

# Software Process Improvement in Graduate Software Engineering Programs

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## Abstract

Abstract – At the École de technologie supérieure (ÉTS), software process improvement (SPI) is taught in lecture format and with a 10-week implementation project in an organization by teams of students of the graduate software engineering curriculum. The SPI course is taught using a ‘problem-goal-solution’ approach where students learn that any process improvement initiative must be based on issues preventing an organization in achieving its organizational goals whether the organization is a company or a not-for-profit organization. An important aspect of this course is the management of technological change where students learn and put in practice in their project the ‘soft’ issues which are part of most SPI organizational initiatives.

## 1. Introduction

As reported by Charette [Cha05], software specialists spend about 40 to 50 percent of their time on avoidable rework. The ability of organizations to compete, adapt, and survive is increasingly dependent on quality, productivity, development time, and cost. Systems and software are growing larger and more complex every year. For example, mainstream cars have between 20 and 30 million lines of code (LOC) and top-of-the-line cars contain 100 million LOC and it is expected that LOC will increase by 50% by 2020 [Fle14]. Software process improvement (SPI) is even more important when we consider all the software development projects that have partially or totally failed, the numerous incidents and the financial losses generated by those failures. As an example, recalls due to software

errors, which account for about 60-70% of vehicle recall in European and North American markets, can lead to multimillion and even multibillion dollar losses.

The École de technologie supérieure (ÉTS), a 7,800-student engineering school, began offering its graduate SPI course to professional students in 2000. The aim of this specific SPI course is to ensure that software engineering students are aware of the importance of SPI, and that they understand and are able to manage and apply SPI practices in real organizations. The professor who designed the SPI course has an industrial experience of more than 20 years, mainly in defense and railway sectors. The course is made up of lectures, practical exercises, and a team project in industry. A continuous process of student evaluation is carried out to ensure that the concepts are well understood.

This article is divided into two sections. First, the authors present an overview of the SPI course, in a second section projects performed by students in organizations are briefly described.

## 2 Software Process Improvement Course

The SPI course, a 3-credit course (i.e. 9 hours per week including 3-hour lectures) over a period of 13 weeks. Each lecture topic is illustrated with industrial examples, international or professional standards, and process improvement model practices. To ensure that students grasp the importance of SPI activities, the business model concept and the cost of quality concept are stressed throughout the course. When performing SPI activities as part of their projects, students must make tradeoffs between technical issues and ‘soft’ issues such as the management of cultural changes.

There is a wide spectrum of development approaches for organizations developing software. Figure 1 illustrates the spectrum of approaches on 2 axes. The horizontal axis (from left to right) illustrates the level of ceremony, from a low ceremony approach with little documentation (e.g. agile approach) to a high ceremony approach with a comprehensive documentation (e.g. plan driven CMMI approach). The vertical axes illustrate the approaches based on the

level of risk. The top axis illustrates a low risk linear approach using a waterfall approach while the lower part of the axis illustrates a risk-driven project using an iterative approach. ISO/IEC 29110 is located at about the center of both axes.



Figure 1: Positioning of the ISO/IEC 29110 (adapted from [Kro03])

Initially, the SPI course used the CMMI model developed by the Software Engineering Institute (SEI). The CMMI was selected because many organizations, especially defense and aerospace enterprises, were already using it and it was available in French at no cost from the SEI. The ÉTS engineering school is located in Montréal. A survey of the software development companies was done a few years ago in order to obtain a picture of this industry in the Montréal area. As illustrated in Table 1, it was found that close to 80% of software development companies have fewer than 25 employees. In addition, over 50% have fewer than 10 employees.

Table 1: Size of software development companies in the Montreal area [Gau04]

Size (Number of employees)	Software Companies		Total Number of Jobs	
1 to 25	540	78%	5,105	29%
26 to 100	127	18%	6,221	36%
over 100	26	4%	6,056	35%
<b>TOTAL</b>	<b>693</b>	<b>100%</b>	<b>17,382</b>	<b>100%</b>

Since a large percentage of students attending the SPI course were working in small organizations, the emphasis on the use of the CMMI framework was gradually reduced to switch to a new ISO set of standards and guides: the recently published family of ISO/IEC 29110. The ISO/IEC 29110 standards and guides have been developed specifically for enterprises, organizations and projects having up to 25 people. The ISO/IEC 29110 management and engineering guides are available in English and French, at no cost, from ISO. They are also available in Portuguese and Spanish.

## 2.1 ISO/IEC 29110

The ISO/IEC 29110 standard “Lifecycle profiles for Very Small Entities” [Lap08] is aimed at addressing the issues identified above and addresses the specific needs of VSEs [OC11a] [OC11b] and to tackle the issues of poor standards adoption by small companies [Co108] [OC09]. The approach [OC14] [Lap13] used to develop ISO/IEC 29110 started with the pre-existing international standard ISO/IEC 12207 dedicated to software process lifecycles. The overall approach consisted of three steps: (1) Selecting ISO/IEC 12207 [16] process subset applicable to VSEs of up to 25 employees; (2) Tailor the subset to fit VSE needs; and (3) Develop guidelines for VSEs.

The basic requirements of a software development process are that it should fit the needs of the project and aid project success. And this need should be informed by the situational context where in the project must operate and therefore, the most suitable software development process is contingent on the context [Jen13] [Cla12]. The core situational characteristic of the entities targeted by ISO/IEC 29110 is size, however there are other aspects and characteristics of VSEs that may affect profile preparation or selection, such as: Business Models (commercial, contracting, in-house development, etc.); Situational factors (such as criticality, uncertainty environment, etc.); and Risk Levels. Creating one profile for each possible combination of values of the various dimensions introduced above would result in an unmanageable set of profiles. Accordingly VSE’s profiles are grouped in such a way as to be applicable to more than one category.

Profile Groups are a collection of profiles which are related either by composition of processes (i.e. activities, tasks), or by capability level, or both. The “Generic” profile group has been defined [OC10] as

applicable to a vast majority of VSEs that do not develop critical software and have typical situational factors. This profile group does not imply any specific application domain, however, it is envisaged that in the future new domain-specific sub-profiles may be developed in the future.

Finally, the results obtained from systematic literature review of the ISO/IEC 29110 standard [Mor14] show that there is an increasing interest on it.

Figure 2 illustrates the activities of the project management and software implementation processes. The Project Management process and the Software Implementation are described in great details in the guides. As an example, each activity is composed of a set of tasks with inputs, outputs and roles. For all inputs and outputs, the guides describe a typical content.

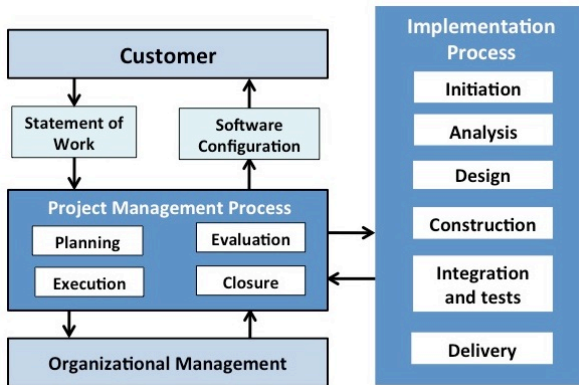


Figure 2: Basic profile processes and activities [Lap15a]

## 2.2 The Course

The approach used for software process improvement is covered in the book titled ‘Making Process Improvement Work’ [Pot02]. This approach includes the following four steps: 1) Determine the business goals and the problems that an organization wishes to solve; 2) Determine organizational goals and identify problems; 3) Prioritize identified problems; 4) Develop and implement a SPI plan. The topics presented in class, listed in Table 2, are supported with weekly reading assignments.

Throughout the course, the students are exposed to the management of technological and cultural changes using a book titled ‘Managing Transitions: Making the Most of Change’ [Bri09]. The book describes a change

using a three-phase of transition model as illustrated in figure 3.

Table 2: List of SPI course topics

Theme	Content
Introduction	Challenges faced by organizations developing products comprising software. Benchmarking process performances. Improving process performances (e.g. quality, productivity, turnaround, etc.) Outsourcing and off shoring.
Models, Standards and Methods	The IDEAL improvement model from the SEI. The Capability Maturity Model Integration for Development ISO/IEC 29110 standards and guides for Very Small Entities (VSEs) Process performance assessment methods. Goal-Problem approach.
Management of Organizational Changes	Description of the organizational context of a change project. Organizational culture assessment. Change history assessment. Stress level assessment. Sponsorship assessment. Change agent’s capability assessment. Motivational factors assessment. Change readiness assessment. Deployment/installation plan

During the course, students are introduced to the recently published ISO software development standard ISO/IEC 29110 [ISO12] targeting Very Small Entities (VSEs). Students use the engineering and management guide included in ISO 29110 which is freely available in English or French from the ISO, as a framework to help them understand when software quality practices are used in a development project and why. They also use the guide as a framework for their team project.

The course has been designed in such a way that teams of 4 students can apply the SPI practices, presented in the lectures, in an organization. Since many graduate students are already working in an organization, it was quite easy to identify a topic for

improvement and obtain the support of the management of the organization. To reduce the burden to the organization, this employee is the interface with management.

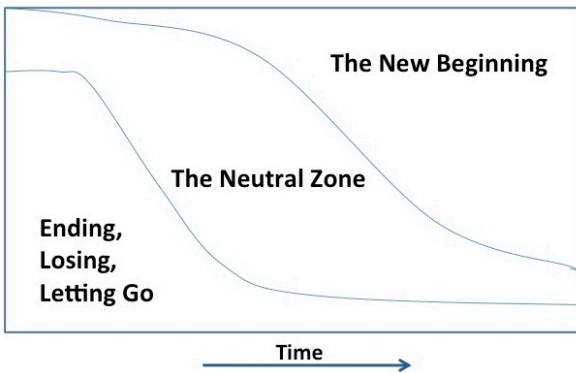


Figure 3: Three-phase transition [Bri09]

As mentioned above, the approach used for the SPI course is focused on solving an organizational problem. The activities performed by the students are:

- Develop a team member's contract (e.g. roles, responsibilities, expectations)
- Define the business context (e.g. type of product, customers, challenges)
- Identify business objectives, challenges and barriers.
- Develop a business case.
- Develop a communication plan.
- Measure and analyze organizational issues related to the management of change.
- Perform a mini-diagnostic of the performance of a process.
- Develop a mini-improvement/installation plan.
- Document the solution (e.g. a process).
- Implement the improvement plan

A vast majority of students are quite knowledgeable about the technical issues but they are not no knowledgeable about the management of technological change. Since the management of change is a key element of a successful process improvement program, a series of actions were done to facilitate the development, implementation and adoption of the processes, methods and tools [Lap98]. A set of assessment tools provided, described in table 3, helped the students understand the 'soft' issues of a technological change in an organization.

Table 3: Elements measured with the IMA Tools

Title of Tool	Description
Organization's stress level	Evaluation of the priorities for resources in the organization
Sponsor assessment	Evaluation of the resources, reinforcement (e.g. motivation) and communications commitments made and demonstrated by the sponsor(s) of a change project
Change agent skills	Evaluation of the skills and motivation of those responsible for facilitating the implementation of organizational changes
Individual readiness	Evaluation of the reasons why people may resist an organizational change
Culture assessment	Assessment of the fit between the desired change and the actual organizational culture in order to identify potential barriers and to leverage actual cultural strengths
Implementation history	Assessment of barriers and lessons learned from previous change projects (since past problems are likely to recur, this tool allows identification of the issues that need to be managed for the change project to be successful)

The assessments performed allow the students to better identify potential barriers to a proposed SPI and guide them in developing mitigating actions to increase the likelihood of the success of their improvement project. Table 4 describes the deliverables and the presentations made by students of the SPI course.

### 3 Software Process Improvement Project in Organizations

To illustrate the SPI projects done, we briefly describe, below, a few organizations where software process implementation projects conducted by graduate students.

#### Organization 1

*Background:* The company, of about 140 employees (14 software developers), designs and sells electric powertrain systems in the automotive field. Their products are embedded software that controls the operation of engines in real time and embedded

software that controls the interactions between the components of a vehicle. Property management and audit of building health.

*SPI Project:* A compliance study was conducted to establish the difference between the processes in place and those proposed by the Entry profile of ISO/IEC 29110. An action plan has been developed to organise the software process improvement activities. An analysis of differences between ISO/IEC 29110 was conducted. An economic impact assessment was conducted using the methodology developed by ISO.

#### Organization 2

*Background:* Property management and audit of building health.

*SPI Project:* document existing business processes, analyze them and identify those with potential for improvement.

#### Organization 3

*Background:* An engineering company specialized in the integration of interactive systems, communication and security in the area of public transportation such as trains, subways and buses and railway stations, stations and stops of bus.

*SPI Project:* Start-up of 4 people in 2011. Many customers in the public transportation ask for a CMMI level 2. Implementing the CMMI<sup>®</sup> Level 2 Process Areas was too demanding for a start-up of 4 people. ISO/IEC 29110 has been used as the main reference for the development of the management and engineering processes. A gap analysis between CMMI level 2 and the ISO/IEC 29110-based processes was done.

#### Organization 4

*Background:* Medical device R&D enterprise.

*SPI Project:* The Basic profile of ISO/IEC 29110 was used to document and implement a quality management system. ISO 13485 was used as the framework for the quality management system.

#### Organization 5

*Background:* A project conducted at ÉTS for a unit responsible to promote activities for graduates and to raise money for the financing of the ÉTS foundation.

*SPI Project:* The software project developed a web portal using the Basic profile of ISO/IEC 29110. The portal allowed graduates to register to activities, modify their personal information.

#### Organization 6

*Background:* An enterprise specialized in industrial process control. A department of 13 employees.

*SPI Project:* ISO/IEC 29110 Entry profile was used to assess practices in use. The management of requirements was the focus of the project.

#### Organization 7

*Background:* An IT start-up involved in the development of web traffic surveillance.

*SPI Project:* A start-up of 4 employees. Documentation of the software development process using the Basic profile of ISO/IEC 29110.

#### Organization 8

*Background:* An IT service department of a large banking institution supporting the work of traders.

*SPI Project:* A department of 8 employees. Analysis of current practices. Development and implementation of requirements management practices using a traceability matrix.

#### Organization 9

*Background:* A large civil engineering and construction firm.

*SPI Project:* A department of 15 people. Responsible for the development and maintenance of software for the other units of the company. After an analysis of current practices using ISO/IEC 29110, the improvement implemented a change request management process.

In addition to the one-semester graduate SPI course, a few students decided to pursue the work done during the 10-week project as their graduate project. The following paragraphs briefly describe these projects.

An implementation project has been conducted in an IT start-up VSE by a team of two (part-time) developers [Lap4]. Their web application allows users to collaborate, share and plan their trips simply and accessible to all. The use of the Basic profile of ISO/IEC 29110 has guided the start-up to develop an application of high quality while using proven practices of ISO 29110. The total effort of this project was nearly 1000 hours. Using the management and engineering practices of ISO/IEC 29110 enabled the start-up to plan and execute the project expending only 13 percent of the total project effort on rework.

An implementation project has been conducted in an IT start-up founded by a graduate student. The VSE has 5 employees at the Montréal site and 2 employees

in a site in Tunisia. The VSE offers software development services, Web solutions, mobile applications as well as consulting services to implement ERP solutions.

Table 4: Topics on course

Deliverables	Value
1. Project Plan and Contract between Team Members	4%
2. Project Overview	5%
3. Business Case	5%
4. Communication Plan	5%
5. Organizational Culture Analysis	5%
6. Diagnostic of the Organization	5%
7. Sponsorship Evaluation	5%
8. Updated contract between team members	0%
9. Analysis of the Motivational Factors	5%
10. Organizational Stress Analysis	5%
11. Change Agent Capability Assessment	5%
12. Change Readiness Assessment	5%
13. Process Description	5%
14. Improvement/Installation Plan	5%

A Canadian division, of about 400 employees, of a large American engineering firm has implemented a program to define and implement project management processes for their small-scale and medium-scale projects. The firm already had a robust and proven process to manage their large-scale projects. Their projects are classified into three categories as illustrated in Table 5.

Table 5: Classification of projects by the engineering firm [Lap15b]

	Small project	Medium project	Large project
Duration	< 2 months	> 2 & < 8 months	> 8 months
Team size	<= 4 people	4-8 people	> 8 people
Number of engineering specialties	1	>1	Many
Engineering fees	\$5,000 - \$70,000	\$50,000 - \$350,000	> \$350,000
Percentage of projects	70%	25%	5%

The division documented the business goals as well as the problems that it wished to solve. The division used the project management process of the Entry profile of ISO/IEC 29110 to document their small-scale project management process and they used the project management process of the Basic profile to document their medium-scale project management process.

An ISO methodology was used to estimate the anticipated costs and benefits over a period of three years. An estimate of anticipated costs and benefits over a period of three years was made by the improvement program project sponsors. Table 6 shows the results for the first three years of this cost/benefit estimation.

Since the utilization of ISO/IEC 29110 was very successful in the development of their project management processes, the recently published systems engineering ISO/IEC 29110 Entry and Basic profiles will be used to redefine and improve the existing engineering process (ISO 2014, ISO 2015). This process will address the activities required from engineering requirements identification to final product delivery.

Table 6: Costs (in \$CAD) and benefits estimations from implementing ISO/IEC 29110 [Lap15b]

	Year 1	Year 2	Year 3	Total
Cost to implement & maintain	59,600	50,100	50,100	159,800
Net benefits	255,500	265,000	265,000	785,500

### 3 Conclusions

Many changes have been made to the SPI course since it was initially set up in 2000. The challenge was to ensure that all these improvements met the objectives of the course. At ÉTS, students evaluate both the course and the professor. Following the improvements, the course scored 4.34 for a maximum score of 5, while the average score for the courses of the graduate software engineering program was 3.83. The use of ISO/IEC 29110 instead of the CMMI greatly facilitated the understanding and implementation of a software engineering framework suitable for most VSEs of the Montreal area.

The authors think that the current SPI course lectures and projects in industry provide a solid foundation for software engineers, even though SPI is still perceived as a low priority by most SMEs and VSEs. However, the profession of software engineering is still young...and Rome was not built in a day.

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