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Enhancing Engineering Project Management Through Process Alignment

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Abstract: In order to lead successful projects, coordinating the different business units of a company is compulsory. This paper proposes a framework to make companies' practices evolve toward a better alignment of the business units based on their processes, and illustrates it with project management and systems engineering processes. Indeed, all the different organization units intend to serve the common global objective to satisfy the customer needs, and need to closely collaborate during projects. However, work organization in companies often leads to barriers between these stakeholders, with the result of an incoherent decision-making that may compromise project execution. Therefore, the issue of processes alignment from different domains lies at the very heart of ongoing research topics and ranks first among economic and industrial concerns. This paper uses a qualitative approach to show how different business units' processes can be integrated and illustrate this framework by aligning the systems engineering and project management processes within a certain engineering project context. By using the proposed framework, different teams (or even different companies, in a context of distributed enterprise) can align their practices, while also making them evolve toward a better compliance with standards.

Keywords: Systems Engineering, Project Management, Standard Alignment, Process Integration

EMJ Focus Areas: Program & Project Management, Systems Engineering

Many technical projects end in failure or do not end with the expected success; the product or service does not meet customer expectations, is only partially compliant with specifications, or is not delivered on time or at expected cost. Extensions of project time and budgets are generally required in order to achieve acceptable results. Often, it is not the technical complexity that is involved, but rather problems in the management of objectives and alternative solutions, inconsistent team expectations, incompatible stakeholders' practices, lack of coordination between activities, to name a few (Andres & Zmud, 2002; Blackwell et al., 2009; Patanakul, 2014). This raises questions about how to improve the management of engineering projects in order to have a better approach and better results. To improve project performance and to successfully lead projects, a thorough coordination of the different stakeholders involved (teams, business units, suppliers …) is mandatory, as highlighted in (Brammer & Millington, 2004; De Graaf & Loonen, 2018; Hsiao, 2014; Rajkumar, 2010). Indeed, although stakeholders each might have specific visions and targets, they need to serve the common global project objective to satisfy the customer needs at the end, and therefore must closely cooperate during the whole projects. However, work organization, often designed in silos, as stated by (Forsten-Astikainen et al., 2017; Kevan, 2016; Serrat, 2017), leads to segregation between stakeholders, each referring to his own specific processes, with as result an incoherent decision-making that may compromise project execution. Efficiently managing technical developments is a strong source of motivation for companies as well as for international standards organizations and governments; the issue of process alignment lies at the very heart of ongoing research topics and ranks first among economic and industrial concerns, as demonstrated by recent surveys in (Rebentisch & Prusak, 2017; Tallon, 2007; Tallon & Kraemer, 2003).

Some studies (e.g., Conforto et al., 2013; Faraj & Sproull, 2000; Hernandez-Vivanco et al., 2018) revealed that efficiently coordinating stakeholders during the project is vital for companies. To illustrate their conclusions, the authors took the case of systems engineering and project management domains, that are two critical factors for the success of engineering projects (Cook & Ferris, 2007; Locatelli et al., 2014; Philbin, 2008). They demonstrated that aligning practices allows delivering better solutions and has a great impact on organizations and on the customers' satisfaction. This means integrating people, objectives, processes and procedures, understanding everyone's role and their values, promoting collaboration over competition, sharing information, using combined standards. (Faraj & Sproull, 2000; Karlsen, 2002; Rebentisch & Prusak, 2017) indicated that the use of one unique standard comprising both Systems Engineering and Project Management is one of the potential ways to improve cooperation, thus reducing budget slips, scheduling errors, and a variety of challenges that affect the final project outcome. However, the authors did not provide any pragmatic solution to integrate different processes, referring to different standards, toward a unique standard.

This paper thus proposes an operational framework to align processes from different standards in order to better integrate different business practices, and illustrates the proposal in the context of an alignment of Systems Engineering and Project Management practices. The section 'Literature Review' gives an overview of the scientific context. The section 'Research methodology and proposal of a framework' presents our research approach and the resulting framework we propose for enhancing engineering project management through processes alignment; it is applied in a case study. The following

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section discusses the results, their interests and limitations. Then the paper considers the implications on the practice of engineering management. Finally, it concludes on the contributions and gives some perspectives for future research.

Literature Review

This section gives a broad overview on the current state of research as reported in literature. Two main questions are addressed: the need of coordinating practices and the issues and stakes of integrating Systems Engineering and Project Management.

Need of Coordinating Practices by Aligning Processes

Several analyses (Aziz & Hafez, 2013; Johnson & Gustafsson, 2006; Liu & Atuahene-Gima, 2018) outlined that, in today's highly competitive industrial environment, companies have to find solutions to keep improving their performance for market positioning reasons. To this goal, they need to better control and shorten development cycles while maintaining the achievement of objectives (Griffin, 2002; Meredith et al., 2017; Meyer & Utterback, 1995). (Conforto et al., 2013; Hardman & Colombi, 2012; Mir et al., 2016) proposed several complementary solutions that can contribute to this: define, precisely describe and promote a set of best practices, clearly define the objectives, the roles and responsibilities, make teams cooperate, manage the data and ensure their continuity all along the project in-between stakeholders, select a few of reliable suppliers and partners, deploy standards and seamless tools. At the same time, the trend in industry is toward cooperating teams, larger projects with more and more partners and also companies' merger to either bring in complementary knowledge or to strengthen existing knowledge. The goal remains the same: developing a product or a service, fulfilling the clients' requirements, within an optimal design and development approach. This brings people with different backgrounds working together. However, they naturally base themselves on their own framework that usually relies on procedures from their "home" company or department. As a result, these different perspectives potentially lead to important misunderstandings.

The awareness to organize work and manage competencies differently is a major stake, allowing organizations to be consistent with business models between suppliers and between different entities inside the company (Chesbrough, 2010; Morris et al., 2005; Pedersen et al., 2018). Indeed, (Goh, 2002; McKinsey Global Institute, 2013) and more recently (Gupta et al., 2019) analyzed that, as companies often are structured in silos by business units, this usually leads to an extension of development cycles, to projects failures or to projects that do not reach their objectives (costs, delays, quality, customer satisfaction). Some more studies (Davis, 2017; Engelbrecht et al., 2017; Standish Group International, Inc, 2015) have assessed that project success rates were less than 40% only (delivered on time, on budget, with required features and functions). However, each business unit is not a stand-alone entity, it is connected to the others, and a good cooperation, based on common bases and common understandings, is a must.

These observations are not new, and (Leach, 2014) already noted this situation. However, the industrial situation regularly and progressively grew along with the quest for continuous improvement. Pushed by the growing complexity of systems that are being developed as well as stronger quality constraints, project durations are becoming longer and longer (Chaudhuri & Boer, 2016; Maylor & Turner, 2017). Companies are actively looking into their processes, their associated Product Life-Cycle Management (PLM) tools and their organization, to try to understand how and why this is occurring. It turns out that, beyond the necessary continuity in data management and tool interoperability, a major key to improve their global performance lies with the mastery and the consistency of the processes used by the multiple stakeholders involved in systems development (Aversano et al., 2016; Mardani et al., 2015; Tallon, 2007).

Integrating Systems Engineering and Project Management: Issues and Stakes

Let us illustrate this urgent need of better coordination through process alignment with the case of systems engineering and project management. The context is that, with the growing systems complexity and increasing size of projects, the roles of systems engineers and project managers progressively became more crucial (Ahmed & Anantatmula, 2017; Cohen et al., 2014; INCOSE-UK, 2009). However, a cultural barrier has steadily grown over time between them. As noted by several surveys (Rebentisch & Prusak, 2017; Sharon et al., 2011; Zeierman & Ben-Asher, 2016), the chief systems engineer is working on the (technical) solution of a development, while concurrently the project manager is working on the project organization. The former focuses on the technical accountability, the later on the overall managerial elements of the project. They often do not operate for a final perspective, they often see the project as "yours" or "mine," without necessarily see it as "our problem." In this situation, it frequently happens that systems engineers and project managers "live their own life," erroneously believing that what they do is different, thus forgetting that their job is part of a whole (Arnold, 2012; Langley et al., 2011; Rebentisch & Prusak, 2017). Consequently, projects' expenditure rises, projects need more time to reach the desired goal, and even then, often provide suboptimal solutions to the customers (Conforto et al., 2013; Langley et al., 2011; Walden et al., 2015).

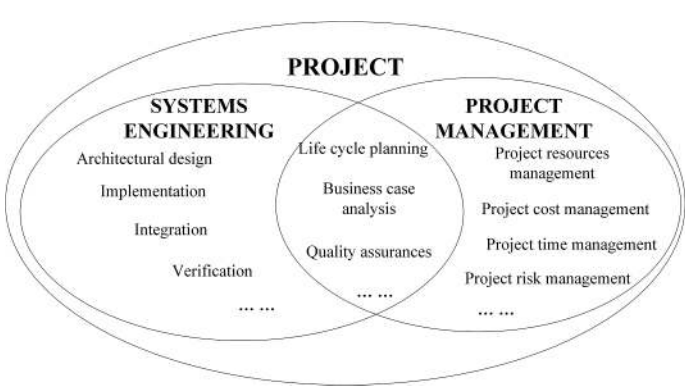
The joint Alliance INCOSE-PMI, together with the Massachusetts Institute of Technology (MIT), conducted several activities to show how organizations can become more efficient and can get better performance outcomes (PMI & INCOSE, 2016). Among a few, one way of improvement is to integrate the methods, tools, and performance from systems engineering and program management (Dasher, 2003; Oehmen et al., 2012; Rebentisch & Prusak, 2017). (Laporte et al., 2016; Saaty, 2004; Sharon et al., 2011) argue that the future of engineering projects depends on a team integrating both systems engineers and project managers. They are supported in their opinion by (Componation et al., 2008; Hart, 1995; Sols & Salado, 2019), that are convinced that creating a stronger alignment and integration between project management and systems engineering practices can help delivering complex large-scale engineering projects which align with objectives within schedule projections, as well as deliver the requirements to the customers' perspectives.

Ho and O'Sullivan (2018), Hussain et al. (2009), and Rebentisch and Prusak (2017) argue that the use of standards or standardization framework can improve the project efficiency. Among the pathways toward this alignment (Barafort et al., 2002; Faraj & Sproull, 2000; Rebentisch & Prusak, 2017), underline the interests of using of combined standards and of a better coordination of procedures at a transversal level, to ensure the uniformity and coherence of practices, by formalizing (description and modeling) and harmonizing the stakeholder practices. Indeed, depending on the size of the company and its history, there may be a single standard, or several specific standards (Delisle, 2019; Laporte et al., 2008; Tarí et al., 2020). Analyses of standards can allow identifying where difficulties may reside, which sources may induce inefficiency, and studying how to optimize the activities. For instance, important overlaps can be noticed between the scope of systems engineering as described in the SEBoK or Capability Maturity Model Integration (CMMI) (BKCASE Editorial Board, 2019; Fiorèse & Meinadier, 2012; Rebentisch & Prusak, 2017) and the scope of project management as described in the PMBoK (PMI, 2017). Looking at the processes from the concerned standards, several similarities can be identified. For example, life cycle planning, business case analysis, and quality assurances are considered in both Systems Engineering and Project Management (see Exhibit 1).

As underlined by (Langley et al., 2011; Rebentisch & Prusak, 2017; Sharon et al., 2011), project execution can notably benefit from exploring the similar or complementary aspects of systems engineering and project management functions and activities. However, the absence of common standards or explicit connections between systems engineering and project management put the responsibility on benefiting from the close relationships on the shoulders of the people actually performing the work, i.e., systems engineers and project managers. Sage and Rouse (2014), Sharon et al. (2011), and Rebentisch and Prusak (2017) advanced that systems engineering and project management are two lightly integrated domains that could benefit from a stronger integration. These authors proposed that actual systems engineering management practice involved continuous cognitive zigzagging between systems engineering - the product domain - and project management - the project domain.

Several initiatives addressed this issue. The two disciplines can be disjointed, partially intersecting, or one can be seen as a subset of the other (Adcock et al., 2016; Ferguson, 2007; Turner et al., 2016). (Adcock et al., 2016; Sharon et al., 2011; Turner et al., 2016) identified that the overlap between systems

Exhibit 1. Overlaps Between Systems Engineering and Project Management (Kossiakoff et al., 2011)



engineering and project management depended on the environment and organization. From the INCOSE and PMI experts' point of view, the root for the observed problems can be found in the (mis-)alignment of processes, roles, and languages (Arnold, 2012; Rebentisch & Prusak, 2017; Sharon et al., 2011). The conclusion was that, in real life, the interaction of the two domains often results in mismatched expectations and confusion as to who has the responsibility for each process/knowledge area, in part due to mismatched process descriptions according to standards.

Very few standards clearly define relationships between these disciplines. Laporte et al. (2008), Laporte et al. (2016), and O'Connor and Laporte (2012) attempted to address the integration of systems engineering, software implementation, and project management with the recent ISO/IEC 29110 series of standards and technical reports, stepwise published since 2011 (ISO/IEC, 2011) and aiming at helping Very Small Enterprises (VSEs). The goal of this standard is to support the VSEs with the relevant international standards to their business needs and also to justify the application of the standards to their business practices. In this series of standards, fewer processes are defined than in the other standards and guides. The SEBoK (Systems Engineering Body of Knowledge) (BKCASE Editorial Board, 2019) deals with the relationships between systems engineering and project management in its part 6 but does not suggest how to integrate them. Looking at the state of the art and state of practices, it appears that there is a true need for a methodological guide to progress toward a better alignment of processes.

Research Methodology and Proposal of a Framework

Research Methodology

Our research objectives are to:

- Develop a comprehensive framework for aligning the processes from different business units;
- Validate the applicability of the framework using a project involving systems engineering and project management;
- Discuss the usefulness of the framework to assist the project managers to better and collaboratively manage the project.

To these goals, an analysis of the commonly used standards in systems engineering and project management was done. Overlaps and similarities between them were identified, but also incoherencies between processes (Xue, 2016; Xue et al., 2017, 2020). This led to results on the 'alignability' of the different standards and the evaluation of gaps to align them. Following this phase, several projects were analyzed and in particular, an industrial survey was done (Vargas et al., 2018; Zheng et al., 2017) so to see how standards were used in industry and what the real issues were resulting from badly aligned practices. Several pathways were considered so to overcome the issues and thanks to an additional industrial survey, these findings have been given a broader scope for the alignment of processes between the different work units. The retained pathway was to improve cooperation between teams by an integration of referred standards. Once the problem stated and the objective clear, we contributed to build this integration with the proposal of a framework to align the processes described in standards step by step.

The obtained framework was tried out on projects so to get some insight and be able to assess its interests and limitations.

Consequently, the research approach proceeds into three steps: an assessment of the importance of process alignment from the need of coordinating practices by aligning processes and alignment of systems engineering and project management perspectives, the development of the framework, and experimentation on a case study. From an epistemological viewpoint, the approach can be characterized as a kind of exploratory, grounded research which means that the development of the framework is based on the literature review and on the analysis of the alignment of processes.

Proposal of a Framework

If we analyze the use of processes in the companies, they (suppliers for instance) need to demonstrate the quality of their processes. Often, however, companies have in-house practices that grew over the years and that they manage thanks to their experience; sometimes they rely on defined processes, but, according to (Mendling et al., 2017; Röglinger et al., 2012; Vallurupalli & Bose, 2018), these are scarcely optimized.

To reassure their clients (or meet the authorities requirements), and also to improve their efficiency, companies need to comply with some well known and very largely spread standards or recognized best practices' guides, so that clients and authorities can be confident in the quality of their practices (Brunsson et al., 2012; Tarhan et al., 2016; Uzumeri, 1997). Several situations can be distinguished: (1) either the company already refer to standard practices, or (2) the company uses in-house practices and thus needs to demonstrate that they comply with a standard or to make them evolve toward a compliance, or (3) the company is not mature enough to have developed in-house practices yet, and needs to select a standard and to be as compliant as possible with. In the two last cases, they need to first identify a short selection of standards that are relevant to them, then evaluate these standards in order to determine the one they will adopt. They need to refer to at least one standard defining engineering processes and another standard for project management. To be efficient, the interest of the company is to directly adopt standards that are coherent with one another, to overcome the drawbacks mentioned in the previous section (misalignment of processes, ambiguous roles, and incoherence in overlapping). Once standards are selected, a precise look at potential remaining difficulties to effectively align processes must be taken, in order for the company to finally define then adopt the set of coherent processes that results from this alignment.

Our proposal thus naturally consists of two general steps, as shown in Exhibit 2: analyze the 'alignability' of standards and align processes from standards.

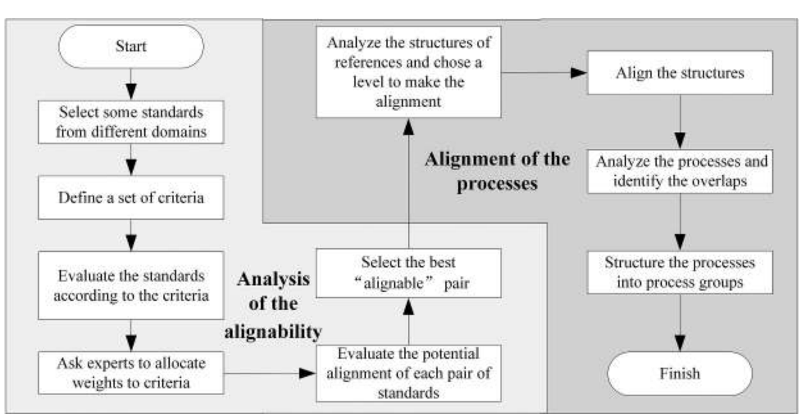
First general step: Analysis of the "alignability" of standards.

The methodology here aims at analyzing and comparing standards from different domains to evaluate their ability to be aligned. This analysis consists of six steps as follows (see Exhibit 2):

Step 1: Select standards from each domain. In the first step, different standards are collected, that are suitable for the domain of activity of the company. According to the company profile (large group, small and medium enterprise . . .) and its scope (software, manufacturing . . .), the set of standards selected is likely to be different. For example, whereas software companies may want to bring in software engineering standards and agile project management norms, mechanical engineering-oriented companies may rather favor more traditional management and engineering standards. The choice belongs to the person or department in charge of performing the study to select the best possible, relevant standards. This collection process could be implemented by using brainstorming, expert ranking, or Delphi methods.

Step 2: Define comparison criteria. To evaluate the different standards, a set of criteria should first be defined. Such criteria can include, for example, the level of detail that each standard is going into, or the frequency with which the standard is updated, the latter showing the reactivity to changes in the economic environment. The study of Sheard and Lake (1998) is one of the most important references that compared the systems engineering references. The criteria defined in this study are widely used for the study of systems engineering references. For this reason, it was used as starting point in the current study. A seminar was organized within the framework

Exhibit 2. The Two-Steps Global Framework



of this study so to gather around 50 different industrial experts that led to a consensus on a general list of criteria:

- Content – describing the number of processes defined by the standard and how they are put together;
- Level of detail – explaining how precisely the processes or activities are described, how detailed the standard is;
- Year of publication – giving a lower value if the standard is older;
- Revision frequency – describing the update dynamics with respect to methodology and techniques;
- Number of management processes – indicating the number of processes related to project management;
- System life cycle – describing the type of system life cycle defined by the standards;
- Process structure – evaluate the possibility to align the processes from the process structure perspective.

However, the person or department that wants to use our methodological proposal has to choose the best possible criteria for her/his own context, and should not be limited with this list of criteria. For example, a company working in a very fast evolving domain may favor norms and standards that are frequently updated, aiming at staying connected to the state of the art in the domain. Moreover, it should be noted that companies can have their own point of views on how to define the comparison criteria, and these criteria should be defined considering the companies context. For instance, they can be collected through a survey answered by the company's systems engineering and project management experts. The experts can be selected based on the method proposed by Hadad et al. (2013). Meanwhile, several other methods could be used to this aim, by brainstorming, expert ranking, or using methods such as Delphi, Analytic Hierarchy Process, Analytic Network Process, Data envelopment analysis, binomial coefficient method, to name a few. Several software tools and applications could be used during this step. Such as the Microsoft Excel, DEA-Solver, DEAP, MaxDEA, MATLAB to only name a few.

Step 3: Evaluate the standards according to the criteria. The standards that will be used for a study need to be assessed with respect to the selected criteria. The actual evaluation of each standard or norm for the selected criteria asks for a strict homogeneity in the assessment; the evaluation must be done using strictly the same approach, preferably by the same person(s), or maybe the same group of people using the same approach. Absence of such a strict homogeneity will not allow for a balanced comparison of the standard pairs. In this step, it should be noted that the marks for criteria do not mean the degree of "alignability"; the degree "alignability" relies on the distance of the same marks from both systems engineering and project management standards. The less distance they have, the more "alignable" they are. To support calculation in this step, software tools such as Microsoft Excel or MATLAB could be used.

Step 4: Allocate weights to criteria. Once the standards have been selected, the criteria defined and the selected standards evaluated with respect to each criterion, the stakeholders responsible in a company or project need to express their interest in certain criteria with respect to others. The concerned company management (quality department, norms, and standards department, process methods, and tools departments ...) are asked to express the relative weight they want to give to each criterion. For example, a company working in a relatively stable technical environment may want to favor technical detail in the standards to be taken into consideration, giving less importance to the frequency with which these standards are updated. A company working on developments that need to take into consideration the latest aspects may give a higher weight on the update frequency so to be sure to have the latest information on board. Therefore, a different weight pattern can be expected for different company sizes (large groups, SMEs (Small and Medium Enterprises) and VSEs (Very Small Enterprises)). Many techniques can be used in this step, to get the criteria weights such as factor analysis method (Chin, 1998), analytic hierarchy process (Mon et al., 1994), Delphi method (Linstone & Turoff, 1975), binomial coefficient method (Mendoza & Prabhu, 2000). As in the previous step, this calculation could be done with Microsoft Excel, MATLAB, or any other calculation tool.

Step 5: Evaluate the potential alignment of standards. Once the weights have been assigned to each of the criteria, the potentiality of alignment of a standard from one domain with a standard from another domain is done using the weighed calculation of the absolute value of the difference between these marks. This difference leads to an appreciation for each possible pair. This appreciation, referred to as distance, gives a higher potentiality of "alignability" when the distance is smaller. The distance is calculated using the following formula (1):

$$D_{mn} = \sum_{i=1}^{N} w_i |v_{i_m} - v_{i_n}| \quad (3.3.)$$

N denotes the total number of criteria evaluated for each standard pair m (systems engineering) and n (project management).

V_{im} denotes the value of the ith criterion of the mth standard.

w_i denotes the weight that is assigned to the ith criterion in the calculation.

D_{mn} denotes the distance between the standard pair m and n.

This simple calculation process could be supported by any existing calculation software.

Step 6: Select the best "alignable" pair of standards. Now, all the calculated distances have been evaluated, the most "alignable" pair of standards can be found with the minimum value of D_{mn}. Proceeding this way, pair by pair, the pair of most "alignable" standards can be obtained.

Remark. It should be noted that in working this way, two distinct sources of impacts can be identified.

On one hand, the choice of criteria and the weights associated to each criterion by the stakeholders, leading to a direction on where process alignment can go for the concerned company.

On the other hand, the contents of each norm or standard will guide the way the actual assessment takes place.

These two sources of impact are independent from each other and have a strong impact on the final result.

Second general step: Aligning processes from standards. As starting point for this step, two standards have been assessed as “alignable.” This section will explain the methodology for aligning the processes of the two standards. The presented methodology has the advantage of being able to be used for any kind of process; one can think of processes from different business units, from external sources, homegrown procedures, or even from other companies. The analysis is organized around four steps as shown in Exhibit 2.

Step 1: Analyze the structures of standards and chose a level to make the alignment. Standards generally are hierarchically structured into several levels. Given the diverse origins, all standards’ structures are likely to be different: the number and names of levels, the level of abstraction and precision of the descriptions may vary. Considering these differences, the first step is to analyze the structures of standards, in order to determine at which level of their structure could be aligned. Each level of standards structures is evaluated according to the level of abstraction (process level, activity level . . .) and the level of detail of the description. Then, a suitable level of the structure where the alignment would make sense is identified. The result of this step is the choice of levels in each of the standards’ structures to proceed to the alignment of standards.

Step 2: Align the structures. A deeper look at the processes, tasks or activities to align will reveal either that the standards have suitable processes or activities for the chosen level defined, or that no obvious matching between the standards appears.

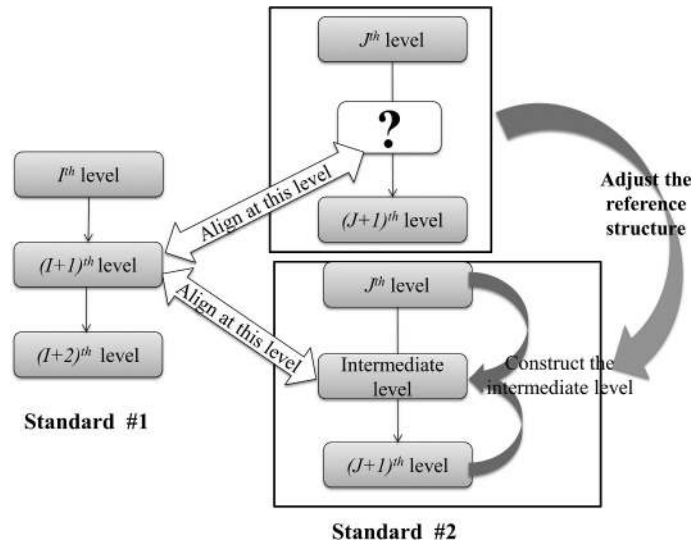
In the first case, there is no need to analyze and compare processes because alignment will be relatively straightforward and this step can be skipped.

In the second case, a complementary analysis needs to be done to determine how processes from the standards can be best aligned in order to create an intermediary level to align processes.

Illustration: In Exhibit 3, standard #2 has two levels of abstraction: one of high level and one very low level. Here, in the first step, it was decided to align the two standards at an intermediate level (i + 1) of standard #1; there is no direct matching with either level (j) or (j + 1) of standard #2. An intermediate level needs to be created for the standard #2 by refining level (j) and by abstracting the information level (j + 1) level to get a corresponding level of abstraction as level (i + 1) of standard #1. This induces adjusting the standards structure and creating an intermediate level in the second standard to align it with the first one. After the adjustment of the standard structures and the alignment of the processes are at the same level of detail.

Step 3: Analyze the processes and identify the overlaps. The integration of processes in Step 2 could lead to an identification of potential overlaps between the processes. The analysis in the current step aims at the similarities and differences between the processes. If descriptions are completely identical, descriptions can be merged into a single process description. If the processes have the same names but different meanings, distinguishing names need to be introduced. This step results in a set of integrated processes from the two standards. As multiple standards and guides define different processes, this step will involve a heavy text analysis to identify overlaps. However, with the development of Artificial Intelligence, several technologies and software tools for text mining have been developed and could be used during this step, such as Google Cloud NLP, IBM Watson, or Lexalytics.

Exhibit 3. Elaborate an Intermediary Level to Align Project Management (PM) and Systems Engineering (SE) Processes



Step 4: Structure the processes. The last step is to define a new structure of the integrated processes according to different project contexts to be easily applied during the complete project life cycle. Following the context in which the development takes place, a company can choose suitable processes according to its scale. This step brings flexibility that may in particular interest VSEs that have a more difficult task to relate the available resources to the processes described in the systems engineering and project management standards.

Remarks. The presented four-step methodology provides a comparative analysis of processes, identifying the main differences between their descriptions in standards, evaluating the ability of standards to be aligned, aligning the processes and structuring them in a new suitable structure.

In order to structure the processes for a development project, a company may, for example, decide to align the structure of one standard with that of partners in order to make them compatible. Let’s take the example of an acquisition of a smaller company by a large group. It may be expected from the smaller, acquired company to bring its processes in line with those of the group. However, for specific reasons (e.g., keeping a startup like behavior) the group may also decide to only partially adapt the structure.

If a development project takes place in one and the same organization, meaning the complete project life cycle takes place in the same organization, it is easier to apply all the integrated processes. If the development project is done with external suppliers, then the creation of the new structure has all its benefits. For example, for the external suppliers the executing phase of the development is more important than the closing phase of the project, even though they still need to pay attention to planning, monitoring, and controlling. Small external suppliers most likely have little attention to pay to such a closing phase, as the project closing is done within the clients' organization.

Result from a Case Study

This section aims at presenting the results obtained by experimenting with the application of the framework on a case study. It will be shown how the framework allows for aligning SE and PM processes according to the project context. The project is a scholar project, with as objective to apply systems engineering discipline on the definition, development, realization, and operation of a LEGO robot. The project was aiming at mastering the details of every systems engineering process in order to implement the SE practices successfully. Meanwhile, the project members also needed to write a research report on how they managed the project execution. In this illustration, the project team will emphasize the project context on three project phases (planning, executing, controlling, and monitoring) and three steps of the system life cycle (conception, development, production) (see Exhibit 4). A subset of these standards will be analyzed and aligned according to this project context.

The application of the framework proceeds in two steps, first analyze the alignability of SE and PM standards then align processes from standards.

Assessment of Alignability

Step 1: Choose standards from each domain. Based on the Sheard and Lake (1998), Xue et al. (2014), and Xue et al. (2015), five most important systems engineering standards and two famous project management standards are considered, respectively, ANSI/EIA 632 (ANSI/EIA, 1998), IEEE 1220 (IEEE, 2005), ISO/IEC 15288 (ISO/IEC, 2015), INCOSE Systems Engineering Handbook (INCOSE, 2015), SEBoK (BKCASE Editorial Board, 2019), PMBoK (PMI, 2017), and ISO 21500 (ISO, 2012).

Step 2: Define comparison criteria. This step will choose or define comparison criteria with as starting point the already mentioned study of Sheard and Lake (1998) that compares the systems engineering standards available according to four criteria: scope, level of abstraction, system life cycle, and systems engineering management processes guidance. Since then, the ANSI/EIA 632, IEEE 1220 and ISO/IEC 15288 standards have been updated several times, and two additional guides, the INCOSE Systems Engineering Handbook and SEBoK, have been published. However, less recent research analysis has been comparing them. It was therefore decided to compare the latest versions of the five previous systems engineering standards and two important standards from the project management domain: PMBoK and ISO 21500. The "level of abstraction" criterion introduced by Sheard and Lake (1998) was taken over as a basis and considered as "level of detail"; we also use the "system life cycle" as an important criterion for evaluating the project scope. Five additional criteria were defined in accordance with the objectives defined by the company, evaluating the vivacity of the standard or norm ("year of publication" and "revision frequency"), its ability to address the management ("content" and "number of management processes") and the hierarchical structuration of processes ("process structure").

Step 3: Evaluate the standards according to the criteria. For the seven cited standards, the result of these criteria is shown in Exhibit 5.

Marks given on the level of detail and the revision frequency of these standards are relative. The higher a mark is, the better this criterion is fulfilled by the standard in question. However, a high mark does not have a specific interpretation as to the performance quality of a standard or norm; the goal here is exclusively to evaluate the most "alignable" pair of standards, not the performance quality of individual standards. Looking, for example, at the criterion "level of detail," it cannot be concluded that a more detailed standard (i.e., with a higher mark), the more "alignable" the standard is. The marks defined and used are only for evaluating the distance of the systems engineering and project management standards on the same measurement perspective. The closer the marks on level of detail of both standards are, the easier to align the systems engineering and project management standards. For example, if the systems engineering standard has the same level of

Exhibit 4. Limited Subset of Processes

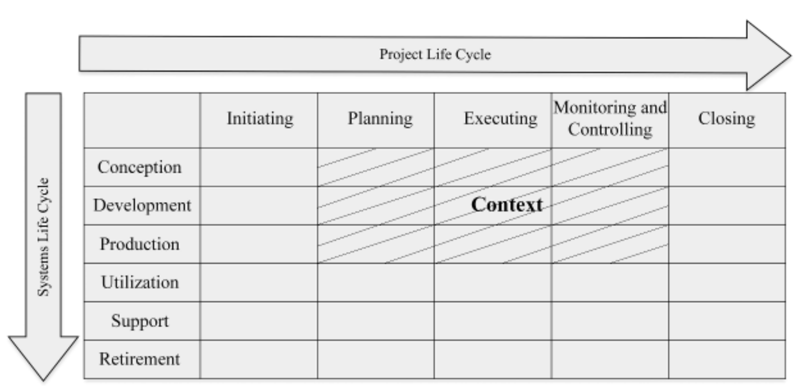


Exhibit 5. Evaluation of Standards According to the Criteria

Criteria \ References	ANSI/EIA 632	IEEE 1220	ISO/IEC 15288	INCOSE SE Handbook	SEBoK	PMBoK	ISO 21500
Content	13 processes	8 processes	31 processes	31 processes	31 processes	49 processes	39 processes
Level of detail	■□□□□	■■■■□	■■■□□	■■■□□	■■■■■	■■■■□	■■□□□
Year of publication	ANSI/EIA, 1998	IEEE, 2005	ISO/IEC, 2015	INCOSE, 2015	BKCASE Editorial Board, 2019	PMI, 2017	ISO, 2012
Revision frequency	2	3	4	4	2	6	1
Number of management processes	3	1	14	14	14	49	39
System life cycle	Enterprise-based	Typical	Life cycle processes	Life cycle processes	Life cycle processes	Life cycle processes	Life cycle processes
Process structure	Process-activity (output)-task	Process-task	Process-task -(input, output)	Process	Knowledge area-activity	Process-task -(input, output)	Process-task -(input, output)

abstraction and the marks for evaluating the level of abstraction is very low, but the distance between them on this criterion is zero; based on this criterion, they are the most "alignable" systems engineering and project management standards because they have the same level of abstraction. The more "alignable" the standards are, the much easier to cooperate between the systems engineering and project management process and related stakeholders.

The final result of the standards marks is based on the seven criteria and shown in Exhibit 6. Reconsidering the seven criteria, the following rules were selected in this paper:

- Content – the more processes the standard has, the higher the mark;
- Level of detail – the more level of detail a standard has, the higher the mark;
- Year of publication – the more recent the publication, the higher the mark;
- Revision frequency – the higher the update frequency, the higher the mark;
- Number of management processes – the more management processes the standard has, the higher the mark.
- System life cycle – the more general the system life cycle is, the higher the mark;
- Process structure – the more layer the process has, the higher the mark.

Step 4: Allocate weights to criteria. In this step, the weights for each criterion are defined so that the comparison can take place. Different methods can be applied to do so, detailed interviews or workshops with the concerned parties give a good input. During such workshops, the different stakeholders can appreciate the importance of each criterion and try to see what parts would be best for their project or for their company. Different stakeholders have different interests: the criteria weights differ according to the stakeholders. In this case study, the project numbers expressed that the level of detail of each process was the most important aspect to take into account. The revision frequency was also considered important,

Exhibit 6. Giving Mark to Each Standard

Criteria \ References	ANSI/EIA 632	IEEE 1220	ISO/IEC 15288	INCOSE SE Handbook	SEBoK	PMBoK	ISO 21500
Content	2	1	3	3	3	5	4
Level of detail	1	4	3	3	5	4	2
Year of publication	1	2	4	4	6	5	3
Revision frequency	2	3	4	4	2	5	1
Number of management processes	2	1	3	3	3	5	4
System life cycle	1	1	2	2	2	2	2
Process structure	2	1	3	4	1	3	3

as the project group wanted to take on board the most recent advances on the state of the art of the concerned areas systems engineering and project management. This criterion therefore had the second highest weight. The five remaining criteria were given the same weight. Normalizing to a "total" weight of 1, the criteria weights were then selected to as shown in Exhibit 7.

Step 5: Evaluate the potential alignment of each pair of standards. Using formula (1) the distance between the different standards can now be calculated. Exhibit 8 shows the results of the example for norm ANSI/EIA 632 and guide PMBoK, calculating the absolute value of difference for these standards.

As an example for calculating the distances, formula (1) can be used. The comparison between ANSI/EIA 632 and PMBoK then becomes the absolute value of difference for this pair is:

$$\begin{aligned} D_{11} &= 12\% * |2-5| + 25\% * |1-4| + 12\% * |1-5| + 15\% \\ &\quad * |2-5| + 12\% * |2-5| + 12\% * |1-2| + 12\% \\ &\quad * |2-3| \\ &= 2.64 \end{aligned}$$

Following this method, all the absolute value of differences of each pair systems engineering and project management standards are calculated and shown in Exhibit 9.

The lowest value concerns the standard pair ISO/IEC 15288 – PMBoK.

Step 6: Select the best "alignable" standards. Using the weights as defined above, the conclusion is that the pair of ISO/IEC 15288 and PMBoK, having the lowest absolute value of differences, would be the most "alignable" standards for this scholar engineering project.

SE and PM Processes Alignment

As an illustration of the methodology presented above, integration is done on a sub-set of systems engineering and project management processes following the results of the first general step, that the most "alignable" standards are ISO/IEC 15288 for systems engineering and PMBoK for project management. In the following, the methodology is performed step by step.

Step 1: Analyze the structures of standards and chose a level to make the alignment. In this step the goal is to determine at

Exhibit 7. Giving Weights to Each Criterion

Criterion	Content	Level of Detail	Year of Publication	Revision Frequency	Number of Management Processes	System Life Cycle	Process Structure
Weight	12%	25%	12%	15%	12%	12%	12%

Exhibit 8. Giving Mark to ANSI/EIA 632 and PMBoK

		ANSI/EIA 632						
		Content	Level of Detail	Year of Publication	Revision Frequency	Number of Management Processes	System Life Cycle	Process Structure
PMBoK	Content	|2-5|						
	Level of detail		|1-4|					
	Year of publication			|1-5|				
	Revision frequency				|2-5|			
	Number of management processes					|2-5|		
	System life cycle						|1-2|	
	Process structure							|2-3|
	Weight	12%	25%	12%	15%	12%	12%	12%

Exhibit 9. Evaluation of the Distance between Systems Engineering and Project Management Standards

PM \ SE	ANSI/EIA 632	IEEE 1220	ISO/IEC 15288	INCOSE SE Handbook	SEBoK
PMBoK	2.64	1.98	1	1.12	1.54
ISO 21500	1.36	2	1.06	1.18	1.74

which level the standards could be aligned. ISO/IEC 15288 follows the structure as shown in Exhibit 10: four process groups, including 31 processes. Each process is described in terms of "purpose," "outcomes", and "tasks and activities."

PMBoK is also organized in three levels: 10 Knowledge Areas, covering 5 process groups, each process being described by "inputs," "tools and techniques," and "outcomes" (see Exhibit 11). A Knowledge Area represents a complete set of concepts, terms, and activities that make up a professional field, project management field, or area of specialization. The 49 processes are organized into five process groups.

For both standards, three levels of decomposition can be identified. These levels are, however, not directly matching. Going deeper in detail on each level, correspondences can be found. Here we focused on the level of detail of processes description on the one side or knowledge areas description on the other side. A detailed explanation has been provided in (Xue et al., 2015). After comparing the different levels of description available at different levels of the hierarchical structures of systems engineering processes and project management knowledge areas, we found that the level of detail of "process" in ISO/IEC 15288 is similar to the level of detail of "knowledge area" in PMBoK, while the level of detail of the "activities" in the ISO/IEC 15288 is at the same level of detail as PMBoK's 'processes.' Exhibit 12 illustrates the case of the "Quality management" process of ISO/IEC 15288 and the "Project quality management" Knowledge Area of PMBoK. A direct match can be identified between tasks and activities of ISO/IEC 15288 and processes from PMBoK at the same level of decomposition. The "process" level of ISO/IEC 15288 is the similar to the "Knowledge Area" level in PMBoK,

Exhibit 10. Structure of ISO/IEC 15288

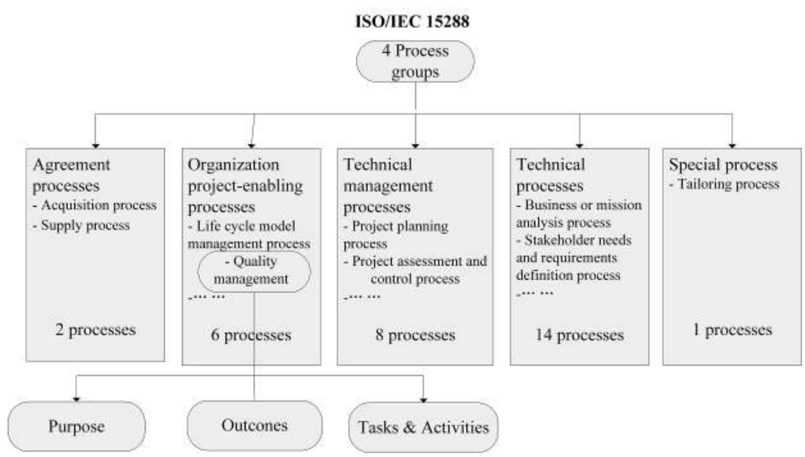


Exhibit 11. Structure of PMBoK

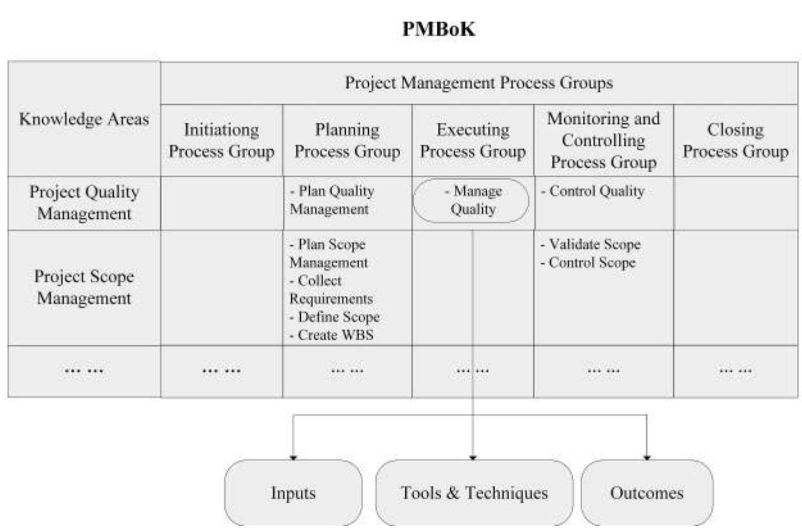
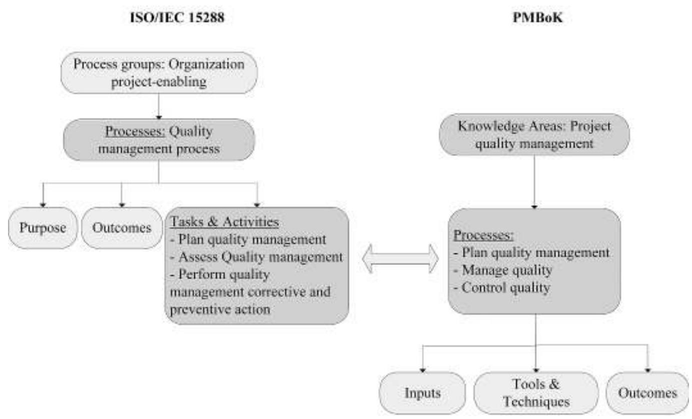


Exhibit 12. Alignment of the PMBoK and ISO/IEC 15288 (Xue et al., 2015)



so the level of detail of PMBoK's "processes" is the same as the "activities" of the ISO/IEC 15288. This is where focus will be given.

Step 2: Align the structures. Even though the number of processes and Knowledge Areas is not the same, the 31 processes of ISO/IEC 15288 can now be compared to the 10 Knowledge Areas of the PMBoK. Both standards' structures analyzed and having found the best level to align them, the processes of PMBoK need to be regrouped to align the structures. As we analyzed before, the processes of ISO/IEC 15288 and the knowledge areas (KAs) of PMBoK are at the same level of detail. After the comparison of the standards, it is necessary to regroup the processes from PMBoK into the aggregated process at the same level of detail as the processes of ISO/IEC 15288. PMBoK not only classifies the processes according to the knowledge areas, but is also organized according to the project management process groups (see Exhibit 13). So, the processes of the PMBoK are localized in two dimensionalities: "knowledge area" and "project management process group" (see Exhibit 13). The rule adopted to regroup the processes is based on "knowledge area" and "project management process group" of PMBoK. The processes related to the same "knowledge area" and the same "project management process group" are regrouped into the same integrated processes. For example, from one dimensionality (project management process group), the three "Plan cost management," "Estimate costs," and "Determine budget" are located in the group "Planning process group;" from another dimensionality (knowledge area), the three processes are located in the knowledge area "project cost management," so they are regrouped into a new process "Cost planning process" (see Exhibit 13).

After regrouping the processes of PMBoK into integrated processes, these integrated processes have the same level of detail as the process of ISO/IEC 15288 (see Exhibit 14), the original processes of PMBoK being now sub-processes of the integrated processes. The level of detail of the process is located at the intermediary (medium) level of the standards structure. As we see, the ISO/IEC 15288 and PMBoK have more than 100 tasks and activities while there are less than 20 process groups totally; so aligning references is not easy at the lowest level or highest level. The most suitable level for this alignment is at the process level based on the detailed level (as shown in Exhibit 14).

Step 3: Analyze processes and identify the overlaps. In the previous step, the 49 processes from PMBoK were regrouped into 30 aggregated processes as presented in Exhibit 15. As the ISO/IEC 15288 also has systems engineering management activities and processes, some overlaps exist between the two standards. There is a need to analyze in detail the ISO/IEC 15288 and the PMBoK (integrated) processes so to identify the overlaps. If after a deep analysis some redundant activities are found between the two standards, and these are merged.

As an example (see Exhibit 16), in the "Stakeholder Need & Requirements Definition Process" of ISO/IEC 15288 there are five activities: "Prepare for Stakeholder Needs and Requirements Definition," "Define stakeholder needs," "Develop the operational concept and other life cycle concepts," "Transform stakeholder needs into stakeholder requirements" and "Manage the stakeholder needs and requirement definition stakeholder requirements." The activities of "Define stakeholder needs" respectively correspond to the "Plan scope management" & "Collect requirements" and "Define scope" & "Create WBS" of "Scope plan process" in the PMBoK. One natural solution could be to suppress the duplicated activities from ISO/IEC 15288 to avoid overlaps (see Exhibit 16), but only after detailed comparisons of the details of the activities.

Sometimes, standards use the same words, but in reality focus on different things. The PMBoK's system of interest is a project whereas ISO/IEC 15288's system of interest is a product or a service. This may happen in each knowledge area and in each process. For example, "risk management process" in ISO/IEC 15288 deals with a product or service, whereas "project risk management" in the PMBoK deals with a project as an activity. Nevertheless, "approaches," "processes," and "steps" in ISO/IEC 15288 and PMBoK still have the same meanings. For example, every tasks and activities of the process "risk management process" in ISO/IEC 15288 matches almost every process of the knowledge area "project risk management" as shown in Exhibit 17.

Exhibit 13. Regrouping Processes from the PMBoK

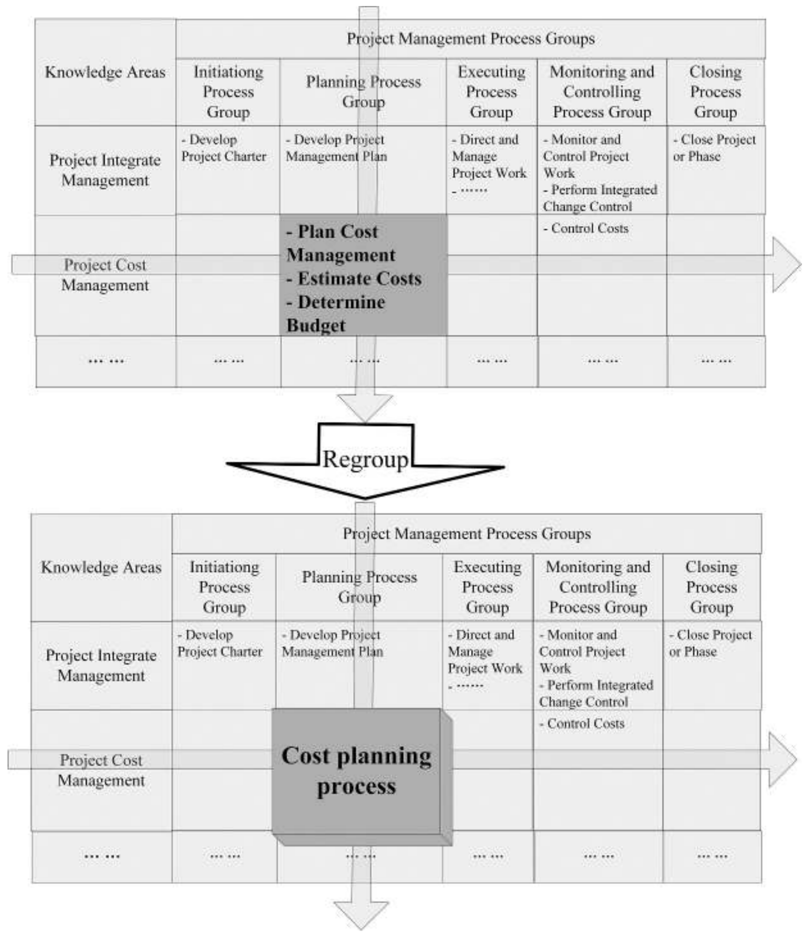
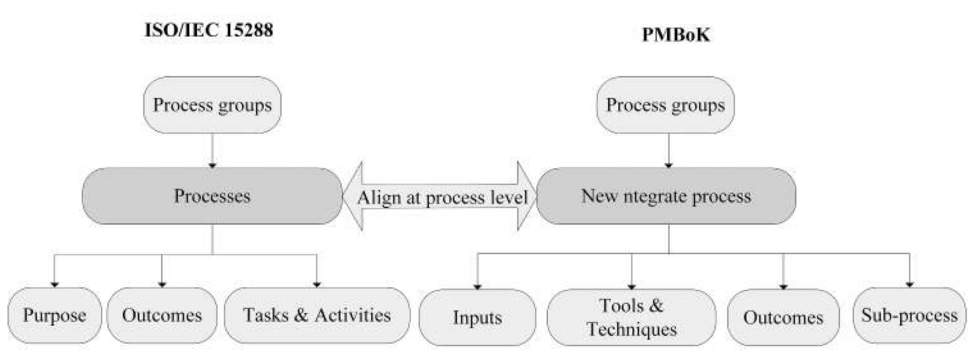


Exhibit 14. The Best Level for the Alignment of Processes from ISO/IEC 15288 and PMBoK

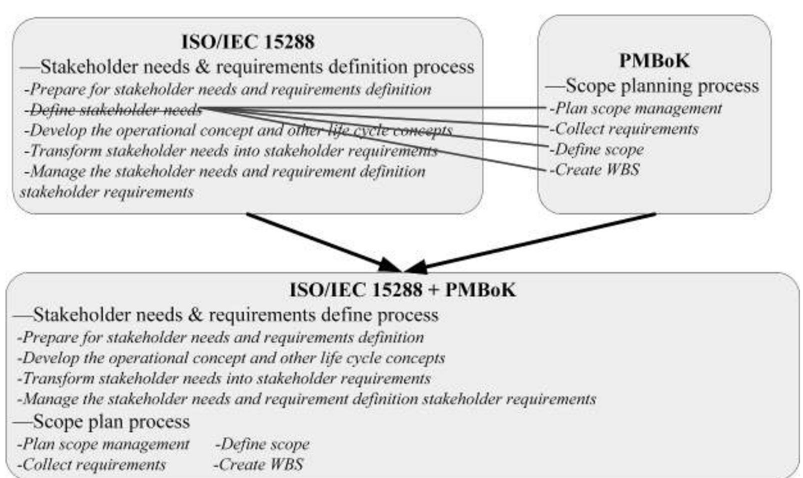


Step 4: Structure the processes. After the elimination of the overlaps of both standards, a new set of integrated Systems Engineering and Project Management processes is now available. In step 4, the goal is to structure these processes according to the different phases of a project. In this case study, the focus is on the development stage of a project; "Planning," "Executing," and "Controlling." The 23 corresponding organizational processes out of the 30 from the "Planning process group," "Executing process group" and "Monitoring and controlling process group" in PMBoK, as well as 12 technical processes from the "Technical

Exhibit 15. The Integrated Processes of PMBoK

	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring and Controlling Process Group	Closing Process Group
Project integration management	Integration initiating process	Integration planning process	Integration executing process	Integration monitoring and controlling process	Integration closing process
Project scope management		Scope planning process		Scope monitoring and controlling process	
Project schedule management		Schedule planning process		Schedule monitoring and controlling process	
Project cost management		Cost planning process		Cost monitoring and controlling process	
Project quality management		Quality planning process	Quality executing process	Quality monitoring and controlling process	
Project resource management		Resource planning process	Resource executing process	Resource monitoring and controlling process	
Project communications management		Communications planning process	Communications executing process	Communications monitoring and controlling process	
Project risk management		Risk planning process	Risk executing process	Risk monitoring and controlling process	
Project procurement management		Procurement planning process	Procurement executing process	Procurement monitoring and controlling process	
Project stakeholder management	Stakeholder initiating process	Stakeholder planning process	Stakeholder executing process	Stakeholder monitoring and controlling process	

Exhibit 16. An Example of Resolving the Overlaps



processes group" (items underlined in Exhibit 18) in ISO/IEC 15288 are selected. The proposal is now to structure the processes into three process groups: "Planning Process group," "Executing Process group" and "Controlling Process group." The result of the combination is shown in Exhibit 18.

Based on the given context, 35 integrated processes are selected from PM and SE references (see Exhibit 18). It should be noted that lifecycles in SE and PM are different. The SE references are less process oriented than PM references. So, in these 35 integrated processes, 23 organizational processes are selected from PMBoK while 12 technical processes are selected from ISO/IEC 15288. Another reason is that ISO/IEC 15288 offers some systems engineering management processes that totally meet or are partially included in some processes from PMBoK. So, the number of processes from SE is less than from PM in this case study.

Exhibit 17. Focus on Different Systems in ISO/IEC 15288 and PMBoK

Risk Management Process (ISO/IEC 15288)	Project Risk Management (PMBoK)
Tasks and Activities: • Plan risk management • Manage the risk profile • Analyze risks • Treat risks • Monitor risks • Evaluate the risk management process	5 processes: • Plan risk management • Identify risks • Perform qualitative risk analysis • Perform quantitative risk analysis • Plan risk responses

Discussion

This paper presents a framework aiming to provide guidance for the integration of the systems engineering and project management practices. The approach is shown in Exhibit 2 and illustrated with the integration of processes from international standards. It defines a clear succession of steps to align pairs of processes considering the different structures in standards and analyzing the overlaps resulting from the alignment of processes. It is experimented on a real-world case study that allowed validating the approach and drawing lessons from the results.

The case study shows the choice of criteria and the weight associated to each criterion. It also shows how to integrate the processes from systems engineering and project management standards in a given context. In this case study, most commonly used international standards were analyzed (ANSI/EIA 632, IEEE 1220, ISO/IEC 15288, INCOSE Systems Engineering Handbook, SEBoK, PMBoK, and ISO 21500). When turning to aligning in-house developed procedures with international standards, for instance, the exercise can lead to identifying which international standard is closest to the in-house developed procedures.

The current study aimed at proposing such methods to align the general practices as described for systems engineering and project management, easy to be understood and applied industry organizations. This framework being generic in its set-up, the range of applications is much larger. On the one hand, staying on the same domain, companies having an existing set of (in-house) processes and looking for having them evolve toward a better integration can use this methodology to analyze and compare their processes with other standards and guides. On the other hand, looking at larger domains than project management and systems engineering, the methodology allows for analyzing any procedure, norm, standard, or guide with another, and for making these procedures evolve.

In the current study, the integration of systems engineering and project management is done largely manually, as can be seen in the case study. This means that the alignment results may be different with potential different viewpoints of different experts and stakeholders. Thorough aligning of the viewpoints for an organization is therefore essential, so to allow the appropriate selection of the concerned references.

With the development of artificial intelligence text mining technologies, tools could be developed following the presented framework, allowing in particular larger companies and projects to overcome the manpower required for the presented framework.

Implications to the Practice of Engineering Management

The presented framework aims at a better integration of systems engineering and project management methods. The implications to the practice of engineering management are numerous. First of all, a better integration of the methods, starting with a better understanding of both domains by those concerned, will allow for smoother projects. Secondly, the implementation of the proposed framework has as an impact that engineering project managers would be more acquainted with international standards of systems engineering and project management, and that they could align (if wished) to the latest international references. In addition, the framework allows making a comparison and an alignment of in-house procedures with the best "alignable" international references, so to replace or complement their own processes.

Exhibit 18. Relationship between ISO/IEC 15288 and PMBoK

Planning (Pl)	Executing (Ex)	Controlling (Co)
• Develop project management plan • Scope planning process • Schedule planning process • Cost planning process • Quality planning process • Resource planning process • Communication planning process • Risk planning process • Procurement planning process • Stakeholder planning process	• Quality executing process • Resource executing process • Communication executing process • Business or Mission Analysis Process • Stakeholder Needs & Requirements Definition Process • System Requirements Analysis Process • Architectural Design Process • Design Definition Process • Systems Analysis Process • Implementation Process • Integration Process • Verification Process • Transition Process • Validation Process • Operation Process	• Integration monitoring and controlling process • Scope monitoring and controlling process • Schedule monitoring and controlling process • Cost monitoring and controlling process • Quality monitoring and controlling process • Resource monitoring and controlling process • Communication monitoring and controlling process • Risk monitoring and controlling process • Procurement monitoring and controlling process • Stakeholder monitoring and controlling process

Conclusions and Perspectives

In the current context of general competition imposed by the liberalization of trade, manufacturers must reduce time and costs, and increase the quality of products, to meet the consumer expectations. The competitiveness of a company is therefore based on its ability to lead projects. Whereas project management and systems engineering are both contributing to the success of (technical) developments, the concerned standards are not unambiguous and as such do not contribute to bring more technical and more organizationally oriented teams closer together. Therefore, it is necessary for firms not only to correctly implement SE and PM processes but overall to integrate practices from both domains and make them collaborate to break down the cultural barrier that separates communities of practitioners.

To achieve this goal, this paper describes an overall framework, comprising two phases, to come to more homogenized development processes so to overcome existing cultural gaps between systems engineers and project managers. We explored an option to reduce the gap between systems engineers and project managers, relying on the alignment of processes from SE and PM domains. The implementation of our proposal has been shown on the case study. Such approaches can be thought of for complex development projects, for example, but also within the framework of mergers and acquisitions, where an alignment of development processes usually takes place.

In the presented case study, the five most important systems engineering standards and guides (ANSI/EIA 632, ISO/IEC 15288, IEEE 1220, INCOSE Systems Engineering Handbook and SEBoK) and two project management references (PMBoK and ISO 21500) were analyzed to evaluate whether and how the standards and norms could be aligned. The alignment of some processes from ISO/IEC 15288 and PMBoK was illustrated within a given context. Following a clear set of steps; it proceeds by analyzing the different structures of standards and overlaps resulting from regrouping processes. The range of applications goes beyond the peculiar case of aligning SE and PM processes and can be referred to in other different contexts.

It should be noted that evaluations are based on the actual context and history of the company. This framework proposed in this paper is generic. Depending on the situation for a given project and company, other criteria may be defined; they may depend on the nature of the project and the company's business. Marks given to the indicators are based on the experts' experience. Evaluation of standards with respect to a given criterion thus is mostly qualitative.

In addition, our proposal, involving mainly human operations, can induce a rather important workload. The use of tools at the different steps, to perform calculations, is recommended.

To go further in improving collaborative work in engineering projects, beyond aligning standards, which is a good way of coordinating systems engineers and project managers, as pointed out by Conforto et al. (2013), other options can be thought of, such as responsibilities and decisions sharing, or enhanced information sharing. What is required is a different mind-set, making systems engineers and program managers collaborate within a "shared space," where they can drive the project team's performance and success toward achieving a cooperative mission: having a satisfied customer. This new mind-set recognizes that two separate views on the same problem does not help and that on the contrary each discipline would benefit from having a better focus on the processes of the other practitioner's disciplines. In this way, program managers and systems engineers will develop a common appreciation of the dual roles that each group must play and will understand that they are like two interlocking pieces of a jigsaw puzzle. Only when they are synergistically brought together can the larger picture emerge, and the puzzle can be solved. The whole can become greater.

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