AN EVALUATION OF THE BENEFITS AND DIFFICULTIES OF IMPLEMENTING ISO/IEC 29110 INTERNATIONAL SOFTWARE STANDARD IN ACADEMIA AND INDUSTRY

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ABSTRACT

Very Small Entities (VSEs) have a suitable place as the principal producers in a software product supply chain. This leads to a commitment to achieve high-quality software products. To help them, experts from various countries collaborated to develop the ISO/IEC 29110 series of standards and guides. However, it is necessary to adequately transfer this knowledge to them in this standard; in other words, building conditions that make it happen are required. This paper analyzes 23 benefits and difficulties of VSEs that improve their processes using a basic ISO/IEC 29110 standard profile as a reference.

Keywords: VSE, software standards, software development centers, continuous improvement, ISO/IEC 29110.

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UNA EVALUACIÓN DE LOS BENEFICIOS Y DIFICULTADES DE IMPLEMENTAR EL ESTÁNDAR INTERNACIONAL DE SOFTWARE ISO/IEC 29110 EN EL ÁMBITO ACADÉMICO Y LA INDUSTRIA

RESUMEN

Las Entidades Muy Pequeñas (EPM) ocupan un lugar destacado como principales productores en la cadena de suministro de productos de software. Esto conlleva el compromiso de lograr productos de software de alta calidad. Para apoyarlas, expertos de diversos países colaboraron en el desarrollo de la serie de normas y guías ISO/IEC 29110. Sin embargo, es necesario transferirles adecuadamente el conocimiento de esta norma; es decir, crear las condiciones que lo hagan posible. Este artículo analiza los beneficios y dificultades de 23 EPM para mejorar sus procesos, utilizando como referencia un perfil básico de la norma ISO/IEC 29110.

Palabras clave: EPM, estándares de software, centros de desarrollo de software, mejora continua, ISO/IEC 29110

INTRODUCTION

International Software Engineering standards are developed, reviewed by experts worldwide, and approved with the countries' consensus. These standards are essential sources of codified knowledge for academia, enterprises, and government agencies that teach, develop, and maintain software [1].

This codified knowledge is a collection of proven software engineering practices. They suggest practices to enhance software product quality and software process capability. In addition, it aims to help private and public organizations of all sizes to increase either their competitiveness or their capacity to serve their citizens better [1] [2][3][4][5][6].

One of the biggest challenges that software engineering researchers have linked to the transfer of Software Engineering standards to academia (i.e., professors, researchers, students) and industry (i.e., development such as managers, team leaders, developers, testers, and quality assurance) that they will be able to use in their software projects [7].

An example of this problem is in [8]. The authors published the survey results that considered 90 requirements of engineering practitioners regarding the ISO/IEC/IEEE 29148 standard. The data revealed that approximately 47% of respondents, either requirements engineers or business analysts, had to familiarize themselves with the standard. Around 24% had never used it. Despite most participants holding university degrees, universities were only the fifth most common source of knowledge of the standard. Finally, only 22.1% of respondents mentioned university studies as a source of knowledge related to requirements engineering standards.

VSEs develop most software worldwide [4][7][9]. A VSE can be an enterprise, an organization (e.g., a government agency, a non-profit organization), a department within a medium or large organization, or a project with up to 25 members [10].

Even when the ISO/IEC 29110 was created to meet this type of organization's needs. To enable the use of international standards and avoid feeling detached from their environments was not easy. This is mainly because before this series of standards and guides were published; most VSEs did not have the experience and time to adapt and tailor "larger" software engineering standards like ISO/IEC/IEEE 12207 [9].

As a solution, ISO/IEC 29110 aims to assist VSEs in adopting proven practices, leading to improved product quality, shorter delivery times, and reduced rework and development costs.

This paper evaluates the benefits and difficulties of implementing the ISO/IEC 29110 standard in a sample of 23 VSEs in a Mexican region.

According to INEGI, a 2020 study on Mexican economy found that 95% of the business companies are micro-companies (0-10 employees), and 4.0% are small companies (11-50 employees) [11]. Due to the size of organizations, these data highlight the relevance of using standards like ISO/IEC 29110. This paper analyses a sample of VSEs using a six-step method to facilitate the implementation of the standards.

The paper is organized as follows: Section 1 provides the literature review and conceptual framework, including an overview of the ISO/IEC 29110 series of standards and related studies. Section 2 describes the knowledge transfer of the materials and methods developed and employed for VSEs. Section 3 presents an analysis of results. Section 4 discusses benefits. Section 5 outlines conclusions and future work.

1. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

1.1 ISO/IEC 29110 series of standards

ISO/IEC 29110 offers a set of standards and guides featuring a minimal subset of international Engineering Standards, known as profiles, tailored for VSEs [1][2][9]. They explicitly target VSEs that create non-critical products and need more experience in processes of systems engineering or software engineering lifecycle standards, like the ISO/IEC/IEEE 12207 lifecycle process standard [2][3][7][12].

The core of Software Engineering ISO/IEC 29110 consists of a series of management and engineering guides that concentrate on software engineering practices for project management and software implementation.

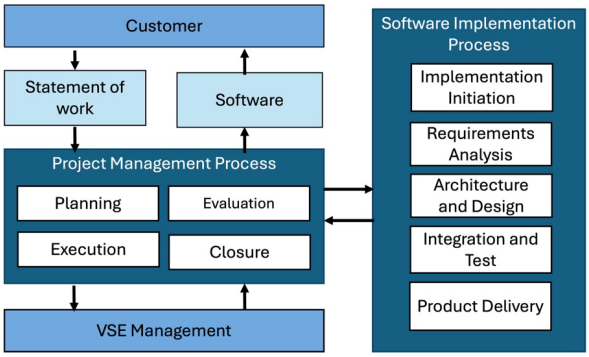
An ISO working group was mandated to develop a four-step road map, called profiles, targeting VSEs, ranging from start-ups to grownups (e.g., start-ups with lack or low experience related to the selection of the appropriate processes from software engineering standards and tailoring them to a project's needs and those with expertise in that field) [5]:

1. An entry profile is designed for a start-up or a small-scale project, like those requiring a six-month effort.
2. A basic profile targets VSEs that develop a single product with one team.
3. An intermediate profile is aimed at VSEs, which involves developing a product, focusing on business management, implementing project management software, and establishing an acquisition process.
4. An advanced profile targets VSEs that want to grow and remain independent, competitive software development businesses.

Figure 1 offers a broad overview of the standard. As illustrated, the process begins when a customer submits a statement of work (SOW). Then, a VSE's management decides whether to accept or reject a project. If accepted, a project planning phase will begin, leading to the start of the project. Consequently, the VSE will carry out the project as planned while overseeing and controlling both the project and the product throughout the software development phases.

Ultimately, the customers receive the product outlined in the SOW, which may include user documentation, installation manuals, and codes.

Fig. 1. ISO/IEC 29110 Basic Profile processes



Source: [7].

The processes in Basic profile software comprise some fields from a Software Engineering Body of Knowledge (SWEBOK®) [7]. They include activities such as requirement gathering, design, construction, testing, quality assurance (including reviews, verification, and validation), configuration management (version control, change requests, and release management), engineering management, engineering models and methods (including traceability), and engineering processes. The basic profile also oversees customer and software development organization iterations.

1.2 Related work

Some researchers have identified the challenges of implementing models and standards in software development enterprises to support the creation of high-quality products within budget and on schedule by efficiently optimizing efforts and resources [1][2][3][4][5][6][13]. This paper presents a set of papers providing experience in implementing ISO/IEC 29110.

In A Multi-Case Study Analysis of Software Process Improvement in VSEs using the ISO/IEC 29110, Laporte and O'Connor reported one Canadian startup and a Peruvian with a small IT team of 6 developers of a large financial institution [14]. As

the main benefits, they highlighted that VSEs could adequately plan and execute their projects and develop their products using software engineering practices.

In VSE Software Project Management with ISO/IEC 29110, O'Connor and Laporte reported a pilot project in two countries: Canada, an IT department with four staff, and a French VSE with 14 people [15]. This paper highlighted the benefits of implementing software project management using deployment packages.

Implementing ISO/IEC 29110 in two tiny Peruvian software development enterprises. Díaz et al. [16] reported implementing ISO/IEC 29110 in two VSEs in Perú. They reported the main benefits of improving adherence to the standard, a VSE organizational culture, regarding using proven practices such as improved time management through schedules and enhanced project monitoring using performance indicators. Besides, relevant improvements obtained a defined process and templates for new projects.

An empirical software engineering experiment was conducted to assess the implementation of a subset of an ISO/IEC 29110 software process by four teams of undergraduate students in Ecuador [17]. The same research reported the results of implementing ISO/IEC 29110 in academia. The paper focused on implementing a subset of the Software Implementation process of the Basic profile of ISO/IEC 29110 in Ecuador [17]. They highlighted the benefits of better performance and quality software. This could enable them to enhance competitiveness and explore new opportunities in national and international markets.

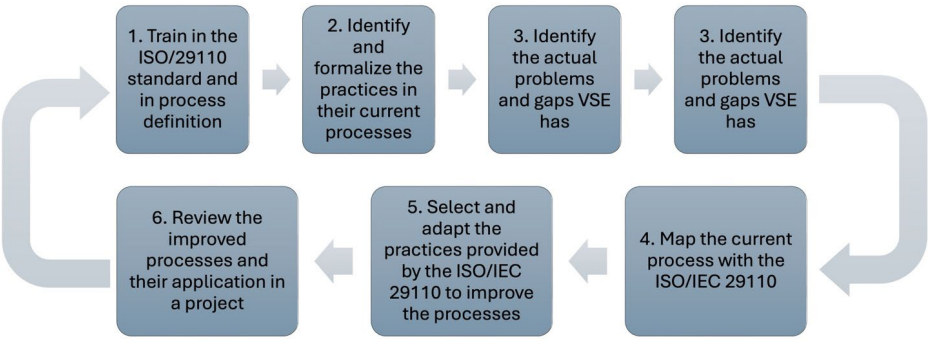
Related to implementing Software Engineering standards in VSEs from Startups to Grownups [3], Laporte, Muñoz, Mejía, and O'Connor reported the implementation of ISO/IEC 29110 in eleven VSEs. The article highlights benefits such as decreasing rework, reinforcing project planning and control activities, improving communication, verification and validation activities, and reducing cost and development time.

Finally, in the Software Quality Observation Model based on ISO/IEC 29110 for VSE Development Entities. Redondo-Acuña and Florian-Gavaria reported an observation model [6]. This model contains 22 indicators to assess the quality of tasks, to measure the state of quality in software development process of VSEs, and to help them toward a standard certification.

1.3 Six-step method

Three authors of this paper participated in creating a six-step method to implement ISO/IEC to a set of VSEs [18]. Figure 2 illustrates the method when adopting the Basic ISO/IEC 29110 software profile.

Fig. 2. The six-step method VSEs followed [source: adapted of.



Source: [5]

The execution of the method provided in Figure 2 is:

1. To perform step 1, we performed a series of 30-hour workshops.
2. To perform steps 2 to 5, we held a series of meetings with VSEs. On average, there were about four meetings, each lasting about four hours.
3. To execute step 6, a minimum of 2 meetings and a maximum of 4 meetings were held for 4 to 6 hours. The number of meetings depended on VSE culture, team size, project size, and type, and experience using models and standards.
4. To perform steps 2 to 5, a set of meetings was conducted with VSEs. On average, there were about four meetings, each lasting about 4 hours.
5. To execute step 6, we held a minimum of 2 meetings and a maximum of four 4-to-6-hour sessions.

The number of meetings depended on VSE culture, team size, project size and type, and their experience using models and standards.

2. MATERIAL AND METHODS

This research employs qualitative methods to analyze benefits and challenges, focusing on interpreting a phenomenon through individuals' explanations [19].

The authors created and conducted two surveys to obtain information on the set of VSEs.

A survey allows the use of a questionnaire or an interview with many people. It is also a research method performed in retrospect [19], based on a past event in which people were involved. In the case of this research paper, we used a questionnaire.

To achieve the aims of this research, the authors invited VSE managers to fill out two brief questionnaires at different intervals to gather information about their experiences after one, two, or three years of implementing the international standard.

Our initial sample comprised 21 VSEs with experience in implementing the standard; however, a few did not. Failing to answer the questionnaire led to a collection of 13 questionnaires for Survey 1 and 8 questionnaires for Survey 2.

The results collected by the questionnaire are analyzed to derive descriptive and explanatory conclusions.

- Survey 1 focuses on gathering information about adopting the best practices.
- Survey 2 focuses on collecting data from people who keep getting certifications regarding what they expect versus the reality of implementing an ISO/IEC 29110 standard.

We decided to adopt a descriptive approach that enables us to make assertions about VSEs having experience implementing the basic profiles of ISO/IEC 29110. Subsequently, the information was classified into two elements:

- Benefits: These include the technical and human benefits identified by managers because of international standard implementation.
- Difficulties: It contains the problems VSEs should face while implementing an international standard.

3. RESULTS

As published in [3] [5] [20], we implemented the method with excellent results from 2017 to 2022 in academic and industrial domains. Table 1 summarizes the complete sample of VSEs that used the method shown in Fig.2 to implement a standard and how they interacted in the project from 2017 to 2022. The table lists two types of VSEs: university Software Development Enterprises (SDEs) and Software Development Centers (SDCs).

Table 1. Sample of VSEs in which the method was applied

Year	Number of VSEs participating for the first time in the program	Number of VSEs keeping their participation in the program
2017	8 VSEs (4 SDE and 4 SDC)	
2018	7 VSEs (2 SDE and 5 SDC)	7 VSEs (3 SDE and 4 SDC)
2019	6 VSEs (4 SDE and 2 SDC)	14 VSEs (5 SDE and 9 SDC)
2020	2 VSEs (1 SDE and 1 SDC)	19 VSEs (9 SDE and 10 SDC)
2021		19 VSEs (9 SDE and 10 SDC)
2022		20 VSEs (9 SDE and 11 SDC)

Source: own elaboration.

As a result of implementing the method, it is noteworthy that by 2022, the state of Zacatecas had 20 VSEs certified to the Basic ISO/IEC 29110 software profile. According to the 2022 official registry of the certifying body, Mexico accounts for 120 of the 169 Basic ISO/IEC 29110 software profile certified VSEs in Latin America [21].

The next sections present the analysis of the research benefits and difficulties. It is essential to emphasize that, of all the 20 VSEs presented in Table 1, we received 13 responses for Survey 1 and 8 responses for Survey 2. This represents a significant limitation of this research, so due to the sample size, the results cannot be generalized. Furthermore, the reasons why VSEs chose not to continue with the project were financial and unrelated to the technical issues concerning the standard.

3.1 Software Development Centers (SDCs) of university environments

This method was implemented in the SDCs of 11 universities. The teams that integrate into an SDC to develop a project typically consist of students, with a professor acting as the project manager and supervisor.

The software development approaches employed are traditional, including Waterfall (predictive) [18], and agile, such as Scrum (adaptive) [18]. It is important to emphasize that all universities involved in this program provide software to actual internal and external customers and engage senior students who develop software, including systems engineers and information technology engineers.

All SDCs continued to work within the program from 2017 to 2022. Some case studies detailing the implementation of the ISO/IEC 29110 standard using the previously published method include articles discussing the benefits SDCs obtained [20] and articles related to practical analyses in [5].

Technical benefits related to the SDCs' identified process project, and product-related improvements are as follows:

1. To improve the definition, documentation, and implementation of software project development processes, ensuring they become valuable SDC inclusion process assets.
2. Roles require more commitment to activities rather than making assumptions about what they should entail. SDCs identified the knowledge students must acquire before taking on a specific project role.
3. To improve the development team and customer responsibility. Most of them mentioned a change in customers because of increased trust regarding developing quality products.

4. Adopt a straightforward standard to manage software development projects. Students were pleased with using an international standard because they felt comfortable in an environment that provided guidelines and process assets to conduct their work.

5. Enhancing activities related to validating and verifying project tasks, such as software testing, will help students avoid rework and understand the significance of ensuring quality.

6. To design a set of work product templates to accelerate the process implementation. Students acquire skills to develop the software engineering resources necessary to undertake a project.

Human benefits related to the improvements the SDCs have identified for people are listed next:

1. Professors and students will understand the standard better and will learn how to implement SDC without a complicated process and with no excessive bureaucracy.

2. Professors are more qualified to convey to their students the knowledge documented in ISO/IEC 29110 standards. They learn the standard and provide an environment that allows them to practice their new knowledge, which gives them the experience and skills to teach the standard more effectively.

3. Students gained experience working on real projects implementing software engineering practices based on international standards. This has been a significant SDC contribution for students, as it enables them to earn their grades and believe in their ability to take part in or lead software projects.

4. SDCs improve the management of commitments between the development team and customers, providing software engineering resources that allow them to understand customers' needs.

5. SDCs allow students to move faster in their learning process because they have applied their theoretical knowledge.

6. They contribute to training better-qualified engineers for the software industry with knowledge and confidence to work under international standards.

7. They capture new customers' interest by demonstrating their capability to deliver quality software and the skills of their software engineers.

8. They have technical support that facilitates understanding ISO/IEC 29110 standard and its implementation.

9. Students accelerated the integration of the concepts taught in class when developing software for real customers using ISO/IEC 29110.

Difficulties related to processes, projects, people, and products are provided next:

1. More professors should be actively engaged and dedicated to SDCs, as they do not receive financial incentives.
2. Some institutions have had terrible past experiences with implemented projects that did not monitor progress and achieve program goals. Furthermore, they feel frustrated because they have not achieved short-term and medium-term goals.
3. For the first time, many professors applied a standard, having to understand it to deploy knowledge to their students. Moreover, only some students who participated in the teams participated in the project execution. Therefore, they should help with software development in their daily activities outside the SDC to increase their workload.
4. Professors engaged in SDC projects have limited time to complete them due to academic program constraints to which they must respond.

3.2 Software Development Enterprises (SDEs)

The method was applied to a sample of 10 SDEs. Software development approaches include traditional approaches such as waterfall, Agile approaches such as Scrum or using only a few agile practices, and Hybrid approaches such as TSP® (Team Software Process) and Scrum or CMMI® and Scrum.

Most SDEs develop software products as their main activity. Three produce embedded software. Nine SDEs worked as part of a 2017- 2020 program. Three SDEs left the program due to financial issues unrelated to implementing ISO/IEC 29110, such as the need for more new projects due to the COVID-19 pandemic.

Some of the case studies, which provide a detailed method implementation in SDEs, were published as follows: articles related to the benefits VSEs obtained [3][5] [22] and a practice level analysis in [5]. Then, a summary of the main benefits and difficulties is provided.

Technical benefits regarding the improvements SDCs have identified related to processes, projects, and products are next provided:

1. Updating their software development processes and process assets based on acquired knowledge, producing documentation that offers value to them and their customers.

2. Improving customer communication, formalizing agreements from the beginning of a project to project closure. It is relevant to highlight that most VSEs only perform a contract after starting a project.

3. SDCs may adopt monitoring and control practices, enabling them to perform better project control and visibility because implementing standard facilities improved their performance.

4. Achieving a standardized methodology to manage software projects so that the incredibly unforeseen cost is reduced.

5. Enabled software to use in a project, understanding the requirements for software project performance to meet an international standard.

6. Improved project versioning and software delivery help them control their software project artefacts better.

7. This allows products to be placed quickly and efficiently in the market due to reduced rework while improving software quality.

8. Technical support facilitated understanding of the ISO/IEC 29110 standard and its implementation.

Human benefits regarding SDEs' that identified improvements related to people are listed next:

1. Creating a set of role descriptions and responsibilities for specific tasks that support the development of a self-organizing team while highlighting gaps in knowledge and training required to improve role performance.

2. Improving their experience in implementing and using international software engineering practices provided by international standards. Moreover, they become confident in getting better results in their software projects.

3. Enhancing management of commitments between the development team and a customer through communication channels and optimizing software engineering resources to support them.

4. Trained personnel successfully updated their work practices by adopting recent technologies and adhering to international standards.

5. Obtaining recognition based on an international standard will allow them to offer their services to new customers or markets.

Difficulties regarding processes, projects, people, and products are next provided:

1. Support VSE owner management in providing facilities to people involved in the project.
2. Customer mistrust stems from previous negative experiences with projects, often due to inadequate progress monitoring and failure to meet project objectives.
3. Some challenges imply that software engineers interpret ISO/IEC 29110.
4. They had never developed software using documented processes.
5. Gaps in knowledge in specific topics such as traceability, verification and validation, test cases and procedure design, configuration management, and risk management.
6. Resistance (from directors, cultural factors, or employees) to adopting a formal or systematic approach to software development.

4. DISCUSSION

This research analyses the lessons learned from transferring the knowledge content of international standards, such as ISO/IEC 29110 and VSEs.

After analyzing the results of VSE samples, including SDCs and SDEs, the benefits achieved after using the six-step method are the following:

1. Using it enables VSEs to understand their culture and needs as the first step and select ISO/IEC 29110 practices that are highly valued in their processes. This fact reduces people's resistance to using an international standard.
2. Using it enables VSEs to keep their people motivated to implement ISO/IEC 29110 activities and tasks, even when most did not have experience implementing international standards until they used the method to implement the standard.
3. It facilitated organizational change management, increased ISO/IEC 29110 practice comprehension, and considered practices that can reinforce their current processes while keeping the way they work. The method allows them to focus on VSEs' practices and understand gaps and improvement opportunities. Besides, this comprehension enables them to implement ISO/IEC 2911 practices 0 by adapting them to their environment.
4. The method provides key Software Engineering support, allowing quick knowledge transfer to users like VSEs.

The main limitation of the results provided in this research paper is the sample of VSEs that have used our method. However, as Section 2 presented, more publications must give evidence on implementing methods like the one provided in this article.

As software engineering researchers, after analyzing the benefits listed in section 3, we are convinced that implementing Software Engineering standards as ISO/IEC 29110 provides excellent results. On the one hand, in SDCs, the standard has been a critical element in achieving high-quality engineering; on the other hand, SDEs have allowed professionals to improve their knowledge and enable them to improve their software process and their software product quality.

The results emphasize that VSEs can readily adopt ISO/IEC 29110, enhancing their development processes. Additionally, SDCs' implementing project management and software development processes from a Basic ISO/IEC 29110 profile is beneficial in addressing critical software engineering gaps between academia and industry's needs, such as configuration management, standards, models, methods, process, design, and testing

5. CONCLUSIONS

VSEs play an essential role in the software supply chain by creating valuable products and services to meet market needs. In this context, developing Software Engineering standards contributes to achieving high-quality software produced within the budget and schedule initially projected while optimizing resources. Furthermore, implementing codified knowledge in these standards for software development organizations, especially in VSEs, becomes a real challenge.

We know the sample of VSEs presented in this article is too small, representing an essential limitation of the research, so the results cannot be generalized. However, a few articles provide an analysis that provides a clear example of performing an adequate knowledge transfer among an international standard, academia, and industry.

Using methods focused on knowledge transfer allows growing "win-win-win" collaborations and interactions that are easy to deploy worldwide.

Future works will address the following topics:

- Several SMES currently use agile development. Therefore, it is necessary to ensure the use of proven practices that reinforce an agile development approach. DevOps with ISO/IEC 29110 series management and engineering practices were the creation of the guidelines to implement a Basic ISO/IEC 29110 profile in agile environments, which ISO/JTC1/SC7 is still evaluating.

- We live in the Artificial Intelligence era, and most technological solutions are developed using AI. However, according to many authors, around 70% of these types of applications fail when running in an operational environment. This data highlights the need to apply Software Engineering practices to strengthen the development of Artificial Intelligence applications, specifically Machine Learning applications.
- Providing resources to bring practical software engineering practices to academia using innovative approaches such as gamification and serious games.

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