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Systems Engineering and Management Processes for Small Organizations with ISO/IEC 29110

An Implementation in a Small Public Transportation Company

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***Abstract*— Most existing systems and software engineering standards, such as ISO/IEC/IEEE 12207 and ISO/IEC/IEEE 15288, have been developed by and for large organizations not having in mind small and very small entities. As systems are getting bigger, customers as well as systems integrators must work with small suppliers. The new systems and software ISO/IEC 29110 series can be used by small entities such as enterprises or projects within a large organization to develop quality products. CSiT, a small public transportation company, has implemented the engineering and management processes of ISO/IEC 29110 and has recently been successfully audited by a third-party audit composed of 2 auditors. ISO/IEC 29110 was also implemented in CSiT as a good starting point towards implementing CMMI-DEV level 2 process areas and a few practices of Level 3.**

Keywords—systems engineering, software engineering, ISO/IEC 29110, standards, Very Small Entities, VSEs, process, management and engineering guide, CMMI

I. Introduction

CSiT is a Canadian company, established in 2011 in Montréal, providing multi-modal Integrated Communications Systems and information integration for transport. In transit industry, customers often require a CMMI-DEV [1] maturity level from their suppliers. An independent evaluation confirming a CMMI® level 2 increases the opportunity of winning contracts. Similarly, to ensure better work coordination and reduce risks, organizations in this industry prefer working with mature suppliers in order to get timely quality products and within the agreed budget.

II. Motivations and Objectives

After its creation, CSiT learned about the development of an ISO/IEC 29110 management and engineering guide for systems engineering (SE). Systems, in the context of ISO 29110, are typically composed of hardware and software components [2]. ISO/IEC 29110 was seen as a good starting point towards implementing CMMI-DEV level 2 process areas. Thus, CSiT has undertaken an internal project to implement the ISO/IEC 29110 to guide the project management and system development activities.

Several factors prompted CSiT to develop and document their processes. Their first projects were based on employees' experience as well as recognized practices. This approach was effective and agile, but it was not possible to produce consistent deliverables from one project to another and be able

to demonstrate that the work could be done over again since these practices were not documented into company's processes. Also, since there were no templates or checklists, project management and product development activities were done rather informally. Finally, considering business and nature of projects of CSiT, customers often require proof demonstrating rigorous work and a level of maturity.

The company considered the development and implementation of processes as a need. In other words, the situation could become problematic if no action was taken. Specifically, the lack of a CMMI® maturity level or compliance with international standards, such as ISO/IEC 29110, was not an option. CSiT wanted to ensure the company's growth and show its expertise and organizational maturity to its customers.

III. Overview of ISO/IEC 29110

ISO/IEC 29110 (ISO 29110 hereon) defines a Very Small Entity (VSE) as an enterprise, an organization (e.g. a public organization or a non-profit organization), a department or a project having up to 25 people [2]. Worldwide, a large majority of organizations are VSEs. In Europe, for instance over 92% of enterprises, called micro-enterprises, have up to 9 employees and another 6.5% have between 10 and 49 employees [3].

From studies conducted, most VSEs do not have the resources in terms of expertise and money to adapt heavyweight engineering standards [4], such as ISO/IEC/IEEE 12207 software life-cycle processes standard [5] or ISO/IEC/IEEE 15288 system life-cycle processes standard [6], to meet their needs. The ISO 29110 set of standards and guides was developed to address the needs of VSEs [7].

A four-stage roadmap, called Generic profile group, has been developed for VSEs that do not develop critical systems or critical software [8]: Entry, Basic, Intermediate and Advanced profiles. VSEs targeted by the Entry profile are those working on small projects (e.g., at most six-person months of effort) and for start-ups. The Basic profile describes the development practices of a single application by a single project team. The Intermediate profile is targeted at VSEs developing multiple projects with more than one team. The Advanced profile is targeted at VSEs wishing to sustain and grow as independent competitive businesses.

In addition to the ISO 29110 standards that define the specifications of the profiles (i.e. 'what to do'), a set of ISO 29110 management and engineering (M&E) guides has been developed to describe in detail 'how to' [9]. A set of four software engineering M&E guides and four systems engineering M&E guides have been developed to help VSEs that develop systems, having hardware and software components, and VSEs that develop software only.

A. Software Engineering Roadmap

Table 1 illustrates the four-stage software engineering roadmap as a collection of four profiles where each higher profile is a superset of a lower profile. Three conditional processes (i.e. a process that may be mandatory under some specified conditions may be optional under other specified conditions, and may be out of scope or not applicable under other specified conditions) are included in the Intermediate and Advanced profiles: Acquisition Management, Disposal Management and Transition Management.

TABLE I. Software Engineering Four-Stage Roadmap

Process name	Number of tasks			
	Entry	Basic	Intermediate	Advanced
Project Management	18	26	33	35
Implementation	22	41	50	51
Business Management			24	24
Acquisition Management			8 *	9*
Disposal Management				10 *
Transition Management				8 *
Total	**40**	**67**	**107 + 8***	**110 + 27***

B. Systems Engineering Roadmap

The systems engineering (SE) ISO 29110 standards and M&E guides have been developed using, as its main frameworks, the software (SW) ISO 29110 M&E guides and ISO/IEC/IEEE 15288 system life cycle processes standard. With some exceptions, work product descriptions are based on ISO/IEC/IEEE 15289, a standard that defines the content of systems and software life cycle process information products [10].

Each process is composed of a set of activities that are broken down as tasks having defined input, output and role. As an example, the SE Basic profile M&E guide [11], as illustrated in figure 1, is composed of 2 processes: Project Management (PM) and System Definition and Realization (SR). An acquirer (i.e. a customer) provides a Statement of Work (SOW) as an input to the PM process. Then, the management of the VSE decides to either decline or accept the project. If the project is accepted, the planning activity of the PM process will initiate the project until the customer receives, as a result of SR process execution, the product described in the SOW.

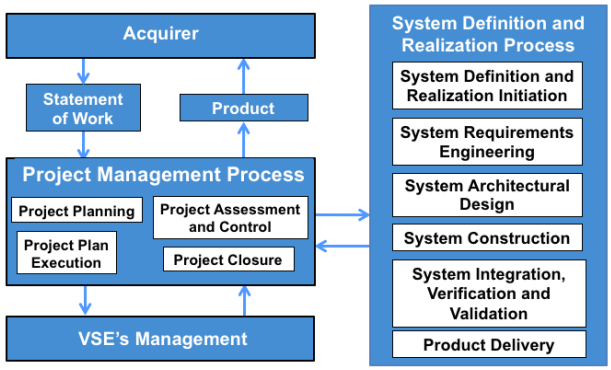

Fig. 1. Processes and activities of the ISO 29110 systems engineering Basic profile [12]

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For illustration purposes, one task of the System Requirements Engineering activity of the SR process is listed in Table 2. On the left side of the table are listed the roles involved in a task. The Project Manager (PJM) and the Work Team (WT) are involved in this task. In the next column, the task is described. The two columns on the right list the input work product required to perform this task and the output work products of this task.

TABLE II. EXAMPLE OF ONE TASK OF THE SYSTEM REQUIREMENTS ENGINEERING ACTIVITY [11]

Role	Task list	Input Work Product	Output Work Products
PJM WT	SR.2.2 Verify the Stakeholders Requirements Specifications with PJM Obtain Work Team agreement on the Stakeholder Requirements Specifications	Stakeholders Requirements Specifications [*initiated*]	Stakeholders Requirements Specifications [*verified*] Verification Report Stakeholders Requirements Specifications [*published*]

The SE ISO 29110 standards and guides are designed to work hand-in-hand with the SW ISO 29110 series. ISO 29110 does not impose a specific life cycle model, therefore leaving VSEs free to choose the model that best suits their needs amongst the cascade, iterative, incremental, evolutionary and agile models. ISO 29110 does not impose a specific method or tools to its users.

C. Diffusion and Implementation of ISO 29110

ISO systems and software engineering standards and guides are usually published only in English. However, international demand for the ISO 29110 standards and M&E guides became so great that they have been translated into Czech, French, Japanese, German, Portuguese and Spanish. A few countries, such as Brazil, Japan, Mexico and Peru also decided to adopt ISO 29110 as national standards.

ISO 29110 has been initially implemented, in many countries, in VSEs developing software (SW) [13]. ISO 29110 has been implemented, amongst others, in IT start-ups in Canada, in Peru [14] and in a VSE co-located in Tunisia and in Canada, in a large financial institution, in a large engineering company [15] and in a large utility provider.

For instance, in Thailand the 'ISO/IEC 29110 Driven Thailand Flagship' is one driver of Thai digital economy [16]. The main components of the ISO 29110 flagship are government vision, leadership and policies, clusters of VSEs, network of consultants and assessors and training and academic institutions. One objective of the flagship was to get over 250 VSEs to obtain an ISO 29110 certification. To achieve this goal, VSEs were trained about ISO 29110. Then, they were guided to perform a gap analysis between their actual software process and the ISO 29110 Basic profile. So far, over 320 private organizations and 15 public organizations have been certified against the Basic profile of ISO 29110 [17].

Since the ISO 29110 engineering and management guides are easily understandable and freely available, it has greatly helped their adoption. More than 15 countries, such as Columbia, Brazil, Canada, Haiti, Mexico, Peru and Thailand are teaching ISO 29110 [18]. In Thailand, over 10 universities are teaching ISO 29110.

IV. APPROACH TO THE IMPLEMENTATION OF ISO 29110 AT CSIT

The ISO 29110 systems engineering Intermediate profile was targeted by CSiT as it applies to VSEs who conduct several projects simultaneously with more than one team. However, the Basic profile was used since the Intermediate profile was not published when the project was initiated at CSiT. The systems engineering Intermediate profile should be published in 2018 [19].

CSiT uses suppliers for the purchase and integration of components that will be used in a product. Therefore, it was imperative for CSiT to establish a supplier management process that defines how to work with them and to reduce project risks. The current version of the SE Basic profile does not describe a supplier management process. This process is covered in the systems engineering and the software Intermediate profiles (20, 21). The CMMI® for Development and the PMBOK® [22] have been used as the main framework to develop the supplier management process.

To better respond to different types of projects, CSiT decided to develop three process groups (i.e. light, standard, full), each being adapted to meet the attributes of projects such as the size and nature. Table 3 shows the three process groups and the frameworks used.

TABLE III. CLASSIFICATION OF CSIT PROCESSES

	Light Process	Standard Process	Full Process
Type of project	Proof of Concept, Prototype Concept validation or Product Deployment at Customer Site Small Project	Typical Project Product intended to be installed at Customer Site Medium Project	Project when CMMI level 2 is required by a Customer Product intended to be installed at Customer site Large Project
Framework to be used	ISO/IEC 29110 Entry profile + CMMI - Supplier Agreement Management	ISO/IEC 29110 Basic profile + CMMI - Supplier Agreement Management	CMMI Level 2

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As illustrated in Table 3, the M&E guide the SE Entry profile is used to document the light process and the M&E guide of the SE Basic profile is used as the main reference to document the standard process.

For a VSE like CSiT, small projects are typically below 1 MCAD (Million Canadian Dollars) projects and, large projects are about 10 MCAD projects. Medium projects fall between these two categories.

The software M&E guide of ISO 29110 was used to document the processes involved in the development of CSiT's main application software application suite called TRANSIS. The guide has also been used to better understand some of the subtleties that exist between the software and the system M&E guides as well as to list the software tasks and deliverables of a project. As an example, the maintenance document has a slightly different semantics in the 2 guides. Both M&E guides indicate that this document is about products. However, in the software M&E guide, the emphasis is on describing the development environment required to compile and maintain a software that has been developed, while in the system M&E guide, the emphasis is placed on the description of a strategy and the maintenance procedures and activities to maintain a system.

CSiT develops its software components using an agile development approach using an iterative development model. Since the tasks and deliverables of the CSiT processes are different to the notation used in the M&E guide, the software M&E guide was used to ensure that there is mapping between all tasks and deliverables of the guide and the tasks performed in projects. As an example, the work product titled 'Requirements Specifications' in the M&E guide is called 'User Stories' in the process of CSiT.

Finally, since the software development and documentation tasks of CSiT are done using a readily available and customizable tool, the M&E guide made it possible to determine the adjustments that had to be made to the software tool such that it was aligned to the M&E guide.

A. Process Documentation

Five types of documents are the foundation of the company's quality system:

- Policies define expectations and direction of the organization about quality and processes. Policies impose constraints and objectives define the vision of the organization, the reasons and motivations about the processes.
- Processes are implementing policies. They define the activities and tasks to guide product development. They define what needs to be done, by whom and when to produce the expected results. Their descriptions are not dependent on tools or technology.
- Procedures support the execution of processes. They describe step-by-step actions to take (i.e. the "how to") to perform a task of an activity of a process. Procedures, sometimes called instructions, can describe how to use a tool, a template or a checklist to perform a task.
- Support material is a set of tools, which support the procedures and facilitate the work to be performed.
- Organizational standards provide guidelines in order to standardize the work and results. For example, there could be a standard for defining how the files should be named during the project and a standard to define the coding rules of a specific programming language.

To reduce the number of documents in the document structure, it was decided that all policies would be consolidated into a single document and that they would describe management's expectations at all levels to ensure and maintain a quality management system. Similarly, to reduce the number of documents, it was decided that short procedures would be combined in the same document that the processes to which they relate. Independent procedures will be created only when a task is complex.

CSIT decided to leave aside, for the moment, the creation of training material. Training material can take time to develop and do not really provide value at this time. The company prefers to promote the training of employees and interactively in person rather than by reading a document or viewing a presentation. Documented processes of CSiT are used as training material for new employees.

It was decided that documentation of CSiT processes would consist of two parts: a graphical part and a textual part. Each of these parts has different but complementary goals. The graphical part is primarily targeted at "experts", while the textual part is targeted mainly at "beginners" (e.g. a new employee) or an intermediate user (e.g. an employee who has participated to an engineering project).

The ETVX notation (i.e. Entry-Task-Validation-eXit) was developed in the 80s at IBM [23]. Given its simplicity of use, this notation has been adopted by many organizations. The textual part is a detailed description of activities, tasks and interactions between the activities of a process. The textual part describes the tasks, i.e. what to do, and the roles associated with each task.

The documentation of the supplier management process led to the creation of additional templates: request for proposals, supplier selection matrix, purchase order and purchase agreement. Also, three sections have been added to the project plan of the Basic profile: a list of acquisitions and potential suppliers, an acquisition plan/strategy, and a supplier management plan.

B. Selection of Measures

The M&E guide lists the tasks associated to the collection and use of measures (e.g. resource, cost, time). The SE Basic profile does not detail how to collect and analyze the measures.

The forthcoming SE Intermediate and Advanced profiles will provide more details about the collection, analysis and utilization of measures.

At CSiT, the selection of measures was based on two principles: a measure must meet a company's needs for information; and, a measure must be easy to collect using an electronic time sheet or tools. The company's needs for information were:

- To know the overall quality of each work product
- To be able to use the performance of past projects to estimate new projects
- To be able to analyze the efficiency of processes on product quality
- To be able to analyze if the project is successful, to identify gaps and take the necessary remedial action

The following measures were defined to meet company's needs for information:

- Number of errors detected by document type and by phase of the development cycle
- Number of hours worked for each phase of the system development cycle
- The cost of each project
- The attributes of each project such as the number of change requests, the level of risk and the predominance hardware/software.
- Distribution of effort related to the production, review and correction of deliverables
- Resources spent versus those that were planned in the project plan

C. *Verification, Validation and Acceptance Activities*

CSiT's determined the types of peer review activities to be applied to the various work products and deliverables of a project. ISO 29110 states that verifications of work products must be made, but without specifying the type (e.g. inspection, test). For each deliverable as well as for each internal work products at least one type of peer review was selected. Four types of reviews were defined: personal review, desk-check, walkthrough and inspection. Inspection and walkthrough are defined in the IEEE-1028 standard for software reviews and audits [24].

Component and system tests have been defined. These tests are done internally without customer participation. Three types of tests are unit testing, integration testing and system testing.

Finally, tests are made with the customer. These tests are used to validate that the system behaves as required by the customer. In this case, two types of tests could be performed: in-factory and on-site tests.

D. *Determination of the Baselines*

ISO 29110 mentions the obligation to create a repository and baselines during the project. However, it does not mention the content of these baselines or the project phase where they must be created. Each VSE should establish its own set of criteria. At CSiT, it was decided that the phase, where baselines will be created, would be documented in the project lifecycle of projects or the systems development lifecycle. A table was created to define each baseline to be established as well as the work products that should be part of the baselines.

E. *Definition of the Project Tree in the Configuration Management Tool*

A generic project tree has been established to indicate where each work product will be stored in the configuration management tool such that projects deliverables are classified in the same way from project to project. A subset of this tree is shown in Figure 2. It shows the contents of each folder. Each acronym is defined in the nomenclature standard of the VSE.

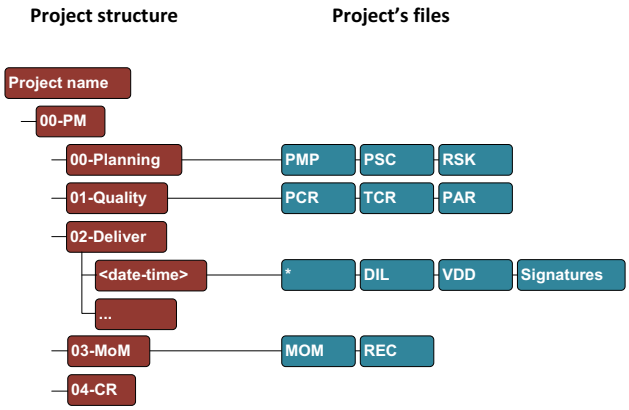

Fig. 2. Subset of project tree in the configuration management tool

F. *Coverage between frameworks*

As mentioned earlier, the project goal was to implement ISO 29110 and to complement it with CMMI® level 2 requirements. In order to determine the achievement of this objective, an analysis of the coverage of CSiT processes was performed. This analysis was done in two stages. First, the correspondences between the CSiT processes with ISO 29110 have been defined. Then, connections between the processes of CSiT and those of CMMI® were defined. These mappings have been represented graphically, as shown in Figure 3.

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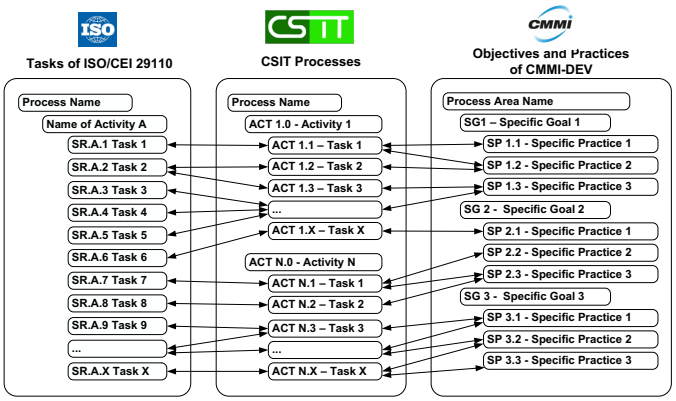

Fig. 3. Mapping of CSiT processes

An analysis confirmed that the processes of CSiT fully cover the objectives and tasks of the processes defined in the Basic profile of ISO 29110. During this analysis, mappings and tailoring have been documented. This documentation also explains the tailoring decisions of CSiT.

Figure 4 illustrates the approximate coverage of processes of CSiT to the CMMI® Level 2 process areas before the documentation of the supplier management process (REQM means Requirements Management, PMC is Project Monitoring and Control, PP is Project Planning, CM is Configuration Management, PPQA is Process and Product Quality Assurance, SAM is Supplier Agreement Management and MA is Measurement and Analysis). The organization will add the necessary practices to achieve CMMI-DEV Maturity Level 2.

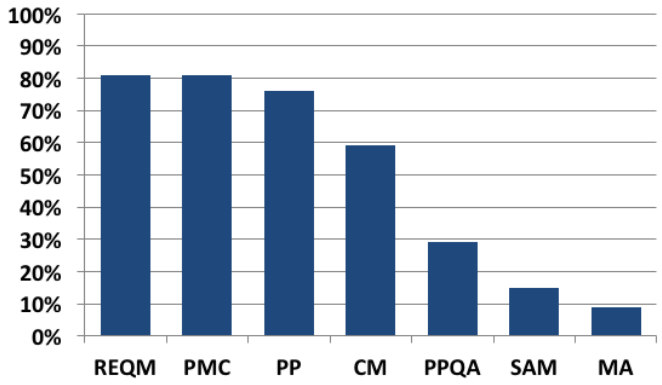

Fig. 4. Coverage of CSiT processes to CMMI-DEV level 2 process areas

CSiT has also started the implementation of CMMI-DEV Level 3 process areas such as Validation & Verification, Technical Solution, Requirements Definition, Product Integration and Risk Management.

V. Implementation and Self-Assessment

CSiT started the development of a product suite called 'TRANSIS' in 2012. This product is a multimodal information data integration system with interactive extensions for operators and users of public transport. The TRANSIS project was intended to apply the management and technical processes and adjust them if necessary, ensuring a gradual adoption of the new work methods.

A self-assessment score sheet was used to verify the coverage of CSiT processes to the Basic profile. This score sheet was used to indicate the activities, tasks performed as well as the documents produced during a project and determine the level of coverage with the Basic profile.

VI. Conduct of a Third-Party Audit

At the time CSiT was ready for a certification audit similar to ISO 9001 audits, there was no audit scheme available for ISO 29110 in Canada. CSiT then decided to request the conduct, by external auditors, of a third-party audit. For the first audit, internal product development and software development were not within the scope.

The steps of the third-party audit are illustrated in figure 5. Once an audit request is transmitted to an auditor, an analysis of documentation is performed to verify the readiness of the organization. Then, a written agreement is signed by both parties. This agreement describes, amongst other, the scope of the audit and the plan for the next steps (e.g. on-site audit). A confidentiality agreement is also signed by the auditor.

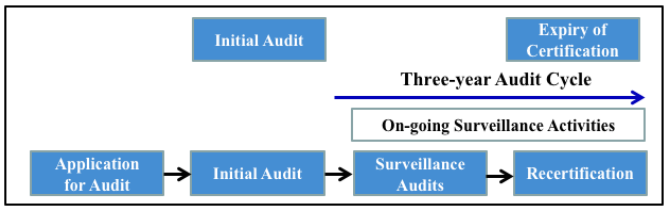

Fig. 5. Third-Party Audit Cycle

The on-site audit, of about 8 hours, was conducted in 2016 to review objective evidence such as processes and project specific documents (e.g. project plan, requirements specification, change request) and interview officers and employees of the VSE. Five persons of CSiT participated to the interviews and provided answers and requested evidences. Two projects were used to prove conformance to the SE Basic profile of ISO 29110. No non-conformance were identified, a few observations were noted and 5 best practices were noted by the audit team. The auditor and the technical expert were of the opinion that the VSE demonstrated that it was well on the way to achieving the objectives of the Intermediate profile.

A letter was issued by the organization that manages the compliance program attesting the conformity based on ISO 29110 documents audited. The letter of compliance is subjected to a period of validity of one year.

Since the first audit, the management of CSiT believes there is a greater awareness of the importance of using the processes. As an example, are looking for better ways to adapt processes to their daily activities.

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VII. Benefits for CSiT

Standards are sources of codified knowledge. Many studies have demonstrated the benefits of standards, such as increased productivity and quality [25]. As stated by Garcia « When an organization selects a standard that fits its context well, and plans the adoption thoughtfully, it's most likely to achieve the standard's advertised benefits » [26].

Two categories of benefits observed by CSiT are listed in Table 4: observable benefits in day-to-day project activities and benefits to the VSE as a business.

TABLE IV. Day-to-Day Benefits and Business Benefits

Day-to-Day Benefits	Business Benefits
• Standardized work and consistent deliverables across projects • Avoids reinventing the wheel for each project • Work is done in a systematic and disciplined way • Better quality of deliverables and products • Better project management and project monitoring • Reduction of project risks • Better communication within the team because the semantic of communication is standardized	• Better credibility to bid on tenders • Access to markets that require certification of a quality system in line with the business practices of the company • Better recognition of the quality of work done and products developed • Better trust from customers and business partners • An important step towards a maturity level of the CMMI® (a CMMI® level is a requirement of some customers)

VIII. Lessons Learned

The initial approach at CSiT was to develop one process at a time, documenting it graphically and then textually. The problem is that by doing so, the interactions between processes were not considered. Therefore, when a new process was developed, the team could discover that the already described processes should be modified to better reflect this new process. At some point of the improvement project, it was decided to document all processes in a graphical representation before documenting the textual version of each process. This approach had two advantages. First, it helped to get the big picture of the processes and their interactions. Also, it enabled the team to use and apply these processes faster in a pilot project and determine whether the activities and tasks defined in the process were relevant and if some were missing. The textual description of the process was resumed as soon as the interactions between processes were better defined and the description of activities and tasks of the process was more stable.

It was also learned that processes could be represented graphically in a simple way. Although there are many specialized tools on the market and many process modeling standards, these tools were too "heavy" for the needs of a VSE. A tool such as the Microsoft® Visio was sufficient to document processes as a set of flowcharts.

A document standardizing the terms used should be developed and maintained. It was found that even if two terms that are similar could be considered as synonyms, it could create some confusion. For example, the terms "architecture" and "design" are similar to the extent that they represent how a system is designed or is a solution to a given problem. Some people might interchange the words, but fundamentally each of them represents a different concept. The architecture is the high-level structure of a system, its elements and their relationships while the design describes, amongst others, the detailed implementation-level physical structure, behaviour, temporal relationships of the elements of a system. A control of the terminology used in the business domain of an organization and by its customers is essential.

IX. Next Steps

As part of the ongoing process improvement activities, the VSE is adjusting its processes based on the feedback and lessons learned gathered from completed projects as well as adapting processes and templates to better match different types of project.

The utilization of the processes by all employees is reinforced by an organizational policy mandating an annual third-party audit. A second third-party surveillance audit will be conducted in 2017 with the same auditors as for the first audit.

X. Conclusion

The management and engineering guide of the Basic profile of ISO/IEC 29110 helped raise the organization's maturity by using industry-recognized practices that are consistent from project to project. It can be said that the standard is simple to understand and use. It is also a good starting point for a VSE that wants to cover CMMI-DEV Level 2 and 3 practices. It enables VSEs, such as CSiT, to become more mature more rapidly by adopting systematic, disciplined and quantifiable methods of work, which are typical of engineering environments.

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