C3I Systems acquisition and maintenance in relation to the use of COTS products

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1. Summary

The paper attempts to highlight the main pros and cons of embedding COTS products in military C3I Systems in the overall framework of Systems Acquisition and Maintenance, basing on Alenia Marconi Systems industrial experience. Significant programs are briefly outlined in this sense, providing the reader an opportunity to consider the issue from the "practical" perspective.

2. Introduction

Military C3I Systems are complex, software intensive Systems, conceived and designed to assist the users in the analysis and solution of operational and management problems, be it tactical or strategic.

Given the functionality required and the dynamic environment in which such Systems are called to operate, C3I Systems can be classified as both Real-time Systems and Information Management Systems.

In Real-time Systems reaction times to external events or to user actions must not only be "fast" but also within accurately predictable limits. Information Management Systems, on the other hand, are conceived to facilitate the job to the user, avoiding repetitive or trivial activities and allowing the operator to focus on the most difficult part of the job: the decision making.

C3I Systems combine all such needs. Data coming from electronic sensors must be collected, filtered and fused. They must be correlated to historical or contextual information, elaborated and synthetically presented to the user; this, in turn, will be given appropriate tools to generate control data and exchange orders and messages to cope promptly and effectively with any situation.

Due to the complexity in terms of functions, of amount and types of data to be dealt with, of inbound and outbound interactions with other Systems in the context of a hostile environment, and more, a C3I system usually is a hard test for the system engineer.

The industrial and operational context in which C3I Systems are conceived, procured and operated is complex as well.

The evolving organisation of modern armies, the contemporary social/political changes, the extreme acceleration of the technological evolution and the increased attention to the cost-effectiveness of C3I systems call for the introduction of new methodologies that combined with modern Standards allow Evolutionary System Development. In order to provide affordable, leading-edge capabilities, Defence Industry is seeking to take advantage of commercial technology wherever possible but by doing so it is changing its role and adapting its competence.

In such a framework, this paper deals with C3I Systems acquisition and maintenance considering AMS specific industrial experiences and projects. A rationale is proposed which explains why Commercial-Off-The-Shelf (COTS) products and technology are increasingly used in C3I Systems, together with potential benefits and risks that need appropriate risk mitigation strategies.

3. International Standards

The increasing availability of standards, applicable to the overall C3I Systems engineering process, came in handy to system designers as immediate, practical solutions to many of their basic problems, such as the need to accommodate operational requirements with financial, industrial and technological constraints.

The definition and wide acceptance of standards, pursued by Industry, Customers Associations and Scientific Communities, ultimately allows a systematic approach to complex problems, leveraging from previous experiences and know-how. Most standards, in addition, are "cook books" for partitioning engineering problems, easing the task to rationalise and optimise solutions.

The definition of standards in the information and communication technologies domain is a dynamic

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process and it involves many International Entities and Organisations.

Standards exists today for Military and Civil applications which embrace the whole System Life Cycle, from design up to implementation and production, addressing System Engineering, Software Engineering, Quality and so on. Compliant tools and products are readily available right after the standards themselves.

In this framework methodologies and products that, although missing an "official certification", are accepted by users, makers, and designers for their large utilisation, become "standards" as well.

"DE JURE" standards are therefore those established and proposed by appropriate organisations and working-groups. "DE FACTO" standards are those systems, products and methodologies that for their importance in terms of market weight, popularity and potential economical advantages can not be ignored. It is important to acknowledge the existence of both.

We can observe that, in recent years, Military and Civil Standards tend to converge on core principles, so establishing an important link between civil (commercial) and military application domains (see fig. 1).

As an example, MIL-STD499B and IEEE122 are two important Military and Commercial guidelines that focus their attention on the System development process rather than on the object "System".

Both standards promote innovative concepts, such as:

- the need to adapt the "standard" process to the single project and its specific requirements and risks;
- the recurrent applicability of the processes at all levels;
- the iterative use of the processes (evolutionary Systems Management and Development);
- the combined use of traceability techniques and system models to manage projects complexity by linking operational requirements to system solutions;
- the "project database" to keep memory of choices and decisions made along the project;
- the Integrated Product Team concept, gathering all competencies needed for the whole Life Cycle from the project start.

The convergence of military and civil guidelines can be explained with the commonality found in the design of a complex system, be it for commercial or defence application. System designers have always to consider and exploit technologies, methods and products available on the market or off-the-shelf, while behaving in line with good engineering principles:

- manage efficiently the systems development process, using effectively all technical and human resources;
- implement a modular, flexible, expandable, scalable system;
- optimise functionality;
- maximise reliability, survivability and re-use.

As a result, the convergence of Military and Civil standards is producing the first essential step towards the use of COTS in defence systems: the availability of top-quality COTS products and subsystems compliant to military applications.

But more than that, such convergence opens a new frontier as to the "re-use" or even "dual-use" of military C3I systems, components and functionality in the civil domain and vice versa.

4. C3I Systems "Dual-Use" and "Re-Use"

In this framework, "dual-use" of a C3I system is meant as the possibility to use an existing military system, as it is, in a civil application and vice versa.

This possibility is important, as a typical example, in emergency, unpredictable situations when the deployment of military systems constitutes an immediate solution to compensate the inadequacies and deficiencies of civil protection infrastructures. Such infrastructures, being expensive to maintain, are reasonably sized and designed to cope with limited catastrophes. Military C3I Systems, by definition capable to operate in extreme environmental conditions, provide functions directly applicable to the civil domain such as planning, deployment and management of staff and equipment. As an example, an Army Corps C3I system may be used to organize civil or mixed convoys and the set up, management and logistics of military and civil support personnel and infrastructures in dangerous or threatened areas. This may solve critical situations, provided Military Systems are interoperable with their civil counter parts deployed.

"Re-use", on the other hand, is meant as the possibility to build a C3I System by tailoring components or modules of an existing system and by integrating them with newly developed, "ad hoc" ones. The scope of re-use, more and more a practice in defence as well as in civil industry, includes COTS devices and equipment but may also be applied to architectures, tools, design and development methodologies or even just the system developers know-how.

Trying to consider what makes the difference between any two C3I Systems or, as well, what makes them similar, it is natural to note that any complex system of this class is characterised by the following major features:

- The requirements
- The development and design methodologies.
- The functional architecture.
- The physical architecture.
- The HW and SW technologies.
- The specific functions (so called "applications").

In relation to C3I Systems re-use and dual-use it is important to consider the industrial and technological standards available at all these levels, nowadays common to military and civil domains.

Independent researches and studies, for example, on Requirement Analysis, one of the most important phases in C3I System design, demonstrated that any command and control activity may be decomposed in a logical, looped sequence of steps: data acquisition, data processing, situation assessment, planning, plan evaluation, plan execution and back.

As for the development and design methodologies, Evolutionary Development is taking the place of Waterfall Development as the most efficient and cost-effective methodology. Evolutionary Development is an adaptive approach to Design, Development and Maintenance of C3I Systems. The evolutionary life cycle has long been looked at as the key solution to guarantee the necessary flexibility to cope with operational, technological and economical changes that may occur along the life of a C3I System. This approach implies the use of proper methodologies and tools to define and keep track of system requirements, to develop system specifications, to plan and manage its implementation, integration, test and acceptance, up to the provision of logistics support, adaptive and corrective maintenance. It is often associated with the use of Rapid Prototyping tools and techniques combined with high-level 4GL languages and Object Oriented programming paradigms on top of commercial HW and SW development platforms.

The approach to functional architecture of a C3I System is based upon a standard reference model, the Open System model, which responds to requisites of software modularity, scalability and reusability. This model is characterised by a set of functional layers interacting with each other and providing services through specific interfaces. Besides being compliant to the model, a truly "Open System" uses international standards for such interfaces, so that application modules may be ported and still be able to run and operate from an "Open System" to another. Examples of accepted standards exist for:

- User Interfaces (Motif);
- Application Program Interfaces (API);
- RDBMS queries (SQL)
- Graphic (PHIGS, GKS) and Windowing libraries (Windows, X-Window);
- Communication Protocols (ISO/OSI stack);
- Operating Systems (POSIX)

The Evolutionary Life Cycle and the "Open-System" architecture are common solutions both for military and civil C3I Systems. This in turn implies the use of common:

- design and maintenance methodologies
- architectures and functions
- man-machine interface tools

The standard physical architecture for C3I Systems is the Client-Server one, apt to implement internet and intranet Web architectures, with distributed HW and SW processing (LAN/WAN connecting PCs, workstations, peripherals, database and communication servers) running on top of commercial/ standard OS (Unix/Posix, WindowsNT).

Common technologies include digital transmission devices (Ethernet, FDDI), communication protocols and routers (X.500, X.25, TCP-IP/UDP), multiprocessors ADP, ergonomic I/O equipment (monitors, pointing devices, keyboards).

From the functional point of view, a number of standard services, so called "Common User Functions", are required both for military and civil C3I Systems: Data Handling, Communications Handling, Event Handling, Map Handling, System Management, Security. The use of COTS SW is particularly indicated in digital network control, graphical applications and display, data management and distribution.

The application of standards to C3I military and Civil Systems at all such levels is the bridge between the commercial and the military worlds and favours the use of military modules, functionality and tools in civil systems and vice versa. In this framework, industrial competition and shrinking budgets have been pushing the Operational Users and the System Designer to consider and exploit, to the maximum possible level, technologies available on the market. Gradually but steadily, military requirements have been revised in this new light and partly mitigated, thus allowing the use of commercial products, hardware and software, as system components.

5. COTS Technologies

Full-Mil equipment, developed to address specific military applications, has always been expensive due to

the need to develop advanced but unique and therefore costly solutions. Furthermore, the development cycle time needed for dedicated military equipment often results in technologies being virtually out of date by the time the equipment enters into service.

Suppliers of systems designed to address commercial markets are able to spread their development costs over a higher number of customers and the availability of the product off the shelf drastically shortens the system lead time.

The use of HW and SW commercial components in military Systems appears therefore the easy way to fulfil requirements with reduced budgets. NATO recommendations, along this line, are indeed to:

- use international standards for which commercial implementations exist
- use common specifications for non-standard system components
- promote co-operation for development of non-standard system components

But, even though the technical differences between a COTS product and a MILSPEC compliant one are reduced by the dominant role of standards, many issues remains to be looked at.

Major military requirements impacting COTS HW performance are related to:

- electromagnetic emission control
- "hostile" environmental conditions
- security
- mobility/transportability

The use of commercially available software is even more complex and it bears all the technical implications of software re-use. Examples of major pre-requisites for software modules to be re-usable are:

- portability: software code has to be independent from the operating system and from the hardware configuration;
- interoperability: the interfaces between the software modules and between software and users (MMI interfaces) must be clearly defined and univocally used;
- flexibility: software modules have to work in different operative conditions maintaining their performances.

But apart from such technical difficulties, Alenia Marconi Systems experience indicates that a number of factors deriving from the use of HW and SW COTS products in military applications do increase project risks, the major ones being:

- The difficulty to evaluate the product. Evaluating a commercial product is difficult even if it is "standard" and "certified" in terms of quality. Detailed documentation of the product is rarely available before the purchase; sometimes product characteristics and performances are poorly documented, not documented or even unknown. Only the effective installation and use of the product may allow an expert system engineer to deeply "understand" the product and its compliance to the requirements. Difficulties may arise not only as a consequence of immaturity of released products but also as a consequence of unpredictable performance in stressful environmental conditions. Evaluation is particularly difficult in terms of Security, Interoperability, Robustness, RAMT and Supportability.

- The difficulty to keep the product under control. A commercial product is a "black box" and can not be tailored to the military application. For example, source code of COTS SW modules is never available. But while it is impossible for the systems integrator to modify a COTS product basic functions and structure, market forces may impose frequent release of upgraded versions of the product or of its components. The rapid response of commercial industry to technological developments may also mean the abrupt discontinuation of products. IT market has a rapid rate of turnover in terms of products (a new generation of equipment, typically, appears every 3 years) and suppliers/makers (small and big companies often grow and go bankrupt). This dynamic world is in contrast with the traditional C3I military Systems life cycle (10 or 20 years) and may have negative consequences in terms of logistic and maintenance costs. Even small changes may impact on the whole System Design with major and unpredictable economical consequences.

- The difficulty to support the product. Technical support provided by the vendor is mostly oriented to the average user. When high technical competence is needed, this may not be readily available. In case the production is discontinued, supportability may not be guaranteed.

- The difficulty to procure the product. Product availability-time can not be really controlled. Once the order is placed the delivery time is hardly guaranteed. Even when the product is delivered, its configuration may not be compliant with the order and the time to fix the supply is sometimes unpredictable.

- The "Secret Costs". The price of a COTS product, providing plenty of maybe unnecessary functions, must not be compared with the cost to develop it from scratch but rather with the cost of developing a module that fulfils the minimum, case specific system requirements, to avoid shooting unnecessarily over the target. Price versus Cost

comparison must include guarantees, assistance, maintenance, run-time licenses, upgrading agreements and property rights. Making an accurate estimation of the cost for periodical HW and SW upgrading is difficult. Considering that the price of computing power is continuously dropping and that SW portability costs for an "Open Systems" should not exceed 40% of its acquisition costs, a periodicity of 5 years for system upgrades may be the right balance between costs and state of art performances. A higher upgrading rate may be not convenient in terms of LCC (including logistic support, configuration control and so on).

How to maximise the benefits and minimise the problems associated with COTS based C3I Systems is a critical issue that requires a great deal of engineering analysis and trade-offs along the whole System Life Cycle. The use of commercial components requires a specific and systematic approach to avoid technical and project management problems. System integration of COTS products requires new strategies for negotiation of property rights, estimation of system development and maintenance costs, project planning, risk management. It also requires building sufficient flexibility into procurement contracts. Last but not least, personnel must be trained and proper skills must be developed within the Project Development Team.

6. AMS Spa Land Systems Division Experience

The Land Systems Division (LSD) of Alenia Marconi Systems Spa (AMS) offers services and expertise at all levels and for all phases of C3I systems life cycle, including complex systems design, manufacture, integration and support. This capability matured out of more than 30 years of experience in Battlefield and Air Defence C2 Systems.

LSD policy for C3I Systems acquisition, development and maintenance has long been based on the adoption of the above mentioned international standards and COTS elements have been increasingly used at all levels. In relation to this, two significant recent industrial experiences of AMS LSD are briefly outlined in the following.

CATRIN is the acronym used for a Battlefield Communications and Information System adopted by the Italian Army. The implementation of this tactical system, conceived to provide integrated and automated support up to Corps/Division level, started in the early 90's. The final live evaluation of CATRIN on the field has just been completed and the system is operational. It provides equipment and means in areas where effective co-ordination amongst ground and air friendly forces is required to optimise the employment of sensors, weapons and units, particularly avoiding mutual interference between deployed forces that may lead, in the worst case, to fratricidal casualties.

CATRIN is made of three main subsystems:

- SOTRIN, an integrated telecommunications network and related management functions providing communication services to SORAO and SOATCC subsystems;
- SORAO, providing automated support to battlefield surveillance, target acquisition and correlation, aggregation and distribution of intelligence data.
- SOATCC is the core tactical Air Surveillance, Air Defence Artillery and Army Aviation command and control subsystem

CATRIN was developed through a classic waterfall life cycle based on international and NATO standards available at system design time, such as DOD 2167/A for software development and ISO 7498 for communication protocols.

SORAO and SOATCC, the core CATRIN C2 subsystems, are entirely under the AMS Design Authority. An Open System compliant architecture has been adopted for their design to achieve modularity, flexibility and interoperability with other National and NATO C2 systems. All information is exchanged using NATO standard messages (e.g. Link16 J series and Adat-P3, respectively for "bit oriented" and "character-oriented" messages) through ISO/OSI communication protocols. Commercial protocols have been integrated in the architecture (e.g. X-25 for the WAN; TCP/IP for the LAN) but the selected profile for the higher level of the stack is STAMINA, a military version of the X.400 Electronic Mail civil standard with additional services specifically designed for military message handling. ORBATs have been implemented using a COTS RDBMS (ORACLE) but a Geographical Information System has been developed. Application software packages, coded in ADA, have been designed to achieve a high level of modularity and flexibility. Military operators are able, through user friendly interfaces, even to perform dynamic system reconfiguration IAW the role of the specific Army Corps echelon. The use of such standards and of COTS ADP equipment allows the possible re-use of the CATRIN Command and Control Centres also for civil and/or paramilitary intelligence applications.

CATRIN has, overall, a modular and flexible architecture and it has a high potential for dual-use and re-use. The latest AMS C3I systems, such as C2M, for which the use of standards and COTS

elements has been even more pervasive, enhanced such potential.

C2M is a mobile tactical Command and Control Centre developed for the Italian Air Force (IAF) and devoted to support Air Surveillance, Command and Control functions. The system has the capability to be connected to strategic and tactical networks through standard digital and analogue interfaces.

C2M is made of two modules:
- the CCTA Module for Surveillance & Tactical Control
- the CCOA Module for Operational Control & Tactical Command

CCTA and CCOA are housed in shelters containing work stations, computers, control and management facilities for voice and data communications, radios and crypto equipment.

Surveillance functions supported include:
- Surveillance (MRT included)
- Threat Evaluation & Weapon Assignment/Allocation
- Offensive, Defensive and Support Missions Control
- Centralised/De-Centralised SAM control (Hawk, Patriot)
- Italian Air Force radar integration (RAT-31S, RAT-31SL, FPS-117, HR-3000, ATCR-33);
- NATO tactical Links handling (Link-1, Link-11, Link-11b and Link-16);
- RASP generation
- UHF, VHF and HF radios handling.

Operational Control and Tactical Command functions supported include:
- Air Space Management
- Planning and management of defensive and offensive air operations
- Air tasking
- C2 Resources Management (control, allocation and deployment)
- Command Post Exercise (CPX);
- Full data exchange recording / reduction;
- Handling of Messages coming from LINK1, LINK11B, e-mail and a number of external systems (ACCAM, ICC, AOIS, STARGATE WAN connections)

C2M is integrated with the ACCAM and AOIS national networks and it is interoperable with NADGE (through Link1). As for COTS, C2M is based on client-server ADP architecture implemented with rugged HW COTS elements. Other standards and COTS components used along the development are:
- SW life cycle ISO-9001 standard.
- Designer 2000 / Erwin;
- ORACLE RDBMS;
- Network protocols (TCP/IP, SMTP, HTTP), information exchange (e-mail) and tools (Netscape);
- 10/100 Base-F Ethernet LAN;
- Sun Solaris OS;
- Unix/Windows NT portability;

The implementation of C2M is remarkable in that it has been achieved through integration of COTS elements and of the following heterogeneous components:
- an existing mobile C2 system, modified to implement the CCTA Module
- the newly designed CCOA Module and the "CARONTE" SW subsystem, specifically developed by AMS for the programme
- the ICC (Interim CAOC Capability) Software Module released by the NATO C3 Agency
- the GFE STARGATE Software subsystem (the prototyped version of which, developed by IAF, is being industrialised by AMS through reverse engineering activities and delivered back to IAF as a "product")

New Projects, such as ACCS, follow these trends, trying to use more and more COTS hardware platforms, to integrate COTS software with MILSPEC one, to adopt innovative methodologies (e.g. Integrated Product Teams) and to refer to world wide accepted standards for the whole System Life Cycle.

7. Conclusions

The use of international Standards is the way to achieve C3I Systems scalability, modularity, flexibility and interoperability, allowing such Systems to operate with other national and international C3I Systems, in different and stressful operative conditions and for different applications.

Since C3I Military and Civil Systems have been designed following common standards, the use of COTS components has been increasing and dual-use and re-use potentials have been enhanced.

Use of COTS information technology in military systems offers reduced development and support costs, improved interoperability, reduced technological risk, accelerated deployment, and support the evolutionary development concept.

In addition, the continuing trend to use and establish updated technical Standards is pushing modern C3I Systems to be based on COTS products but these are effectively "black boxes" and raise risks and concerns that must be handled properly.

Major Defence Industries, such as AMS, are adding to their system development and manufacturing capabilities of MILSPEC oriented Systems, the skills needed to offer COTS oriented, system of systems integration. This involves evaluation of technologies and products available on the market, together with innovative system design and engineering methodologies. Technical and commercial knowledge is required to determine when a system or a system component is a good candidate for migration toward a COTS approach.

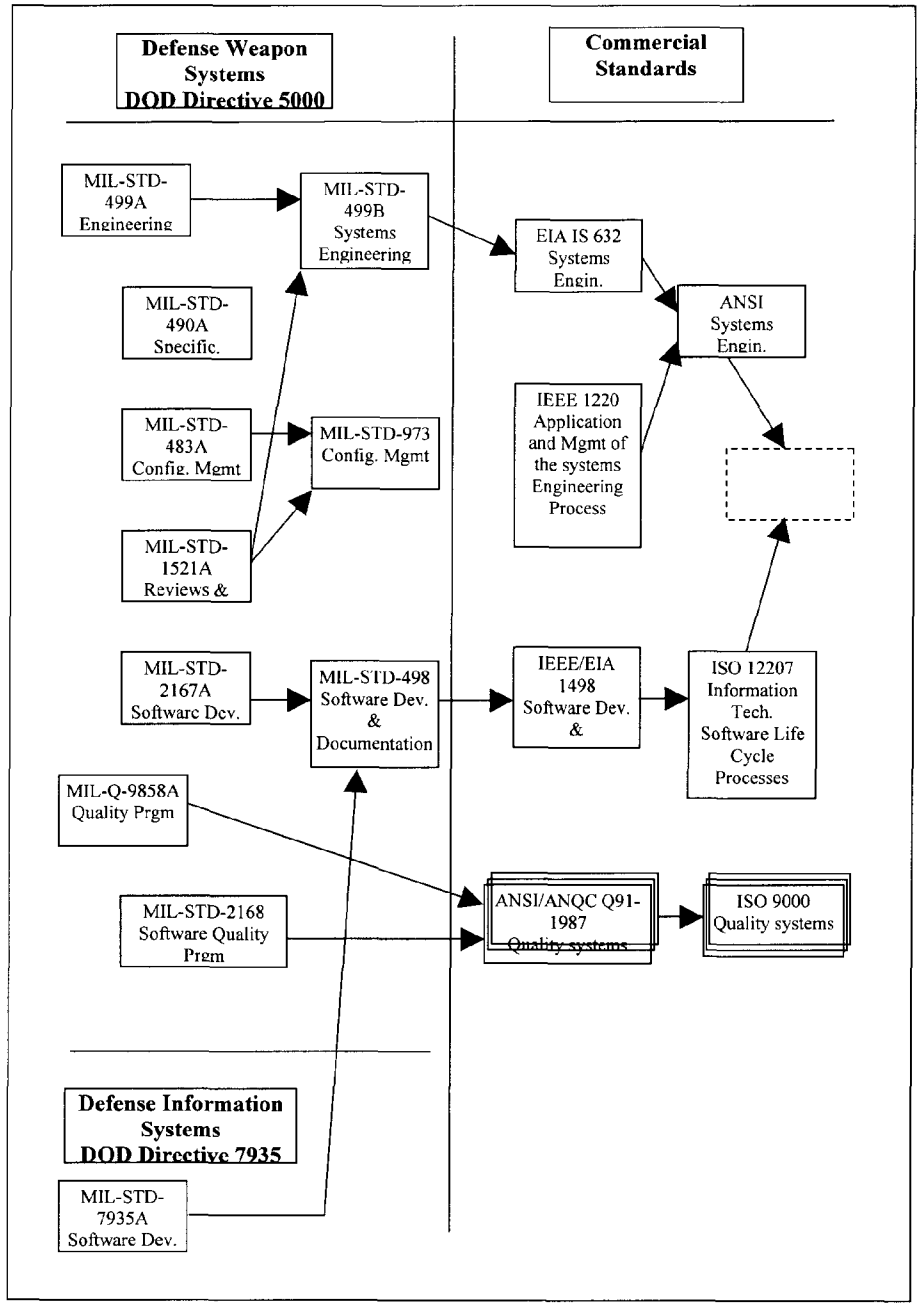

Fig.1 Military and Commercial Standard