides the ship with a complete and integrated Command and Control system.

The Spanish Navy goal is to establish an approach based on asset management principles in the support of the F-100 class in service. The "maintain" phase of the asset life cycle for the F-100 encompasses a significant component of engineering change as well as pure system maintenance. In order to continuously meet new threats, complex systems have a high level of engineering change incorporated in-service. This influences the relative magnitude of change and maintenance within the sustainment function, resulting in a need to implement an efficient systems engineering process that provides a level of technical integrity at least equal to the acquisition phase and sought under the latest reform program.

Therefore, the System Designer role is a key element of the sustainment function. It should be applied as an integral component of any sustainment organizational model. The primary objectives of the Ship Designer role should be:

- To ensure the maintenance of the overall technical integrity of the ships
- To provide a cost effective and efficient approach to sustainment that continually improves maintenance and change implementation.

Maintaining the operational capability of the combat system performance throughout its life cycle, during which new weapons and sensors integrations and changes due to industrial components obsolescence requires an active system engineering capability to ensure system integrity. That engineering capability is provided to the Spanish Navy by Navantia, as F-100's System Integrator or Design Authority, together with its main suppliers, such as Lockheed Martin. The system designer performs this function during the F-100's operational life. Figure 5 shows the organization in the F-100 program.

The Combat System (CS) support requires two fully differentiated tasks which will be discussed next. The first tasks results from the derivatives of the scheduled maintenance and equipment failures, or corrective maintenance. These maintenance activities are under the Spanish Navy F-100 Sustainment organization together with Navantia as main contractor for most of these activities. Support of the Spanish Navy GSSC (Grupo de Soporte del Sistema de Combate) and the industry Technical Support Office (Navantia, Indra, and Lockheed Martin) in the Ferrol Arsenal provide communications with the crew to ensure the effective technical support. This organization serves to reduce the "lower" part of the performance capability gap regarding an ineffective and inefficient logistic support.

This organization also provides *in situ* and on-call support for identifying and solving problems, troubleshooting, on-the-job training, etc. Depot repair of failed items directly or through OEMs (Original Equipment Manufacturers). Supply Support provides the spares needed for maintenance. Availability support for dry-dock (every 5–6 years) and non-dry-dock (every 2 years) availability periods.

Each of these activities are contracted through a traditional transaction driven maintenance. New Spanish contractual laws and Spanish Minister of Defence sustainment requirements will allow change to PBL contracts transferring more risk and responsibility to the industry, increasing the relation cost/efficiency and buying performances instead of resources.

The second task is derived from the need to address system obsolescence, configuration control, and system and capability modernization. For this type of modernization and updating, a systemic approach must address the global problem. This responsibility falls on the In Service Engineering Agents (ISEA).

The Spanish Navy acts as ISEA for Systems Engineering activities supported by the US Navy, Lockheed Martin (LM), as ISEA for Aegis Combat System, and Navantia FABA-Systems, as ISEA for CDS and National Sensors and Weapons (NS&W). This triad is responsible for providing solutions to the "upper part" of the performance capability gap, regarding technological obsolescence and new requirements, and the market obsolescence of the "lower part."

The benefits of engaging the Design Authority in the proposed role in support of F-100 Class sustainment can be framed in terms of efficiency and risk reduction. These benefits are fundamental to successful implementation of sustainment. Identified sustainment benefits include the following:

- The engineering expertise, knowledge base, and design processes are in place for a seamless transition from the acquisition phase without the costly process to build up this base capability from scratch.
- The Design Authority role scope reduces the number of organizations and interfaces involved in sustainment functions manifesting in less contracting overheads and streamlining of processes.

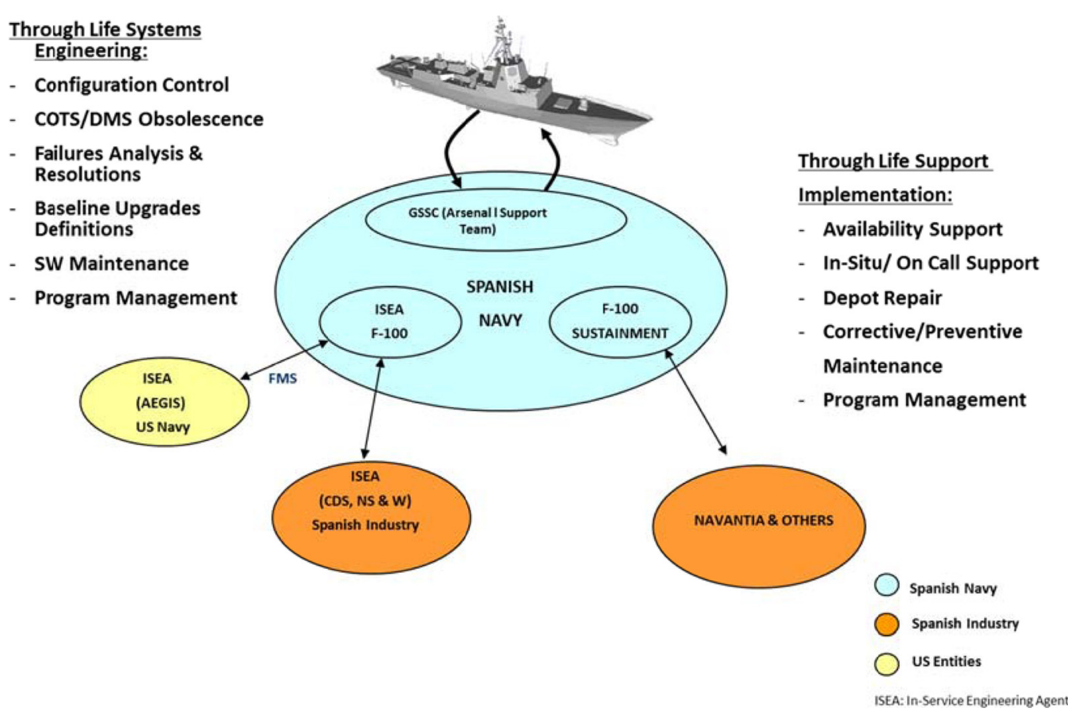


**Figure 5.** Organization of F-100 program. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

- Involving the Design Authority in the change needs assessment will result in reducing change from inappropriate standard specification and eliminate proposed change that is not consistent with the design basis, the result being a reduction in nugatory change effort with immense potential cost savings.
- The engineering change process itself will be streamlined and tailored to the complexity of the change. Time frames for change development will be a fraction of the current model and process overheads significantly reduced.
- Maintaining the design baseline on a continual basis means that engineering change can be based on configured documentation and progressed independent of the ships availabilities in port for inspections. The reduction in delay will again reduce change time frames.
- Assessing cumulative individual changes at a program level will realize more efficient design solutions that consider spatial planning and system support holistically.

Looking at the delivery differences between the F-101 ship of the F-100 class which was delivered in 2001 and the F-105 ship which will be delivered in 2012, technology evolution and the transition to Open Systems Architecture is evident in:

- Processors: Mixed COTS and Military Spec Design (UYK-43/44 & adjunct COTS) in F-101 versus all COTS Computer in F-105
- Software: CMS-2 embedded programming language developed in the early 1970s, C++, Ada, proprietary Operating System in F-101 versus all commercial C++, Ada languages, and Open code Operating System
- Displays: Mixed COTS and Military Spec Design (UYQ-21/UYQ-70) versus all COTS UYQ-70 displays.

New requirements and capabilities have also been introduced into the F-105 ship include: improvements to the missile capabilities (ESSM-Evolved Sea Sparrow Missile), faster speeds due to new diesel engines, improvement in radar cross section reduction, new surface and navigation radars, etc.

The design has enabled the management of market obsolescence and provided the ability to manage obsolete elements (processors, hard disks, FDDI fiber optic interfaces, routers, monitors, etc.) even with diminished manufacturing sources.

### 3.3. Developments at Navantia

Developments at Navantia have taken place in the following three fronts:

a. *Reorganization.* It is important to note that Navantia found it necessary to conduct a significant and comprehensive reorganization in order to help the Spanish Navy achieve their goals. Navantia first created a new Through Life Support (TLS) Division to facilitate the transition from shipbuilder to true provider of life-cycle solutions. This new division is seeded with people from all existing divisions to make it truly companywide. This represents a fundamental reorganization of responsibilities within the company and conveys the message of commitment towards becoming the technological partner of the Spanish Navy and of other customers throughout the useful lives of their ships. Figure 6 reflects how the new Through Life Support

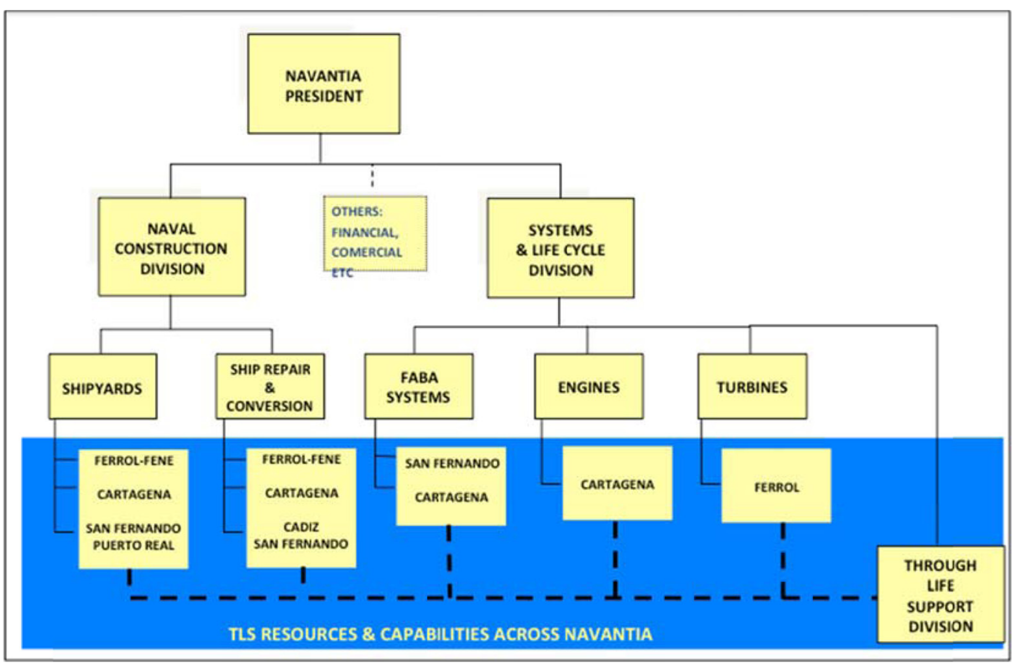


**Figure 6.** The new Life-Cycle Support Division. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Division encompasses all areas and work centers of the company.

b. *Training.* Another initiative found necessary was the implementation of new training programs. New theoretical training with the purpose of developing and reinforcing the necessary knowledge and skills, a most ambitious training program in systems engineering and related disciplines was undertaken over a period of 6 months. The training program has involved over 180 engineers and has totaled over 7800 h. Two business case analyses on performance-based logistics were conducted, one with focus on the Spanish Navy as end customer, the other oriented towards the supplier of a critical subsystem. The cases were performed by two groups of hand-picked engineers and lasted 2 months. The purpose was twofold: to identify the aspects that would be part of an eventual PBL contract (including scope, effectiveness metrics, reward scheme, escape clauses, and transition contract) and to facilitate in general the understanding of the process of negotiating a PBL contract. The Spanish Navy was represented too in the team that carried out the cases, providing valuable inputs and feedback. The scope and depth of the training program, which involved 181 people from all factories and totaled close to 8.000 h in 29 seminars, is summarized in Figure 7.

c. *Procedures.* Success also required Navantia to develop a new, detailed methodology for technology refreshment programs by a group of eight engineers. The methodology allows the identification of needs and opportunities, their alignment with system priorities, their assessment in terms of risk and expected improvements, the estimation of the associated costs and timescales, and the way of bringing all that information into the prioritization of technology refreshment activities that would cope with identified needs or opportunities conducting a time-based economic analysis. To better illustrate the concepts included in the technology refreshment methodology, the entire process was illustrated with five actual examples (three from surface combat ships and two from submarines). The Spanish Navy participated too in the development of the methodology.

Finally, Navantia has undertaken the development of a series of monographs that address systems engineering and support disciplines, and that compile the essence of the available knowledge in those fields. The monographs are available at the "Periscope," Navantia's Intranet. An active policy towards knowledge consolidation and dissemination is considered essential for the successful achievement of the goal of becoming a true provider of life-cycle solutions.

## 4. CONCLUSION

Most large and complex systems have large operational lives during which the performance capability gap becomes an undesired reality. The adoption of performance-based logistics and technology refreshment programs as remedial strategies has proven to be effective and efficient, especially if considered from the early stages of the life cycle, influencing system design. This approach has been applied to the first five Spanish F-100 frigates.

Each of the technology refresh programs have been carried out applying a total systems engineering approach, introducing capabilities incrementally through baseline programs un-


**Figure 7.** Details of the training program conducted at Navantia. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

der rigorous land-based and at-sea testing. From the F-101 (AEGIS Baseline 5 Phase 3) to the F-105 capturing (AEGIS Baseline 7 Phase I) together with national CDS evolution produces a new F-105 Combat System baseline. Each baseline includes its own development, test, production, training, ship integration, integrated logistic support, and back-fit implications analysis.

The F-100 Combat Systems is on an evolutionary path toward an Open System Architecture in order to improve new capabilities (threat evolution), reduced development time, reduced sustainment cost, affordable COTS obsolescence management, and increased human system integration. The goal of this evolutionary path is to enable a more capable, reliable, and adaptable war-fighting approach which accommodates continuous technology changes.

The Spanish F-100 frigates are still in the early years of their operational lives. Presently there are four frigates which have entered service within the last decade and a fifth frigate to be commissioned in 2012. However, it has been shown that the performance-based approaches to bridge the life cycle that have been incorporated in the F-100 class of frigates have yielded significant and promising improvements compared to the previous generations of commissioned frigates in the Spanish Navy. A more comprehensive perspective will undoubtedly be available as the operational lives of the frigates unfold. However, the very nature of the problem, long-lived systems, makes final conclusions for the F-100 difficult as it is in the early life cycle. The authors might have to wait 30 years to report on the "final" findings. By then, technology would change so dramatically that it would be fair to believe the conclusions would be overcome by events.

The in-service phase of the F-100 Program require a sustainment organization with processes, relationships, responsibilities, and authorities that provide the best result for the life of type while most effectively transitioning from the construction phase.

While the Spanish F-100 frigates till have over 20 years of operational life ahead, and thus the eventual success of the adopted support strategies remains to be fully validated, indicators to date demonstrate the steps taken will significantly contribute to meeting the goal of reducing the capabilities gap throughout their operational lives. The combination of performance-based logistics support and technology refreshment programs help reduce to a minimum the capabilities gap.

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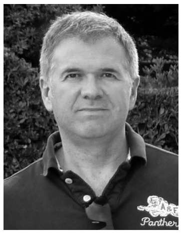

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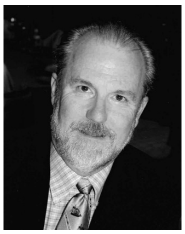

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