Managing Systems Engineering Processes: a Multi-Standard Approach

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***Abstract*—Considering that system design becomes more and more complex to manage, systems engineering standards are useful and necessary for the companies. In order to choose the right standard, this paper presents an analysis of and a detailed comparison between the current releases of the main Systems Engineering standards in system design industry, ANSI/EIA-632, ISO/IEC-15288 and IEEE-1220, and illustrates how to choose a standard on the basis of specific characteristics of the project. For cases where no standard completely satisfies the criteria, we suggest a way to extend and adapt a standard.**

Keywords—systems engineering standards

I. INTRODUCTION

Since 1969, many systems engineering (SE) standards have been drawn up in different fields of application, such as military, aeronautics, automatic and management. The ANSI/EIA-632 [1], ISO/IEC-15288 [2] and IEEE-1220 [3] standards play the most important roles. For companies, it is very important to choose the right standard for successful system development. As many changes have been introduced in current SE standards by the latest releases and as the goals and scopes differ from one standard to another, engineers and managers need help in understanding and analyzing the similarities and the differences between the SE standards when choosing the standard to follow. Few papers deal with the comparisons between the current releases and the evolution of SE standards.

The purpose of this paper is to present an analysis and a detailed comparison between the current releases of SE standards and to illustrate how to choose an SE standard on the basis of specific criteria. For this purpose, we explain how and why we selected an SE standard in one of our research case studies. As the chosen standard did not completely satisfy our selection criteria, we had to find a way to extend and adapt this standard. This paper thus gives the results of a multi-standard reference, based on the contents of two SE standards, mainly according to the following criteria: coverage of the system life cycle, abstraction level, relationships between the processes, and the validation & verification processes.

The paper is organized as follows: Section II introduces the three main systems engineering standards. Section III compares them, Section IV analyses these standards and illustrates how to make a choice between them according to specific criteria; it also suggests extensions for adapting a standard with elements from other standards. Section V summarizes and discusses the different contributions of this paper.

II. A QUICK SURVEY OF THE SYSTEMS ENGINEERING STANDARDS

A. The ANSI/EIA-632:1998 standard

This standard is intended to provide a set of fundamental processes to guide developers in engineering a system [1]. It focuses on the SE of enterprise-based systems [4][5]. Fig.1 gives the structure of EIA-632; it defines 13 processes, organized into 5 groups. For each group, the standard gives the relationships between the processes included in the group.

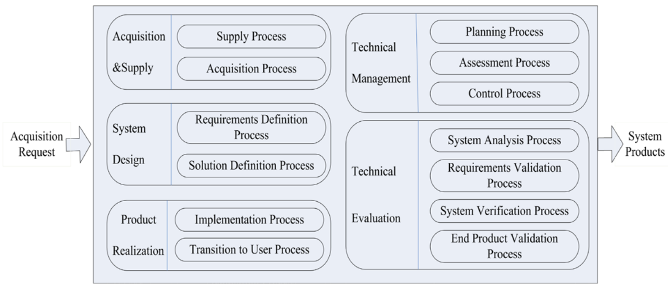

Fig. 1. Structure of the ANSI/EIA-632:1998 standard

One of the most useful features of this standard is the close connection between processes; they are coordinated throughout the project, even if it makes the allocation of responsibility to the different processes more difficult [6]. The standard aims to describe activities and tasks at a high level of abstraction. However, its goal is not to specify the details of "how to" implement process requirements for engineering a system, nor does it specify the methods or tools a developer would use to implement the process requirements [1]. The high abstraction level of task gives more flexibility to the developer for engineering a system because constraints on tasks are less detailed. It thus offers a wide range of applications.

B. The ISO/IEC-15288:2008 standard

This standard was the first international standard to provide a comprehensive set of life cycle processes for most man-made systems [7]. Its purpose is to provide a defined set of processes to facilitate communication among the acquirers, suppliers and other stakeholders in the life cycle of a system [2].

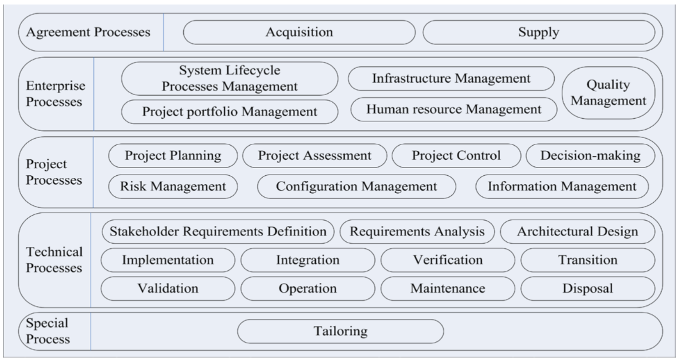

Fig. 2. Structure of the ISO/IEC-15288:2008 standard

Figure 2 shows the structure of it; it organizes processes into 4 groups: agreement processes, organizational project-enabling processes, project processes and technical processes, 25 processes in all. It describes systems engineering at the process level [7]. This standard covers the system's entire lifecycle, from conception through to retirement of the system, and the processes that cover all the stages. It describes the activities in detail. But it does not prescribe, provide or specify systems engineering methods or procedures to address detailed process requirements for the application of this standard.

C. The IEEE-1220:2005 standard

The purpose of this standard is to manage a system from initial concept through development, operations, and disposal. The scope covers the entire system life cycle, while nonetheless focusing more on product development than on life cycle definition and implementation. In this respect, it was more detailed than the EIA-632 and IEC-15288 standards, but this very detailed description makes the standard less versatile.

Figure 3 shows the structure of the standard, which defines 14 general requirements, 6 stages and 8 processes. The latest version considers the context of the system, and the systems engineering management plan. The use of this standard in complement to the ISO/IEC-15288 standard also addressed.

D. Conclusion on the three standards

All standards describe good systems engineering practices. Standards say what should be done, but try not to say how to do it. They therefore focus on processes and their related activities on requirements ('what'), rather than on methods and tools ('how'). They may suggest a life cycle to provide a context for their recommendation, although most specify their suggested life cycles as 'example'. They also vary their focus in a way that mirrors the change in industry outlook [4].

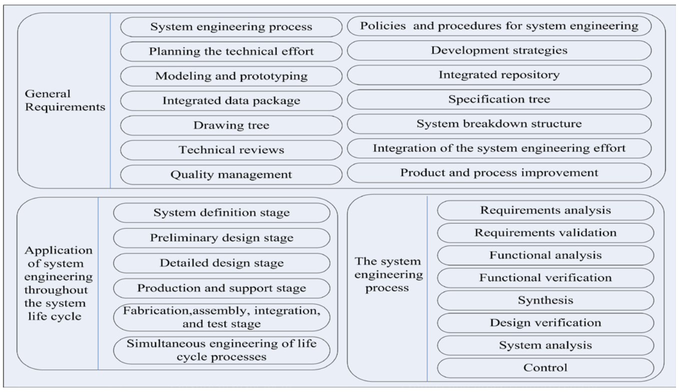

Fig. 3. Structure of the IEEE-1220:2005 standard

In short, the EIA-632 standard is more suitable for engineering enterprise-based systems; it focuses more on the technical management, validation and verification aspects. The IEC-15288:2008 standard is more suitable for engineering complex systems, especially projects that cover an entire system life cycle. The IEEE-1220 standard focuses on the development stage rather than the system life cycle or the technical management aspects.

III. COMPARISON OF THE THREE CURRENT STANDARDS

The EIA-632, IEC-15288 and IEEE-1220 standards are the most important. Obviously there are many differences between the standards. For developers, coverage of the system life cycle is one of the most important criteria for selecting a standard. The abstraction level of the processes or the activities is another important metric because it influences the flexibility and the expandability of the standard, which are inversely proportional to its abstraction level. The different focuses also influence the choice of standard [8]. For example, if the company wants to develop a small hardware system, it may choose the IEEE-1220 standard, because it describes the development stage of systems engineering more detailed. But if the company wants to develop a large software system, that may last for ten years, maintenance and retirement considerations will also be very important for the re-engineering the system; it may prefer the IEC-15288 standard. Table I presents the most important differences between standards, according to comparison criteria defined in [4].

TABLE I. SYSTEMS ENGINEERING STANDARD DIFFERENCES [4]

	ANSI/EIA-632:1998	**ISO/IEC-15288:2008**	**IEEE-1220:2005**
System life cycle	• Assessment of opportunities • Investment decision • System concept development • Subsystem design and pre-deployment • Development, operations, support and disposal	• Conception • Development • Production • Utilization • Support • Retirement	• System definition • Preliminary design • Detailed design • FAIT (Fabrication, Assembly, Integration and Test) • Production • Support
Level of detail	Medium level	Lowest level-task description level	Highest level-process description
Focus	Enterprise-based systems	Product-oriented systems	Engineering activities necessary to guide product development

The system life cycle on which the EIA-632 standard relies is enterprise-based; it defines more stages referring to the enterprise. The focus is on systems and products in general; its concern is implementing the requirements of the standards within a defined engineering life cycle, which can be applied in any enterprise-based life cycle stage to engineer or reengineer a system. The IEC-15288 standard covers man-made systems; the focus is on a set of generic processes applied as appropriate to accomplish the purposes of any one of the phases of a system's life cycle. The IEEE-1220 standard also focuses on systems and products and more precisely on the development stage of the system life cycle, but adds focus on the enterprise (large organization) as well.

Considering the level of detail, the EIA-632 standard describes the system life cycle at a requirement description level. It is more detailed than the IEC-15288, which describes the system life cycle at a process description level. The IEEE-1220 focuses on the practice for engineering a system, especially the development stage; it defines purpose, tasks and outcomes in more detail than the EIA-632. This last focuses on the conception stage; it adds more processes on the assessment of opportunities and the investment decision. IEC-15288 describes the processes at the highest detailed level. Activities, tasks and outcomes are also defined in the EIA-632, but they are less detailed than in the IEC-15288. The IEEE-1220 standard describes the processes at the least detailed level.

The EIA-632 defines the context for application of the standards as the external environment (laws, social responsibilities), enterprise environment (local culture, domain technologies) and the project environment (plans and tools) [1] [4]. The three standards cover different contexts of the project. The EIA-632 covers a small enterprise environment and the project environment, while the coverage of the environment in IEC-15288 is larger than the other two standards; it covers both the enterprise environment and the project environment. But IEEE-1220 only covers the project environment.

IV. Choice of a Standard

A. *Our research objectives*

Nowadays, project management is becoming more and more complex, with the increasing number of partners, the heterogeneity of contributions and the complexity of the systems being developed [9][10]. Our research addresses collaborative engineering questions; our goal is to improve and facilitate coordination between system engineers and project managers, providing them with a method and a tool. Thus we consider processes invoked during the development stage in SE standards, such as the requirements definition process, solution definition process, requirement validation process and the system verification process, and similar processes from the Project Management Body Of Knowledge (PMBOK) [11], a guide which provides guidelines for project management, such as project management processes, project integration management and project risk management. Although SE fixes a few principles and milestones, it does not offer a set of generic processes to monitor project progress, so that the project manager and the project team are required to implement the processes based on the PMBOK methodology. However, some conflicts remain between the processes in the SE standards and the PMBOK. Modeling these processes and interconnecting them would allow better project control. Thus, associating indicators with processes (risk, cost, time, quality, earned value, etc.) together with predictive simulation would greatly facilitate project management decision-making [12]. In our research, our aim is to develop a method and tool capable of guiding project managers and helping them make decisions by simulating, assessing and optimizing different project scenarios, while also enabling early detection of risks and opportunities. To develop this method and tool, we need to be compliant with SE and project management standards. We thus identify criteria by which to evaluate standards according to our research objectives in order to select the most appropriate.

B. *Detailed comparison of standards*

The SE standard selected had to satisfy several specific criteria. Our needs are listed below:

- We need the standard to cover the entire system life cycle, from conception to retirement.
- With increasing project complexity, V&V (validation and verification) becomes more and more important; the standard should provide a detailed view of the V&V processes.
- The object of our research was to find the best tools for coordinating processes and simulating project progress; as a result, the relationships between processes are key points for the comparison of standards.

From these needs, we derive certain criteria for refining the comparison of standards. The extent of coverage and the level of abstraction criteria have already been discussed. We add three new criteria. The first two are validation and verification, each with their respective level of detail. In order to ensure that the simulation of project progress is reliable, we need to know and model the relationships between the processes clearly. It is therefore necessary to study a third criterion, the degree of internal consistency of each standard, to enable an evaluation of the possibilities of cooperation between the processes. The resulting analysis is shown in Table II.

TABLE II. ANALYSIS OF STANDARDS ACCORDING TO THE THREE NEW CRITERIA

	ANSI/EIA-632:1998	**ISO 15288:2008**	**IEEE 1220:2005**
Validation	Gives more details about validation: requirement validation; solution representations, end products validation	Requirement validation	End product validation
Verification	Gives more details about verification: design solution verification; end product verification; enabling product readiness	Function verification	Design verification
Internal consistency	Highest, gives the relationship between the processes, activities	Higher than IEEE-1220:2005	Lowest

The V&V processes of the EIA-632 are the most detailed and the relationships between the processes are the clearest of the three standards. From Table I and Table II, we conclude that EIA-632 satisfies our needs; it focuses on the enterprise-based system and the level of abstraction leaves the user of the standard sufficient flexibility. It also offers more details about the V&V processes. However, the EIA-632 does not meet all the criteria. For example, it does not completely cover the system life cycle, and it does not consider the tailoring process to deal with the development of system complexity.

C. *Our proposal to use a multi-standard approach*

Of the standards, EIA-632 seems the most appropriate. However, no standard fully satisfies all the criteria; we therefore study the possibility of extending the EIA-632 by the addition of some elements to better satisfy our criteria

We choose IEC-15288 to complete the EIA-638. Table III combines Table I and Table II, and shows the coverage (colored portion) of our criteria by the different standards.

TABLE III. FULL COMPARISON OF STANDARDS

	ANSI/EIA-632:1998	ISO/IEC-15288:2008	IEEE-1220:2005
Scope of standard	Defines 5 process groups, a total of 33 requirements for 13 processes, gives tasks and outcomes for each requirement, gives some application context and key concepts	Defines 3 concept groups and 4 process groups, 25 system life cycle processes, gives the purpose, tasks and outcomes for each process	Defines 14 general requirements for developing a total system, gives 8 sub processes for one systems engineering process, gives the tasks and activities for each sub process
System life cycle	Assessment of opportunities Investment decision System concept development Subsystem design and pre-deployment Development, operations, support and disposal	Conception Development Production Utilization Support Retirement	System definition Preliminary design Detailed design FAIT Production Support
Level of detail of the processes	Higher level than ISO/IEC-15288, lower than IEEE-1220	Lowest level	Highest level
Focal point	Enterprise-based systems	Product-oriented systems	The engineering activities necessary to guide product development
Validation	Gives more details about validation: requirement validation; solution representations, end product validation	Requirement validation	End product validation
Verification	Gives more details about verification: design solution and end product verification; enabling product readiness	Function verification	Design verification
Internal consistency	Highest, gives the relationship between the processes, activities	Higher than IEEE-1220	Lowest

We add the maintenance process and the disposal process to EIA-632 to cover the entire system life cycle. Our proposal is thus to choose EIA-632 as the major standard because it satisfies most of our research criteria, but regarding the system life cycle (such as the maintenance and disposal processes), the integration process, the human resource management process and the tailoring process, we propose to complete it with elements from the IEC-15288 standard. The final architecture of systems engineering processes is shown in Figure 4; the processes that are underlined are selected from IEC-15288, the others come from EIA-632.

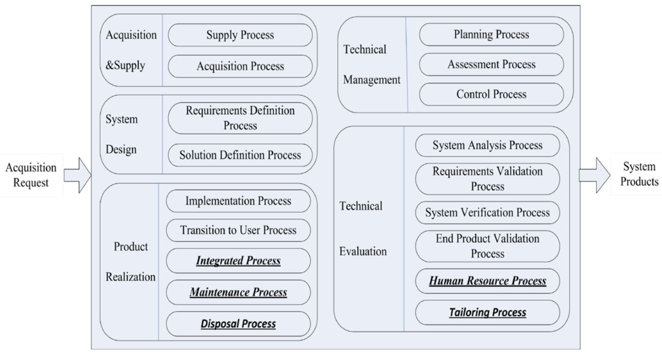

Fig. 4. The final systems engineering processes

At this stage of the study, we obtain a multi-standard SE reference that satisfies general and specific criteria. However, considering the processes of this reference and their relationships in detail, it is necessary to verify the following:

- That the processes extracted from EIA-632 or IEC-15288 are mutually compatible.
- That the processes extracted from the two standards offer a similar level of abstraction.
- That the processes extracted from IEC-15288 can be subdivided into the 5 groups of the EIA-632 standard.
- That the processes extracted from EIA-632 and IEC-15288 share the same vocabulary and that tasks and activities are not duplicated.

The next section analyzes the dangers inherent in this multi-standard approach and validates our proposal.

D. *Discussion of the proposal*

We first have to consider the compatibility of processes. As in the EIA-632 standard that there is no process that is identical to any process we selected from the IEC-15288, this eliminates the principal risk of inconsistency. Second, these processes involve only a few activities. When we execute tasks that correspond to the processes from IEC-15288, we only need to execute these processes instead of the tasks in the EIA-632. We conclude that the processes concerned are mutually compatible.

A second problem concerns the abstraction level. Although the abstraction level of the EIA-632 is higher than that of the IEC-15288, the processes from the two standards have the same architecture. Both standards give the definition, purpose, tasks, activities and the outcomes of each process. So the processes from the two standards can be used in the same way.

A third problem is how to classify the processes from the IEC-15288 into the five groups of the EIA-632. As we showed in Figure 4, the integration process, maintenance process and disposal process are clearly in the product realization group, while the tailoring process is in the technical support group.

A fourth problem concerns the definitions used in the three standards. We compared the definitions in the three standards and found that the brief definitions are identical or similar. For example, in the EIA-632, the definition of "process" is "the process is a set of interrelated tasks that, together, transform inputs into outputs"; in the IEC-15288, the definition of " process" is "the process is a set of interrelated or interacting activities which transforms inputs into outputs". Definitions of "process" in both standards have the same meaning.

After analyzing the four risks defined above, we conclude that they present no real danger for the multi-standard approach and can be avoided easily. As a result, the processes from the different standards can work together very well.

Besides, our proposal is not the first multi-standard initiative; many standards exist in multi-standard form. One of the most popular standards is the Systems Engineering Handbook (version 2.0)[13]. The purpose of this standard is to provide a set of the key activities during SE; it is in conformance with the EIA-632 but proposes some adaptations to it. It also provides some methods and tools for SE. We did not adopt the SE handbook because, although it meets all the criteria in Table III, it is excessively detailed and lacks flexibility. Another example is the IEEE-1220. Its authors thought that it could be used in conjunction with the IEC-15288 because of the different focus of the standards. The IEEE-1220 describes the development stage of the system life cycle in greater detail, and the IEC-15288 describes all the activities throughout system life cycle. Although the abstraction levels of the two standards are different, the authors of the IEEE-1220 proposed using the more detailed systems engineering process and the management requirements to complete the IEC-15288 [2]. We did not adopt IEEE-1220 either because it is only suggested for use in conjunction with the IEC-15288. The multi-standard approach that we propose for systems engineering has the same logic as the SE handbook, using two standards together, and also gives greater flexibility for development.

V. CONCLUSION

Nowadays, developing a system is becoming more and more complex. In order to develop systems quickly and efficiently, it is necessary to implement careful SE management during systems engineering. Many SE standards have been drawn up in recent years; there are many publications of systems engineering management methods like PMBOK. But the lack of consistency and the existence of conflicts between SE standards and SE management make it difficult for project managers and project teams to implement efficient project management. Our research objective was to improve the coordination of systems engineering processes with systems engineering management, in order to help project leaders choose the most efficient and coherent option for best achieving their targets. Considering this objective, the processes we consider must cover the entire system life cycle at an abstraction level that leaves some flexibility for the project team. For project progress to be simulated correctly, the validation and verification processes should be included. It is also important to facilitate relationships between the processes to simplify the simulation of project progress.

After a brief introduction of the most important SE standards, this paper analyzed and compared the three most important. EIA-632 appeared to be the most suitable standard for our purposes. It met most of the criteria, but because of the scale of most systems, it was necessary to use processes from other standards to complete it. We therefore proposed to use processes from the ISO/IEC-15288. After integrating them with the EIA-632, we obtained a multi-standard reference that can cover the entire system life cycle, allows more flexibility and expandability for systems engineering, focuses more on validation and verification and defines all the relationships between processes. This multi-standard is thus well adapted to guide complex systems engineering projects.

REFERENCES

[1] "ANSI/EIA Standard for Processes for Engineering a System". ANSI/EIA STD 632, pp c1-77.

[2] "ISO/IEC/IEEE Systems and Software Engineering - System Life Cycle Processes", IEEE STD 15288-2008, pp c1–84, 2008.

[3] "IEEE Standard for Application and Management of the Systems Engineering Process", IEEE Std 1220-2005, pp c1-66, 2007 .

[4] S. A. Sheard and J. G. Lake, "Systems engineering standards and models compared", in Proceedings of the Eighth International Symposium on Systems Engineering, Vancouver, Canada, 1998, pp 589–605.

[5] J. N. Martin, "Overview of the EIA 632 standard: processes for engineering a system", in Digital Avionics Systems Conference Proc., 17th DASC. The AIAA/IEEE/SAE, 1998, vol 1, pp B32–1–9 vol.1.

[6] J. N. Martin, "Processes for engineering a system: an overview of the EIA 632 and its heritage", Syst. Eng., vol 3, no 1, pp 1–26, 2000.

[7] G. Roedler, "What is ISO/IEC 15288 and Why Should I Care?", Present. Slides ISOIEC JTC1SC7WG7 Geneva Int. Organ. Stand., 2002.

[8] T. Dorqnm "compliance frameworks systems engineering standards" NDIA Systems Engineering &Supportability Conference, October .2000

[9] J. C. Boarder, "The system engineering process", Global Engineering Management: Emerging Trends in the Asia Pacific., Proceedings of 1995 IEEE Annual International, 1995, pp 293–298.

[10] D. H. Rhodes, R. Valerdi, and G. J. Roedler, "Systems engineering leading indicators for assessing program and technical effectiveness", Syst. Eng., vol 12, no 1, pp 21–35, 2009.

[11] "IEEE Guide–Adoption of the Project Management Institute (PMI) Standard A Guide to the Project Management Body of Knowledge (PMBOK Guide)–4th Edition", IEEE Std 1490-2011, pp 1–508, 2011.

[12] K. N. Otto and E. K. Antonsson, "Trade-off strategies in engineering design", Res. Eng. Des., vol 3, no 2, pp 87–103, 1991.

[13] "INCOSE Systems engineering handbook V2.0: A "How to" Guide for all engineers".