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Project Manager and Systems Engineer:

a literature rich reflection on roles and responsibilities

Abstract — There are several definitions of Systems Engineering (SE) in the literature, each with different definitions of its relationship with Project Management (PM), causing a great deal of misunderstanding. The paper offers a broad and critical discussion of the relevant literature with a deep reflection concerning the historical evolution and state-of-the-art of both the definition of SE and its relationship with PM. This endeavor provides two main results: (i) a conceptual framework to define SE in a project based environment and (ii) a model to identify the best formal interaction between the Project Manager and System Engineer based on the project characteristics.

Keywords: Systems engineering; Project Manager; Megaproject; Complex projects; leadership; project organization, stakeholders

1 Introduction

Despite the progress of Project Management (PM) tools and techniques, the vast majority of megaprojects still register poor cost, time and quality performance (Morris, 2008), (Cantarelli, et al., 2012) (Brookes & Locatelli, 2015). In particular, the increasing complexity and dimensions (both physical and economical) of modern systems raise the complexity of their design and delivery (Whitty & Maylor, 2009) (Locatelli & Mancini, 2010) (Vidal, et al., 2011) (Bosch-Rekveldt, et al., 2011) (Whyte, et al., 2016). The boundaries of PM are no longer limited to the delivery project itself between agreed time, cost and budget since there are strong links at program and portfolio level and lasting sustainability impacts over the operation and even the decommissioning (Locatelli & Mancini, 2012) (Brook & Pagnanelli, 2014).

Systems Engineering (SE) emerged 60 years ago to govern this growing complexity in projects. The integration of SE with PM provides a number of benefits (Ekmark & Nelson, 1997):

- it enables realistic planning and provide the means for monitoring and control;
- it enables realistic estimation of costs because the system and the engineering processes are better known in advance;
- it facilitates the identification of work packages at the early stages of the projects;
- it enables the specialists to obtain a holistic view even in large organizations using a common terminology.

Despite the growing body of literature about SE, most of the literature assumes that the Project Manager (PMer) is the project leader. For instance (Kulas, et al., 2013) focuses on the PMer risk attitudes and how they can impact leaders' effectiveness in solving the problems of free-riding and coordination. (Pollack & Algeo, 2015) reflects upon the status of project management, as measured against the traits of the paradigm professions. (Ho, et al., 2012) focuses on the PMer gender influence on task framing in projects, (Müller, et al., 2012) investigates the effect of project complexity on the relationship between project managers' leadership competences and project success. (Badger, et al., 2012) explains the importance of leadership competences as a success factor in projects and advocate for a targeted, on-site introduction and improvement of leadership competencies. More recently (Anthony, et al., 2013) investigates the coordination among department heads. Quite interesting, one of the few authors that does not assume that the project manager is the project leader are (Easton & Rosenzweig , 2015). According to (Forsberg, et al., 2005), the integration between SE and PM improves the coordination and cooperation among specialists, it enables to develop new systems that meet customer needs, it reduces the time-to-market, it improves organizational efficiency and productivity and ultimately it leads to a better competitive position.

Under this perspective, this paper aims to investigate, from the leadership perspective, the SE and its relationship with the PM discipline. In particular, this paper deals with the following two research questions:

- What is the relationship between SE and PM discipline?
- Who should lead projects and how can the Systems Engineer (SEer) relate with the PMer to achieve the ultimate project success?

A systematic literature review was conducted of studies related to the topics SE vs PM and SEer vs PMer. Consequently, this paper offers a broad and critical discussion of the relevant literature followed by a deep reflection. The paper is organized as following. The first part (section 2) presents the state of the art of the SE definitions and its relationships with the PM. The second part (section 3) discusses a framework of SE in the project environment. The third part (section 4) proposes the formal relationships between the SEer and PMer leaderships based on project characteristics. The conclusion (section 5) summarizes the key aspects and insights.

2 Literature Review: Systems Engineering and its relationship with Project Management

2.1 Systems Engineering

There is not a particular date regarding the origin of SE, however it is recognized that the II World War posed a number of engineering and management challenges that led to developing the SE discipline (Kossiakoff, et al., 2011). In the following years, the theory and lessons learned from its application in the military sectors have been incorporated in the so-called "SE standards", i.e. books of guidelines. These evolved from being focused just on the US Military environment to a large range of applications at international level (Locatelli, et al., 2014). One of the key tasks was to describe what the SE is and the leadership role of SEer. In the literature, there are several SE definitions, chronologically presented in Appendix. (Hall, 1962) is the first author describing the rationale of SE. (Machol, 1965) presents the main theory and practice that may be included into the design process. He describes six system environments and for each of them presents the tools and techniques commonly used. (MIL-STD 499, 1969) is the first standard of SE, and widely used as a reference for future documents. It supported the USA defense "acquisition programs" by proving structured guidelines (the so-called "Systems Engineering Management Plan" – SEMP) for the clients and main contractors about the preparation of a request for proposal, prepare the proposal and its evaluation. (Chase, 1974) deals mainly with System Management Organization (SMO). This author presents the criteria and the basic model for effective SMO and identifies the product-oriented management structure as necessary to achieve effective teamwork. (Sage, 1977) describes a matrix for SE that can be used as a framework. The matrix has three dimensions: firstly the temporal dimension includes the phases of system life cycle; secondly the logic dimension includes the steps that are carried out in each phase; thirdly the knowledge dimension includes knowledge from the various professions and disciplines. (Sage, 1977) stresses the importance to maintain the proper relationship among sponsors, client(s) and researchers in a system study. Later on (Sage, 1980) starts from a definition of SE in order to present which are the three objectives of the SE education, i.e.:

- to provide an interdisciplinary framework to encourage and promote facilitation, brokerage and communication;
- to approach problems and provide solutions considering technology, organizational, economic, political, environmental and social perspectives through a methodological framework consisting of formulation, analysis, and interpretation;
- to approach problems and provide solutions using appropriate elements from the systems science and operations research, systems methodology and design, systems management.

(MIL-STD 499B, 1994) describes the Systems Engineering Process (SEP) throughout the system life cycle, highlighting the importance of multidisciplinary teamwork. (IEEE, 1994) specifies the application of SE process throughout the product life cycle and introduces the concept of “Hierarchy of Systems”.

The NASA has been in the last 30 years one of the most relevant organizations involved in the development and application of SE. (NASA, 1995) presents a generic NASA approach and the specific application of SE at the project life cycle for major NASA Systems, including the main concepts and techniques to support its personnel. (Kossiakoff & Sweet, 2003) explains the application of SE methods in each stage of the life cycle model and define SE as an integral part of PM that plans and guides the engineering effort.

The recognition of SE as a profession has led to the foundation of the International Council on Systems Engineering (INCOSE), whose principal aim is to develop and disseminate the interdisciplinary principles and practices of SE (Honour, 1998). (INCOSE, 2000) describes in detail, for each process activity:

- what needs to be done: function (what to do); object (on what); objective (why) and functional participation (by whom);
- how it can be done: input, output, criteria for successful completion, metrics recommended, methods and techniques, tools, examples.

(INCOSE, 2006) shows as SE is very effective in controlling cost overruns and reducing the uncertainty of project execution through the adoption of the "Vee model" (see 3.3 and (Forsberg, et al., 2005)), to visualize the system engineering focus, particularly during the concept and development stages. (Department of Defense, 2013) describes how to apply SE to its acquisition system.

In summary the perspective of SE is wider than PM. The PM is traditionally focused on delivery a certain project on time, budget and scope, isolating the project from the "system". It seems that only recently PM academics (Turner & Zolin, 2012) start to consider the whole life cycle of what the project deliver (e.g. the infrastructure) for a wide range of stakeholders. The SE traditionally looks at the project as a component of the system with a more holistic perspective. The leadership of PM practitioners is traditionally focused on the projects (and its delivery on time, budget and quality), the leadership of SE is focused on the system.

2.2 Relationship between System Engineering and Project Management

According to the "Guide to the Project Management Book of Knowledge (PMBOK Guide)", published and maintained by the (Project Management Institute, 2013) PM is "the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements". The PMBOK is an international standard that provides PM principles and practices applicable to every project. A key actor in PM is the PMer . According to the PMBOK, the PMer is intended as the project leader and schedules, monitors and controls the various project tasks in order to achieve the project objectives. (Roe, 1995) assigns to the PMer the responsibility of managing all aspects of the project including administration, planning, directing, coordinating, controlling, and integrating all technical and analytical efforts. Among its responsibilities there is the enforcement of the SE process. (Booton & Ramo, 1984) focuses on the role of the SEer. The SEer develops the system architecture, understanding the subsystems and their internal and external relationships. (Townsend, 1994) argues that the pattern of success is the synergic application of both SE and PM. According to the author, the SEer has three roles:

1) Engineering manager, since she/he is responsible for "planning, organizing, and tracking the system design elements: technical performance, internal and external interfaces, production and support cost elements, documentation (and data management), configuration management, and test issues".

2) To assist the PMer, since she/he is responsible for risk management and for structuring the technical effort.

3) Technical task manager, since she/he is responsible for the system design. *"System design* decisions account for 70 % of life-cycle costs; total life cycle costs may be affected by as much *as two orders of magnitude".*

In a large project, the SE tasks are often allocated to individual engineers. Each SEer usually controls a subsystem or coordinates the development of elements crossing subsystem boundaries. However this is not optimal and (Ekmark & Nelson, 1997), (Cohen, et al., 2014) clearly show that to achieve a holistic view it is necessary to integrate PM models and methods, (such as organization and planning models, methods for coordination, for monitoring and control, for risk analysis) with those of the SE (such as references models and architecture, product, modelling, design and simulation methods). Planning, in particular, is fundamental since a poor planning is often associated with failure in the execution (Lindhard & Wandahl, 2015).

(Eisner, 1997) is one of the first attempt to analyze the relationship between PM and SE, along with the roles of PMer and SEer. (Considine, 1997) highlights the existing dissimilarity between SE and PM. He identifies and discusses different views of several aspects such as hierarchical decomposition, lifecycle, emergent properties, history/roots, process, R&D, holistic view, focus, driver. For example, considering hierarchical decomposition, (Considine, 1997) shows that SE breaks down the functional requirements of the system to more manageable elements. Their combination will give the desired emergent properties for the whole system. PM, instead, decomposes the scope, with the work breakdown structure, in deliverables and manageable tasks.

According to (Forsberg, et al., 2005), there is an overlap between SE and PM, particularly in requirements management i.e. the management of the project business, budget and technical baselines. Its ultimate goal is to keep the three baselines congruent. Moreover, SEer defines what is to be done technically while functional engineering decides how to do it.

According to (Stem, et al., 2006), both SEer and PMer are important stakeholders in the development and production of complex systems (e.g. military weapons). The PMer has the responsibility of planning and controlling the project’s activities, organizing the resources and leading the work within the constraints of the available time and resources while the SEer is focused on managing technical aspects integrating and balancing the work of specialized engineers from the initial design goals to the production of the final product. The issue of managing resources is acknowledged also in (Bendoly, et al., 2010). They show the challenges for a PMer to share workers across multiple projects (or sub projects), as common in complex and large projects.

(Department of Defense, 2013) considers SEer and PMer two key stakeholders in the development and production of DoD systems and defines for either who has the support or primary role according to the life cycle processes. The PMer exercises leadership, decision-making, and control throughout the system life cycle, establishing and implementing the SE. The SEer integrates various technical management processes to achieve an integrated systems design and includes activities such as the definition of architectures and capabilities and the conduction of functional analyses. The implementation of the SE approach provides the PMer with the information needed for valid trade-off decisions on cost, schedule and performance throughout the project life cycle. On the other side, the SEer is responsible for: 1) reviewing assigned

Systems Engineering Process (SEP)[1] of the project; 2) implementing SEP with PMer; 3) overseeing SEP implementation; 4) assessing the performance of the subordinate lead or chief systems engineers assigned to individual work packages in conjunction with the PMer.

INCOSE and PMI agree that PM and SE share significant objectives (Frank, et al., 2011) (Langley, et al., 2011):

1. delivering value and benefit to customers and end users.
2. integrating the required experience, knowledge, and roles to successfully achieve objectives and complete initiatives.
3. functioning effectively in a more complex environment where project requirements and outcomes are not clearly defined or have numerous components to manage.

Indeed, the practitioners of SE and of PM tend to believe that their activities are separated from each other rather than part of the same whole. While the PMer has overall project accountability, the SEer has accountability for the technical and systems elements of the project. PMer and SEer tend to view stakeholder management exclusively from their own disciplinary perspectives. The result is less than optimal and often dissatisfy the customers or users (Langley, et al., 2011). SEer and PMer have unique capabilities, essential for the project successful execution. However, there is also a "shared space" where PMer and SEer cooperate to drive the project team's performance and success. There cannot be two separate views of stakeholder management, but rather a single one that incorporates all project stakeholders' elements. SE and PM are like two interlocking pieces of a puzzle. Only when they merged the larger picture can become clear and problems resolved.

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[1] (Departement of Defense, 2001) defines the SEP as a problem solving process. Its application is in every stage of system life cycle in recursively manner; and one system level at a time, through a top-down approach. Every application of SEP adds additional detail and definition of the system. The specific activities performed vary as the system development progresses. See section 0 for further discussions.

According to (Kossiakoff, et al., 2011), SE is an integral part of PM. It deals with planning and guiding the engineering effort: setting its objectives, guiding its execution, evaluating its results and defining necessary corrective actions. (Sharon, et al., 2011) affirms that SE includes technical issues that relate to the "product" domain and PM includes managerial issues that relate to the "project" domain and they define the Systems Engineering Management (SEM) as a process conducted by continuous zigzagging between the two domains. It maintains traceability and coherence between the product models and the project plan at all levels through the hierarchical structure of both the product and the project. SEM identifies and manages the relationships between the two domains. These domains are two complementary facets of SEM. SEer must have a combination of technical and managerial skills. These skills along with personal skills are key success factors (Crosby, 2012).

The NASA point of view about the SE and the PM relationship can be inferred through its Competency Framework. The Framework distinguishes SE competencies from PM competencies and identifies common competencies to both SE and PM such as: NASA Internal and External Environments ("agency structure, mission, and internal goals; NASA project management/systems engineering procedures and guidelines; and external relationships"); Human Capital Management; Security, Safety & Mission Assurance; Professional & Leadership Development; Knowledge Management.

According to (Pyster, et al., 2012), there is a significant overlap between SE and PM scope. This overlap regards several management aspects. Both PMer and SEer deal with management issues, such as planning, measuring and controlling, leading, directing, and managing risk. SEer may have a staff position subordinated to the PMer, or on the other hand, he/she may provide the authoritative interface to the customer with the PMer, serving in a staff capacity. For the project success, it is important that there is effective communication between the PMer and the SEer. More issues, such as resource reallocation, schedule changes, system changes and impacts, risk changes, need to be quickly and clearly discussed among them (Fang, et al., 2013).

3 The role of System Engineering in managing projects

This section builds on a broader and critical reflection of the relevant literature previously presented with a deep reflection. This section and the next section 4, are the results of literature review and discussions with academic colleagues and members of PM and SE organizations. So, this is not a bibliometric papers and indeed presents the ideas that the authors elaborated over the last few years of discussion. The goal of these two sections is not to provide a definitive answer, that might or might not exist and will be depending on the ontological and epistemological perspective of the author (Easterby-Smith, et al., 2015), but rather to contribute and provoke a discussion about this crucial topic. Leveraging the literature presented in the previous section, it is possible to provide a conceptual framework of SE leadership applicable in the PM field. SE can be described through four sources that strictly interrelated(Fig. 1): "process" (discussed in section 3.1), "tools" (discussed in section 3.2), "approach" (discusses in section 3.3), and "workforce" (discussed in section 4).

SE is a methodology: it includes the process, called Systems Engineering Process (SEP), which defines "WHAT" needs to be performed. It is the orderly and logical set of steps, or sub-processes, which can be applied in each stage of the system life cycle. SE also includes the tools, called SE Tools, suggesting "WHICH" tools to apply and their appropriate combination. SE is a methodology because it does not determine only WHAT and WHICH, but also defines "HOW". The approach that SE provides to solve the complexity of systems is an open systems approach and a multidisciplinary approach. SE methodology needs workforce for its application. The aspects related to "approach", "process" and "tools" are briefly discussed in the following sections. The aspects related the workforce dimension, the core of this paper, are detailed in section 4.

PLEASE INSERT FIGURE 1 HERE

Fig. 1 SE Framework

3.1 SE Process (SEP)

Regarding the process, the literature provides more than one SEP definition ((Kossiakoff, et al., 2011) (Hall, 1962) (MIL-STD 499B, 1994) (Sage & Armstrong, 2000) (IEEE, 2005) (Bahill & Dean, 1996)). Although these authors use different words, they identify four common steps or sub-processes in the SEP.

1. Requirements analysis. This defines the project scope. The output of this step generates the requirements baseline (IEEE, 2005).

2. Functional analysis and allocation. The functional and performance requirements identified in requirements analysis are the top-level functions. This step determines the lower level functions required to accomplish them; functional allocation sets performance requirements and functional requirements, derived in the previous step, into the functional architecture, through a top-down approach (MIL-STD 499B, 1994).

3. Synthesis. This step defines and designs solutions for each element in the functional architecture, and integrates them to develop a physical architecture (MIL-STD 499B, 1994). To clarify the concept, let us consider the example of a commercial aircraft. One of the top-level functions is *“Provide Crew, Passenger, and Cargo Environment and Services*”. This function can be broken down in many others. Among them, a second-level function is *“Provide Business Services and Entertainment Services”.* This function can be broken down into many functions. Among many, a third-level function is *“Provide, Control and Support Entertainment Services.* This function pertains to television, music, and other entertainment services provided to the *passengers”.* This latter function, with many others, is allocated to subsystem *“Passenger and Crew Accommodation”*.

4. Design verification and validation. The verification process confirms that the design synthesis, resulting in a physical architecture, satisfies the system requirements (IEEE, 2005). It is based on a bottom-up approach that provides progressive verification and then integration, from individual system elements to the total system (Forsberg, et al., 2005). Validation process confirms that the system complies with the stakeholder requirements (INCOSE, 2006).

3.2 SE Tools

Regarding the SE tools, the literature review shows a large number of tools supporting the SEer effort. This paper focuses on the most distinctive tools of SE relevant for the PM.

Modelling, Simulation and Trade-off analysis are the three main decision tools. Models improve communication because they are easy and unambiguous; they enable to incorporate and quickly distribute design changes to several individuals, capturing system requirements and specifications. SE envisages the application of both models and text for the system description with precision and without wasting SE effort (Oliver, et al., 1997). Systems Modelling Language (SysML) is a standard modelling language for SE applications. The greatest benefit of SysML is to provide to system engineers a standard comprehensive model for system specifications. Diagrams, models, and other visual aids, reduce the likelihood of miscommunication (Willard, 2007): an example is the “context diagram” (Kossiakoff, et al., 2011). This tool effectively shows the external entities and their interactions with the system and instantly allows the reader to identify the external entities. Trade-off analysis supports decisions throughout the SEP. It enables to resolve conflicts, to satisfy stakeholder needs, requirements, and constraints and to arrive at a balanced system solution (IEEE, 2005).

SEMP, is the top-level plan for the SEer to recognize to all key stakeholders their own responsibilities to one another, how they interface between each other and also which procedures must be followed to carry out the SE tasks (Department of Defense, 2013).

Requirements Management Tools enable to perform a rigorous change and control of information. The important decisions facing managers of large, complex projects require appropriate support from model views that filter and organize the relevant information (Browning, 2010). The networkability of these tools ensures the connection of dispersed project teams and provides to PMer and SEer an improvement in capability to manage the enormous complexity of the project (Rundlet & Miller, 1994).

3.3 SE Approaches

Regarding the SE Approaches, it is important to highlight that SE is based on Systems Thinking (ST), multidisciplinary approach and open systems approach.

ST integrates reductionism (the concept that everything can be reduced to individual parts) with expansionism (the system can always be a sub-system of some larger system); analysis (breaking down a system into its smallest components) with synthesis (explaining the role of the system in the larger system of which it is a part); cause and effect thinking with circular cause and effect, and complements determinism with indeterminism (Pourdehnad, 2007). For example in an air transport system it is necessary to consider not only the system elements, such as commercial air transport system, but also the system of which it is part of, such as worldwide aviation system and even the widespread environmental aspects (Weiszer, et al., 2015).

SE uses a multidisciplinary approach to ensure that the customers' needs are satisfied throughout system lifecycle (Bahill & Dean, 1996). The SE view encompasses traditional engineering disciplines, technical and management domains (Ferris, 2007) with social, political/legal and human domains (Kossiakoff, et al., 2011). The multidisciplinary approach is expressed by the adoption of Integrated Product Teams (IPTs), which includes all members that impact on the project success.

SE is based on an open system approach. As a business strategy, this approach enables project teams to build and upgrade systems more quickly and affordably by using new commercial products, available from multiple sources. As a technical strategy, it focuses on a modular system design and uses widely supported industry standards for key interfaces. For example, the DoD developed weapons systems with their own, often unique and frequently closed infrastructures, making upgrades or modifications both problematic and expensive. The reduced budgets and increased dominance of commercial technology made obsolete this approach. Now, acquisition managers leverage the investments in commercial markets for affordable product development, e.g. the new weapon must fit in existing vehicle and with no or few modification, upgraded to fit in future vehicles. An open systems approach can substantially facilitate this leveraging. The DoD adopted an open systems approach to facilitate the use of widely accepted, standard products from multiple suppliers (Larson, et al., 2002).

A peculiarity of SE is that its process consists of a top down approach to system development and bottom-up approach to system realization (ANSI/EIA 632, 1999), the so-called “Vee model” (Forsberg, et al., 2005). The left leg of the “Vee”, (the top-down approach), represents the system definition and its decomposition into subsystems, flowing downwards requirements and design. The right leg of the “Vee” (the bottom-up approach), consists of an iterative process of integration, verification and validation with customer requirements from system components at the system level. The top-down approach is intended to facilitate the definition and translation of end users’ requirements in the appropriate way, through a system approach (Bluyssen, et al., 2010); it takes advantage of reuse and off-the-shelf items that satisfy assigned requirements, in order to lessen development costs and shorten development cycle time (Sage & Armstrong, 2000).

4 Leading projects: Systems Engineer and Project Manager

As presented in section 2, in the literature, there are different definitions of the relationship between SEer and PMer: SE and PM as distinct disciplines: (Ekmark & Nelson, 1997); SE part of PM: (Eisner, 2002) (Kossiakoff, et al., 2011); overlap between SE and PM: (Townsend, 1994), (Roe, 1995), (Sheard, 1996), (Ekmark & Nelson, 1997), (Forsberg, et al., 2005), (Stem, et al., 2006), (Langley, et al., 2011), (Department of Defense, 2011), (Pyster, et al., 2012); and SE and PM, parts of System Engineering Management: (Sharon, et al., 2011). After clarifying the key aspects of SE in projects, this section discusses four leadership paradigms of the relationship between PMer and SEer optimized according to the system characteristics (Fig. 1). The best configuration of the relationship between PMer and SEer depends on many factors, such as the size of the project, the number of stakeholders, the level of technical complexity and so on. All these factors can be conceptually traced back to two basic dimensions: complexity and novelty. The first dimension relates to the degree of system complexity. This enables to distinguish Simple Systems from Complex Systems. Complexity is a relevant variable respect to the management of a certain project (Shenar, 2001). Complex "Systems" consists of many different parts strictly interrelated; Simple Systems have opposite characteristics. The second dimension relates to the level of system novelty. This enables to distinguish Consolidated Systems from New Systems. With new systems, the definition of leadership roles and responsibilities, the choice of appropriate organization's structure and the risk management become more critical. The intersection of these two dimensions generates four possible combinations. For each of them a different relationship paradigm is analyzed.

PLEASE INSERT FIGURE 2 HERE

Fig. 2 The Relationship paradigms between Systems Engineer and Project Manager

4.1 Simple System-Consolidated System

If a project is simple or complex, it makes the difference to the management of project (Shenar, 2001). In Simple System-Consolidated System, regular skills to lead the project are sufficient and management issues can be solved through the experience gained in previous projects. Moreover, there is a correlation between rework costs and project size: in small projects, mistreated SE interface definitions and risk resolutions have a lower impact than in larger projects, in which the interdependencies increase exponentially as well as the rework costs (Pyster, et al., 2012). Therefore, the PMer may also be a leader and technical manager, performing both roles of PMer and SEer. The proposed relationship between SEer and PMer is *"Overall Overlap (OO)",* where the PMer performs the role of SEer. For example, the design and delivery of a small solar plant (1-10 MWe) can be considered an example of this project.

4.2 Simple System-New System

In Simple System-New System, the relationship "OO" is inadequate to face the challenges coming from the high system novelty. Due to the nature of the new scope of the work, respect to the previous case (OO), the two roles need to be distinguished. SE emphasizes the planning and design of new systems to better perform the existing operations, or to implement operations, functions or services never performed before (Hall, 1962). With new systems, it is difficult understanding the architecture and the tasks necessary to develop it (Browning, 1999); and the customer often has difficulty in expressing the requirements in a manner complete and consistent, and in terms that can be utilized by a system developer (Eisner, 2002).

For developing new system, a success factors is the adoption of holistic approach in the early stages of the life cycle (Khurana & Rosenthal, 1998). The novelty introduces high management risk and therefore must be carefully managed: consequently, leadership and management aspects become very critical. To manage successfully the system novelty the PMer should play a central role and is in charge of the SEer. It is important that these two players work together being perfectly able to communicate and share information. It can be considered as part of this category all projects that develop unprecedented systems but that have a simple structure with few elements and simple interactions among them, such as the deployment of a new windmill.

4.3 Complex System-Consolidated System

In Complex System-Consolidated System, distinguished roles are necessary: the relationship "OO" can result inadequate for the challenges that the project requires managing. The reason of distinguished roles is that the nature of the work activities is significantly different and depth technical skills become very critical to manage successfully the project. Complex systems, particularly large complex system, are jeopardized by a number of risk, including 'Design Variations', 'Variations by the client', 'Inflation in price of construction materials', 'Dispute for ambiguity of contract conditions' etc. (Wang & Yuan, 2011).

According to (Ryschkewitsch, et al., 2009) SE is about *"getting the right design"*. Complex systems typically fail because of the unintended consequences of their design, the things they do that were not intended to be done. For (Kossiakoff & Sweet, 2003) the function of SE is to guide the engineering of complex systems. According to (INCOSE, 2000), (INCOSE, 2010) (Kossiakoff, et al., 2011) the SE is an effective methodology that can be especially applied to complex systems. The good communication and cooperation between SEer and design specialists also become critical. Moreover, higher system complexity brings higher technological risk, and if also there are safeties issues, the SE Process become fundamental, and consequently the technical effort becomes critical. Complex systems have complex interactions between project risks (Marle, 2015). PMer should be subordinate to SEer, and support it into the guide of the overall management effort. In this case, the proposed relationship between SEer and PMer is "Technical Leadership (TL)" where SEer plays a central role. An example of this kind of project is the replication "N-of-a-Kind" of a nuclear power plant in the same country (Locatelli, et al., 2014).

4.4 Complex System - New System

Worldwide there is increasing requirement of projects (usually large) characterized by complicated interactions with several disciplines involved, critical configuration management, dozens of subcontractors, several dependent systems (Locatelli, et al., 2014). The necessity to deliver this type of projects, very risky and difficult to manage (Oehmen, 2012), has been the historical reason to develop SE. The increasing complexity of projects makes traditional PM tools and techniques inadequate (William, 1999). The complexity of system requires continuous interactions among the members of the project (Eisner, 2002). This complexity can be managed by the integration, (namely by coordination, communication and control) (Baccarini, 1996) and by system thinking (Pourdehnad, 2007) (Shen, et al., 2000). The use of system thinking in PM provides flexibility in planning, communicating and controlling activities; consequently, innovation projects are more successful (Kapsali, 2011). The combination of different processes, such as system integration and project and PMer is necessary for successful megaproject (Davies, et al., 2009). In Large and Complex projects, the activity control is very important (Project Management Institute, 2013).

With new systems, innovative elements have characteristics not yet fully measured or understood and subject to change (Peña & Valerdi, 2014). Their usage in the engineering of new systems increases the risk of incurring in unexpected properties with potential impacts on cost, time and system performance (Kossiakoff, et al., 2011). With new systems, it is difficult to understand the architecture and the needed tasks (Browning, 1999). Highly innovative projects depend on the alignment of organization's resources and processes with risks (Erzurumlu, et al., 2014). Often the customer has difficulties in expressing the requirements in a complete and consistent manner, because he has no awareness of what he wants and/or he does not know the "specific language" that can be clearly understood by a system developer (Eisner, 2002). A success factor is the adoption of a holistic approach in the early stages of the life cycle (Khurana & Rosenthal, 1998).

On the base of the above considerations, the ideal relationship in this situation between SEer and PMer is *"Perfect Integration (PI)"*. The *"PI"* is based on shared responsibilities between SEer and PMer. Usually, the PMer is the only person accountable for the cost, time and quality performance of its projects, but the technical solutions are developed outside its range of authority. The system solution, identified by the SEer, usually engages a large portion of the budget, impacts on the schedule and determines the technical performance. The shared responsibilities between the SEer and the PMer include processes such as planning of the entire project, risk management, stakeholders' requirement definition and integration process. With no integration between SE and PM discipline, the identified system solution is less than optimal (Langley, et al., 2011). The requirements are tracked and managed separately therefore often the result is something different from what the customer or end user expects, and so he is dissatisfied; work and effort are duplicated, and project team members often receive conflicting guidelines. Costs and schedules are developed independently from the technical scope, and the work often exceeds budgets and timetables. Into the perspective of *"PI",* SE should be applied also in the early phases of a project (Department of Defense, 2013) (Watt & Willey, 2003). Usually, the PMer is assigned to generate the proposal during the bidding process and he refers to the SEer (formally or informally due to the company rules) even if he is not officially assigned. It is essential that the technical concepts and the resulting design and interfaces are feasible, hence, that there is the *"PI"* between SEer and PMer roles. This is crucial particularly in the early phases where the SEer ensures that the scope of work in the statement of work includes all the products and services needed to complete the effort (Kossiakoff, et al., 2011). The contribution of SE is also in the project estimation efforts by ensuring the understanding of the overall system life cycle, the identification of dependencies on other systems and organizations, and the identification and planning of resources with key skills (Pyster, et al., 2012).

5 Conclusions

The goal of this paper is to provide a starting point for a discussion about the interfaces and relationships between project and system, project management and system engineering, project manager and system engineers. It is astonishing to see how the different communities (intended as both epistemological communities and professional communities) created a bodies of knowledge and professional associations with a limited interaction between each other. This is quite startling since, to some extent, they share the same ontological domain. Far from providing definitive answers this paper offers a broader and critical reflection of the relevant literature in SE and PM with a deep reflection. The goal is to contribute and provoke a discussion about interfaces and relationships previously presented.

So, if the question is "who should lead projects"? The simple answer, "The PMer" is wrong. It depends on project characteristics and SEer has a lot to say. SE is both a management and technical discipline. The technical concern is based on the "System", which has substantial technical components. This concern is principally technological and is expressed in the interests in designing the right thing to achieve benefits for the user of the system and in producing a system that must be suitable for its social or organizational context of deployment. SE also has a management concern, addressing the governance of the technical work (Ferris, 2007). The authors believe that the ideal leadership roles of SEer and PMer to achieve better project performance depends on the system characteristics. SE enables to define a balanced solution for complexity. PM is the discipline that concerns with the planning and control of the overall project and since SE addresses the planning and control of the technical works, an overlapping of responsibilities always exists. In simple and consolidate systems the PMer performs the role of SEer, in a simple but new systems the PMer should play a central role and he/she is the leader of the SEer. In complex but consolidate systems the PMer should be subordinate to SEer. For new and complex systems, the perfect integration between SEer and PMer is the optimal relationship: this means that the SEer is not second to PMer, but they have shared responsibilities at the same level.

This paper relies on of the extensive existing research done in the SE and PM fields in USA and Europe. A natural progression of this seminar work is the extensions (with other dimensions) and empirical validation of the framework presented in this paper. The authors envisage a tougher discussion about leadership in projects and project-based organizations, particularly in the case of complex and megaprojects. The poor performance of those projects must provide the stimulus for further research and the role of the leadership.

FIGURE 1

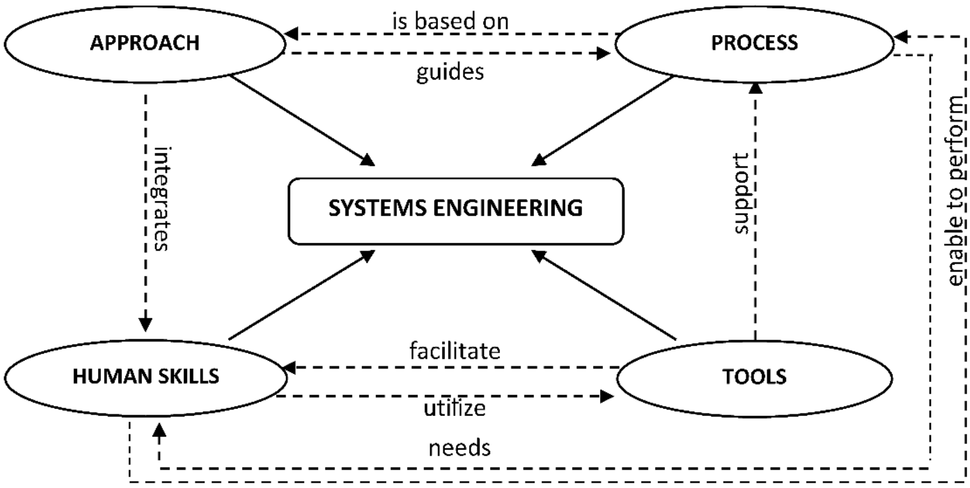
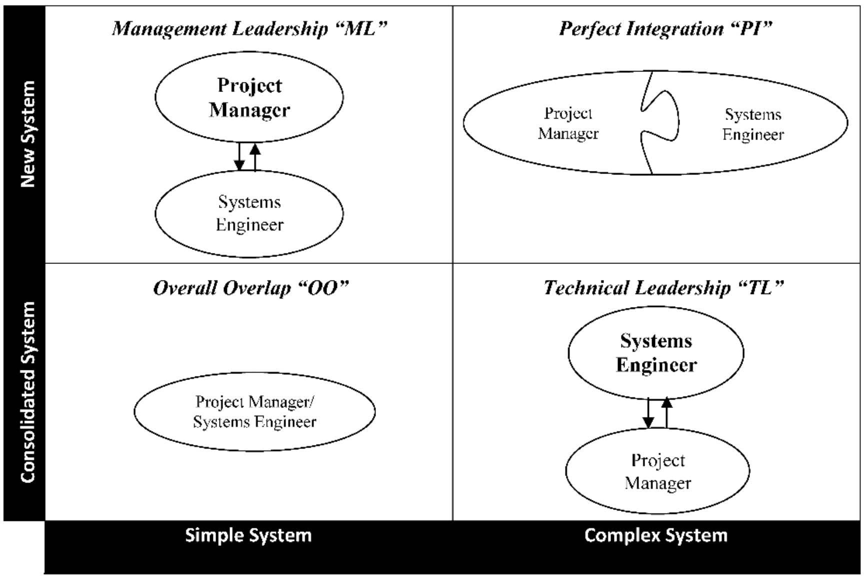


FIGURE 2



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APPENDIX - What is Systems Engineering? A Chronology

Ref	SE Definition
(Hall, 1962)	The most useful mode of definition for SE is by considering it as a process.
(Machol, 1965)	SE is concerned with the design of specific class of systems. Thus, the output of a systems engineer is a set of specifications suitable for use in constructing a real system out of hardware.
(MIL-STD 499, 1969)	SE is the application of scientific and engineering efforts to: transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test and evaluation; integrate related technical parameters and ensure compatibility of all physical, functional and program interfaces in a manner that optimizes the total system definition and design; integrate reliability, maintainability, safety, survivability (including Electronic Warfare), human and other such factors into the total engineering effort.
(Chase, 1974)	SE is the process of selecting and synthesizing the application of the appropriate scientific and technical knowledge to translate system requirements into system design and subsequently to produce the composite of equipment, skills and techniques that can be effectively employed as a coherent whole to achieve some stated goal or purpose.
(MIL-STD 499A, 1974)	The management of the engineering and technical effort required to transform a military requirement into an operational system. It includes the system engineering required to define the system performance parameters and preferred system configuration to satisfy the requirement the planning and control of technical program tasks, integration of the engineering specialties and the management of a totally integrated effort of design engineering specialty engineering, test engineering logistics engineering and production engineering to meet cost, technical performance and schedule objectives.
(Sage, 1977)	SE is an appropriate combination of the mathematical theory of systems and behavioural theory in a useful setting appropriate for the resolution of real world problems.
(Sage, 1980)	It is possible to define SE in terms of its structure, its function, or its purpose. Structure. SE is management technology to assist clients through the formulation, analysis and interpretation of the impacts of proposed policies, controls or complete systems upon the need perspectives, institutional perspectives and value of stakeholders to issues under consideration. Function. SE is an appropriate combination of the methods and tools of SE, made possible through use of a suitable methodology and systems management procedures, in a useful process-oriented setting that is appropriate for the resolution of real-world problems, often problems, often-large scale and scope. Purpose. The purpose of SE is information and knowledge organization that will assist clients who desire to define, develop and deploy total systems to achieve a high standard of overall quality, integrity and integration as related to performance, trustworthiness, reliability, availability and maintainability of the resulting system.
(Booton & Ramo, 1984)	SE is the design of the whole as distinguished from the design of the parts.
(MIL-STD 499B, 1994)	An interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and life-cycle balanced set of system people, product, and process solutions that satisfy customer needs. SE encompasses: the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for, system products and processes; the definition and management of the system configuration; the translation of the system definition into

	work breakdown structures; and Development of information for management decision-making.
(IEEE, 1994)	An interdisciplinary collaborative approach to derive, evolve, and verify a life cycle balanced system solution that satisfies customer expectations and meets public acceptability.
(NASA, 1995)	SE is a robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals. The approach is usually applied repeatedly and recursively, with several increases in the resolution of the system baselines (which contain requirements, design details, verification procedures and standards, cost and performance estimates, and so on).
(Eisner, 1997)	SE is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near-optimal manner, the full range of requirements for the system.
(INCOSE, 2000)	An interdisciplinary approach and means to enable the realization of successful systems.
(Kossiakoff & Sweet, 2003)	The function of Systems Engineering is to guide the engineering of complex systems.
(INCOSE, 2006)	SE is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.
(Department of Defense, 2013)	SE is the set of overarching processes that a program team applies to develop an operationally effective and suitable system from a stated capability need. SE processes apply across the acquisition life cycle (adapted to each phase) and serve as a mechanism for integrating capability needs, design considerations, design constraints, and risk, as well as limitations imposed by technology, budget, and schedule. The SE processes should be applied during concept definition and then continuously throughout the life cycle. SE is a broad topic that includes hardware, software, and human systems. It is an interdisciplinary approach for a structured, disciplined, and documented technical effort to simultaneously design and develop systems products and processes for creating and integrating systems (hardware, software, and human) to satisfy the operational needs of the customer. It transforms needed operational capabilities into an integrated system design through concurrent consideration of all life cycle needs. As systems become larger and more complex, the design, development, and production of such systems or systems of systems (SoS) require the integration of numerous activities and processes. SE is the approach to coordinating and integrating all these acquisition life cycle activities. It integrates diverse technical management processes to achieve an integrated systems design.