FQMaP: Towards a framework quantitative management of processes in small software development organizations

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ABSTRACT

Software development organizations need to control and improve their practices, seeking to reduce variability when executing the necessary processes to elaborate software; therefore, these organizations implement improvement plans to identify factors that affect the processes. Quantitative Management deals with identification, tracing, and control of those incident factors, using data proactively to predict performance and the effect of possible changes in a process. Reference models in software processes development such as CMMI V2.0 and ISO/IEC 33061:2021 address Quantitative Management, but are aimed at big enterprises. Other models such as MoProSoft, COMPETISOFT, and MPS.BR are aimed at small enterprises, but do not include enough elements on Quantitative Management. Execution of a systematic literature review permitted searching for works on Quantitative Management intended for small software development enterprises, indicating necessary practices and how to perform them. This search showed that a proposal is not available that incorporates Quantitative Management practices for software processes aimed small software development enterprises. The referred aspects make it difficult to adopt a Quantitative Management culture within these organizations, it which has become a problem, consisting in that small software development enterprises that do not execute quantitative management practices will have difficulty identifying and focusing on the factors that impact the process performance and, therefore, on the results of their projects. This work sought to tackle this problem by proposing the "framework for quantitative management of processes in small software development organizations" (FQMaP), which allows incorporating practices and techniques that support Quantitative Management of software development processes in these kinds of enterprises. From the evaluation of FQMaP, carried out by following Focus Group technique guidelines, it can be demonstrated that it is a simple proposal and with elements that can serve a company to quantitatively manage software development processes. Also, it has clearly specified its components, showing that its structure is familiar with other process patterns, that would facilitate their interpretation.

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1. Introduction

During the execution of an improvement plan in small software development enterprises, these will eventually need to evaluate and control their software elaboration processes from a statistical point of view, seeking to reduce their variability and, for such, it becomes necessary to evaluate several of their attributes by gathering quantitative data from those attributes and the application of their corresponding analysis. Consequently, entities require managing them in quantitative manner by applying statistical techniques [1]. There are researchers refers

Statistical Process Control (SPC) as a tool for process improvement [2], [3], [4], [5], [6], [7], [8], [9]; although there are disagrees about its application in software processes [10], [11].

Quantitative process management (QPM) uses data proactively to predict performance and the effect of possible changes in a process [12]. These data are analyzed through statistical techniques such as experiment design, control charts, process capability analysis, regression analysis, reliability analysis or sampling according to ISO 10017:2021 [13], and when applying statistical and quantitative techniques to monitor the performance of software development processes, it is said they are managed quantitatively [14].

In the evolution of an improvement plan in software development it's possible to involve QPM, which requires applying statistical techniques to monitor performance in project management [12], [15]. According to [14], it's necessary to apply statistical analyses to the information for obtain processes under control, defined as those in which it is possible to predict the limits of their variability [16].

In the case of Colombia, in the software industry, micro, small and medium-sized organizations represent 80.42% of the total sector [17], which are denominated as very small entities (VSE) and defined as entities with 25 people or less, according to ISO/IEC 29110:2015 [18].

It is true that different reference models have been elaborated for software development such as CMMI V2.0 [19], ISO/IEC 33061:2021 [20], and ISO/IEC 12207:2017 [21], which address guidelines for quantitative management of processes; however, according to [14], given that those models are aimed at large organizations and that, additionally, very few studies have focused their attention on the use of effective practices toward the characteristics of VSE, knowledge of the models by these has been weak.

Now, reference models exist for VSE such as MoProSoft [22], COMPETISOFT [23], MPS.BR [24], and ISO/IEC 29110:2015 [18], but these do not offer enough elements on quantitative management of software development processes. Those models are more focused on defining processes related to low maturity levels, which still do not include quantitative management or optimization practices; furthermore, they have not been found to incorporate the definition of process elements linked to high maturity levels.

The aspects mentioned have hindered the adoption of quantitative management practices within VSE, which entails problems in identifying and focusing on the factors that impact upon the performance of processes. These practices, besides helping in quality assurance of the final product, improve and stabilize processes and reduce variability, allowing predictive analytics in the short term. In this sense, we may understand the variations inherent to processes, as well as the causes of their results. However, the use of statistical techniques to support QPM is still not frequently applied in the software industry, given that its practices are more focused on the processes than on the product, which has complicated their direct application [25].

Thereby, it becomes necessary to research on the use of statistical techniques in the VSE wishing to manage quantitatively their software development processes to predict their behavior. It is pertinent for research to focus on those organizations for them to recognize and use specific QPM elements appropriate to their characteristics and to the types of projects they manage, thus, gaining the opportunity to become more competitive.

To identify related works, a systematic literature review was undertaken that permitted obtaining a total of 47 primary studies addressing themes like: (i) general aspects in process improvement, (ii) harmonization of models, (iii) metrics, measurement and analysis on software improvement, (iv) proposals to improve processes for the VSE setting, (v) proposal and application of methods or techniques to carry out quantitative management, and (vi) quantitative management of software development processes by using solutions like Six-Sigma.

From the aspects described, this paper presents the framework for quantitative management of software development processes in VSEs, denominated FQMaP, which seeks to guide these types of organizations in adopting QPM practices to obtain processes that are under statistical control. FQMaP has three components: (a) *a technical guide* for *QPM* that describes the roles involved, practices, and activities to be conducted to generate the products required, (b) *techniques for SPC* and for statistical analysis, including fact sheets on the necessary statistical techniques to execute the practices and activities of the first component, and (c) *documents and templates*, which includes a user guide that describes a step-by-step example of how to carry out the practices defined in the technical guide by using the techniques for SPC defined in the second component.

The rest of the paper is structured as follows: in Section 2 presents a set of related papers obtained through a systematic literature review; it also indicates the research method used for the development of FQMaP. Section

3 describes the complete structure of FQMaP, and the strategy for its evaluation. Finally, Section 4 concludes the work and outlines areas for future research.

2. Research method

This section briefly describes related works and introduces the research method used.

2.1. Related works

To identify related works, a systematic literature review was planned and executed by following the guidelines presented in [26], the protocol template defined in [27], and the procedure proposed in [28]. After executing the systematic review protocol, a total of 47 primary studies were found and analyzed, classified into studies that address:

(a) General aspects in process improvement such as the studies presented by [29], [30], [31], [32], [33], [34], [35] and [36].

(b) Harmonization of models, presented by [37] and [38].

(c) Metrics, measurement and analysis in software improvement presented by [1], [3], [6], [7], [8], [9], [39], [40], [41], [42], [43].

(d) Proposals for process improvement focused on VSES such as those presented by [44], [45], [46], [47], [48] and [49].

(e) Proposal and application of methods or techniques to lead quantitative management referred by [4], [5], [10], [11], [15], [50], [51], [52], [53], [54], and [55].

(f) Quantitative management of software processes with Six-Sigma, such as the presented by [56], [57], [58], [59], [60], [61], [62], [63] and [64].

Also, papers were analyzed in which SPC tools and statistical analysis techniques have been used for quantitative management of software development processes within the framework of an improvement initiative, highlighting the following:

(a) According to [45], [54], [65], control charts are the most commonly used tool to determine if a software process is under statistical control. In [65] also shows the most common statistical techniques: execution diagram (22.8%), histogram (21.1%), Pareto analysis (21.1%), and scatter plots (10.5%).

(b) In [62] a method to manage and analyze projects with Six-Sigma is proposed, applying regression analysis and experiment design, cause-effect diagrams, control diagrams, scatter plots, histograms, and Pareto diagrams. Additionally, [59] established a processes model of software engineering, where they apply Six-Sigma for its construction. These authors use Pareto diagrams and suggest using histograms and cause-effect diagrams.

(c) Regarding statistical analysis techniques for QPM, the process capability analysis must be included, represented in a capability index for which certain minimum acceptable values are managed [54]. If the value obtained from the index for the process being evaluated is below the minimum, this indicates that the process does not comply with its functional objective even if it were under statistical control [66].

Stemming from the analysis of the studies identified through the systematic review it was found that no proposal is available that incorporates practices and techniques to support the quantitative management of development processes within the context of small organizations.

The studies reviewed address aspects such as the proposal and application of own methods or combined with such as such as Six-Sigma to support some quantitative management practices, but which are not enough because they are not aimed at small organizations or because they do not offer a complete set of practices to quantitatively manage a specific process associated to software development.

Additionally, from the related studies it was determined that to conduct SPC in software development organizations, we must consider the control diagrams that are fundamental to know if a process is or is not under statistical control and the cause-effect diagrams, which are useful to determine possible causes that lead to a process not being under statistical control; furthermore, with regards to the statistical analysis techniques we

must keep in mind the regression analysis that is useful to establish a process performance model and the process capability analysis, which allows knowing if a process complies or not with the desired specifications.

Due to the aforementioned, this work seeks to provide elements that allows better understanding and application of quantitative management of software development processes in small organizations. A set of constituent elements will be presented, which include strategies and techniques for the quantitative management of software development processes that offer options to establish controllable and predictable processes; besides, FQMaP is agree with specific reference models for these types of organizations.

2.2. Research method for the creation of FQMaP

To define and elaborate FQMaP, it was executed some of the tasks proposed by the production method of the OPEN Process Framework [67], which is structured for production of specific development methods. Besides, this method is open and of public domain. It is fundamental to use a methodology such as this because it is considered necessary for FQMaP to be the result of following reliable guidelines, proposed by researchers or organizations recognized in the area of process improvement.

The aim was for the proposal to be developed to have sound theoretical bases, while reflecting good practices in the elaboration of methods, which have already been tested and widely accepted in the software industry. Given that the work team was small in size, it was necessary to adapt the method and select five of the nine tasks indicated:

(a) *Evaluation of needs to solve*. To identify and assess the specific needs related to quantitative management of processes, which is expected to be addressed with the elements to be included in the proposal.

(b) *Construction of the framework*. Construction of the proposal denominated Framework for Quantitative Management of Software Development Processes in VSEs, through the selection of process elements included in existing repositories, from the adaptation of those elements selected and from the integration of the elements adapted to the proposal.

(c) *Documentation of the framework*. The related documents were elaborated with the constituent elements of the Framework.

(d) *Evaluation*. To assess the Framework proposal, with experts on the theme, obtaining the observations, suggestions, and corrections considered necessary.

(e) *Maintenance*. Add, eliminate, or modify the Framework elements identified as the result of the revisions derived from the evaluation activity.

3. Results and discussion

3.1. FQMaP structure

This section presents the characteristics of the FQMaP components. First, its context is presented, thereafter its general structure is indicated, and lastly a description is made of its practices, activities, and products.

3.1.1. FQMap context

FQMaP is aimed at VSEs, which is why it was defined according to the following characteristics, based on the study presented by [68]:

(a) Few roles involved. Bearing in mind that VSEs do not have a large number of personnel, defining an adequate amount of roles to conduct quantitative management of processes is a critical aspect. The fact that those roles are few, would provide the organization the posibility to apply the FQMaP practices.

(b) Few activities and products. Regarding the previous item, the aim is to motivate the organization's personnel upon highlighting that they would not require great effort when applying FQMaP practices.

(c) Specific guidelines to appropriate quantitative management practices. To indicate the minimum practices to perform and how these should be carried out and documented.

(d) Reference guides and user guide. Reference guides provide summarized information on the statistical techniques required to execute the FQMaP practices and activities. The user guide shows how to use the FQMaP elements through a step-by-step example that indicates how to conduct the practices defined in the technical guide.

The practices established in FQMaP, and explained in section 3.1.3, are considered the minimum to execute and have been included in this proposal, bearing in mind the profile of the VSEs and types of projects managed by these, which requires practices that imply quality and efficiency whenever requiring to quantitatively manage the most important processes without incurring in strong expense in time and resources, and to accomplish the goals established for those processes in the short term.

The set of FQMaP practices was defined from inspecting and adapting the essential elements of the QPM practices indicated in the reference models for improvement and evaluation of software development processes of greater use: CMMI V2.0 and ISO/IEC 33061:2021. The models mentioned were considered only as reference, although as a result of that inspection, it was found that most of their elements, as proposed, are inadequate for the VSE setting and, thus, it was necessary to make the transformation, combination, or synthesis of several elements of those models looking for them to be, without losing thoroughness, at the reach of these types of organizations.

Lastly, an organization seeking to implement FQMaP practices, must previously and correctly execute the following processes:

(a) Management requirements. Uses a sole form to document each requirement, so that it is simple to understand and with traceability to the sources from where these are obtained, with other requirements and with other work products. In addition, it makes sure to review the information contained in the samples of the form to detect inconsistencies.

(b) Project planning. Has adopted methods for estimations regarding costs, chronograms, and personnel required for a project; has defined the life cycle model and conducts risk management. All these items are documented in the Project Plan.

(c) Project monitoring and control. Reviews are made periodically of each project area (every 20 days or less) and the result of these reviews is recorded in a document that reports inconsistencies found and the degree of progress. Measures of attributes corresponding to each area of the project are gathered and analyzed.

(d) Management configuration. The organization controls versions of source codes and of each of the documents and stores a history of changes made on them, identifying the individual responsible for said changes.

3.1.2. FQMaP general structure

FQMaP is a proposal aimed at small organizations that allows their incorporating practices and techniques related to quantitative management aimed at software development processes (Fig. 1).
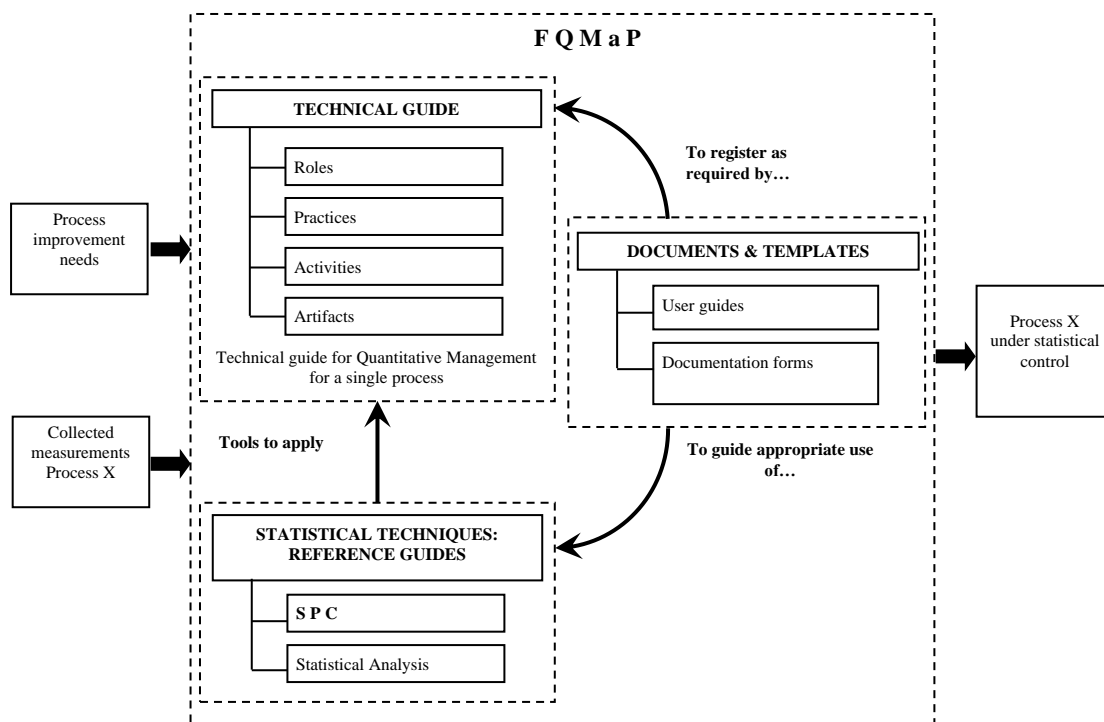

Figure 1. General view of FQMaP

The following describes in general manner the FQMaP components:

(a) Technical guide. Describes the practices and activities, products, and roles involved. Offers evaluation guidelines applicable to processes selected by the organization to assess if the processes comply with the objectives of quality, that is, being under statistical control and accomplishing suitable values of the performance index. It also offers elements of causal analysis to identify incident factors.

(b) Statistical techniques. Includes reference guides of the techniques for statistical control of processes (control diagram and cause-effect diagram) and for statistical analysis (regression analysis and process capability analysis). These techniques are necessary to execute the practices indicated in the technical guide.

(c) Documents and templates. This is divided into two parts: the first contains a user guide with a complete example, which shows step by step how to execute each of the FQMaP practices in addition to how to document them. The second part includes six forms to register the required information.

3.1.3. Description of FQMaP

3.1.3.1. Purpose and objectives.

The purpose of FQMaP is to guide the implementation of practices that support quantitative management of processes in VSEs. Its objectives are:

(a) Establish the minimum elements to guide the quantitative management of processes within a small organization of software development, seeking to obtain controllable processes in the organization.

(b) Facilitate its application in VSEs by using few resources with low cost and little time, looking to obtain viable and visible results in the short term.

3.1.3.2. Definition of practices, activities, and products.

Each process sought to be quantitatively managed must initially have the inputs of characteristic performance measurements. The following shows the general diagram that includes FQMaP practices, inputs, and products applicable to each process sought to manage quantitatively (Fig. 2).

FQMaP offers a guide to manage, monitor, and evaluate specific processes selected by the organization, for example, if the process is to support the construction of software, it is useful to have data on defect density or on percentage of rework; or if referring to the test process, data is needed on efficiency in removing defects. FQMaP indicates that for each process selected a set of activities must be carried out grouped into four big practices, numbered thus:

    (1)   Initial assessment of the performance of a process.
    (2)   Causal analysis.
    (3)   Preparation for quantitative management.
    (4)   Execution of quantitative management.

It is important to note that the product of a practice does not become the input of the following practice because each practice seeks to characterize the status of the process during a specific moment, hence, to obtain that characterization it is needed for the inputs to be quantitative measurements, goals, and objectives analyzed in a way that makes it possible to know what is the situation of the process or know if those goals and objectives have been reached, besides finding explanations for that status; all this is consigned in the respective product. Thereby, the characterization obtained from the status of the process, which is represented in the corresponding product, does not deliver new information for the following practice; its function is that of indicating the status of the process.

3.1.3.3. Relationship between Practices and Roles.

Bearing in mind that the roles involved should be few due to the low number of personnel available in small organizations, FQMaP proposes involving already existing roles (analyst, designer, programmer, tester, quality manager), which are denominated generically: "Responsible for Process", so that they participate actively, but without causing excessive additional burden to their responsibilities.

Due to this, it should be proposed as only new role to include the "Quantitative Management Agent" whose responsibilities are shown in Table 1. This role must comply with the following minimum characteristics: professional with knowledge in improvement models of software processes, basic statistics, SPC techniques, and statistical analysis techniques. Additionally, the "Responsible for Process" must collaborate and provide necessary information for the "Quantitative Management Agent" to generate the products proposed.
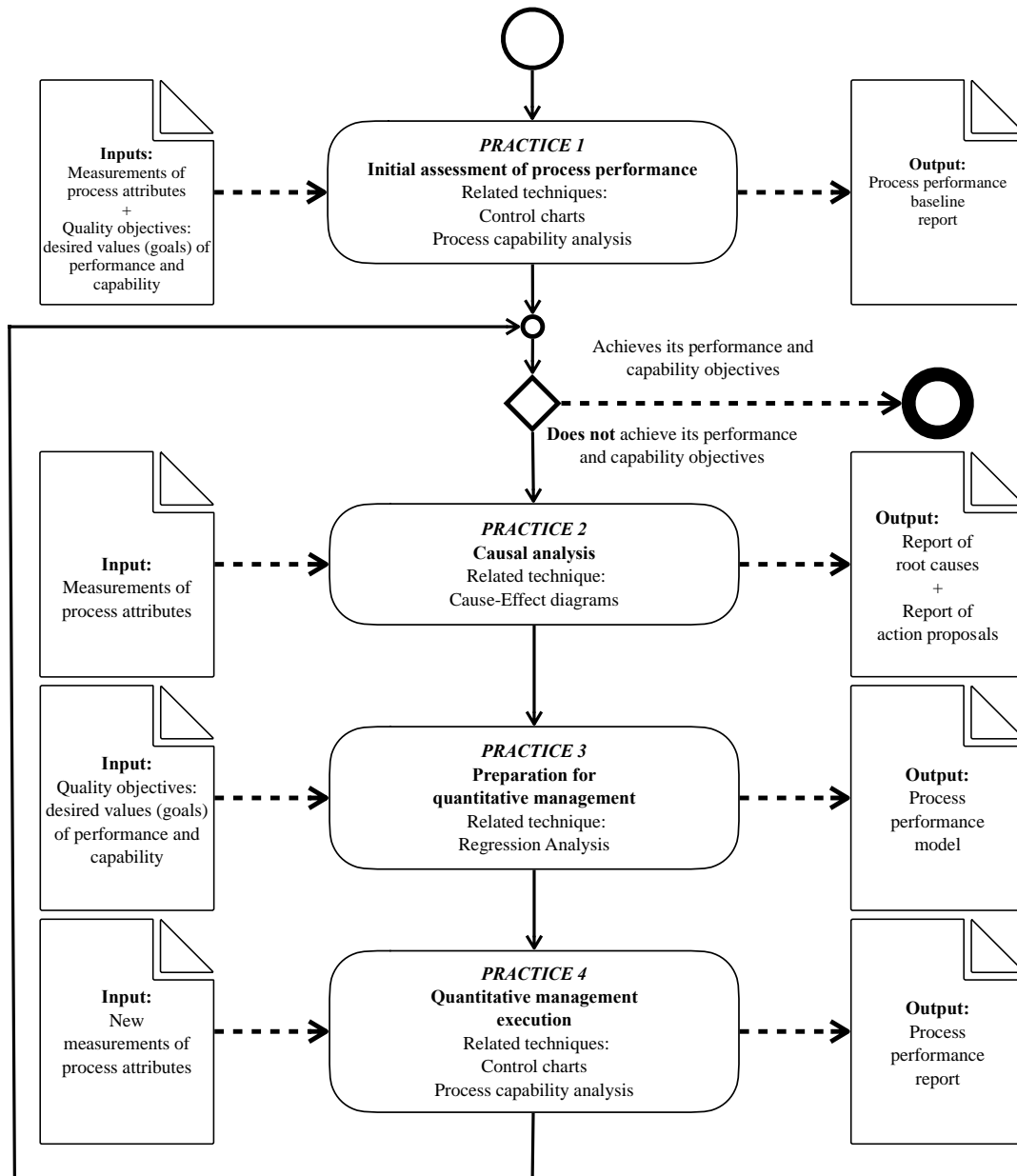

Figure 2. General diagram of FQMaP practices and products

Table 1. Responsibilities of "Quantitative Management Agent"

Practice	Responsibility (Refers to activities associated to practices)
Initial assessment of process performance	(a) Define performance goals of the process justifying its selection including traceability to other processes. (b) Define the process performance baseline. (c) Analyze and report the process performance data.
Causal analysis	(a) Generate the report of results of root-cause analysis. (b) Define action proposals to solve causes.

Preparation for quantitative management	(a) Define quality and performance objectives of the process. (b) Make the report of selected sub processes and attributes. (c) Elaborate the process performance model.
Quantitative management execution	(a) Define performance limits of the process. (b) Elaborate the quality or performance report of the processes supported on statistical control techniques and statistical analysis techniques.

3.1.3.4. Technical specification of practices and relationship with artifacts.

This includes the technical specifications of each practice established in FQMaP, which indicates its purpose and describes the activities, inputs and outputs that comprise it. To elaborate them, some components were used from the Processes Pattern by COMPETISOFT [23]; these are shown in Tables 2 to 5. Additionally, to record the information from each practice corresponding templates have been made to document the work done.

Table 2. Technical specifications of practice 1

Purpose	Characterize quantitatively the initial performance of the selected process
Description	This practice includes the following activities: **P1.A1. Define performance goals of the process** justifying its selection including traceability to other processes. According to the assigned staff, the process attributes of are chosen, as well as the metrics that quantitatively describe such attributes. **P1.A2. Define the process performance baseline.** From the data collected of metrics that describe the specific attribute of the process, a control chart is drawn (type 'p', type 'np', type 'u', or type 'c') that shows the current process performance. **P1.A3. Analyze and report the process performance data.** With the data obtained in the previous activity, it is possible to characterize the initial situation of the process by analyzing the control chart and, simultaneously, it calculates the process capability index. If the analysis indicates that the process is not under statistical control or the performance index is lower than the value defined in P1.A1, it should continue with the other practices indicated by FQMaP.
Responsible	Quantitative Management Agent
Input(s)	Measurements of selected process atribute Quality objectives: desired values (goals) of performance and capability
Output(s)	Process performance baseline report
Related Technique(s)	Control chart Process capability analysis
Technological support	Statistical Package for Social Science (SPSS), Minitab, GenStat, OpenStat.

Table 3. Technical specifications of practice 2

Purpose	Identify variation special causes of the process, and plan and execute the appropriate set of actions and resources to reduce the influence of these special causes and the quality objectives of the process are reached
Description	This practice includes the following activities: **P2.A1. Generate the report of results of root-cause analysis.** With techniques such as Cause-Effect diagrams, the personnel involved in the specific process identifies and prioritizes the causes affecting negatively the process performance. **P2.A2. Define action proposals to solve causes**. The personnel involved in the specific process define and executes the necessary actions to reduce the influence of identified causes. The values obtained from subsequent measurements of the selected attributes of process are compared to expected values; from the new values it is determined whether actions to mitigate the effects of special causes of variation have been successful. In case the outcome is not successful, the activities that make up this practice are repeated. This report should be part of a repository to consolidate records of causal analysis.
Responsible	Responsible of process and Quantitative Management Agent
Input(s)	Measurements of selected attributes of process
Output(s)	Report of root causes and Report of action proposals
Related Technique(s)	Cause-Effect diagrams

Table 4. Technical specifications of practice 3

Purpose	Establish the attributes of the process to monitor and the target value of performance to obtain
Description	This practice includes the following activities: **P3.A1. Define quality and performance objectives of the process**. According to the assigned staff, the values are established to the specification limits of the corresponding attribute to process that requires statistical monitoring. It also indicates the performance index to be achieved. **P3.A2. Make the report of selected sub processes and attributes**. If the complexity of the process requires it, it is recommended to divide it into several sub processes to facilitate monitoring. The staff of the organization indicates what these sub processes are. In any case, it must also indicate the attributes of interest to be monitored. **P3.A3. Elaborate the process performance model.** With the selected attributes, a specific predictive model that will guide the Practice 4 to estimate progress towards achieving objectives is made.
Responsible	Quantitative Management Agent
Input(s)	Quality objectives: desired values (goals) of performance and capability
Output(s)	Process performance model for selected attributes
Related Technique(s)	Regression Analysis
Technological support	Statistical Package for Social Science (SPSS), Minitab, SYSTAT, GenStat, OpenStat, Microsoft Excel

Table 5. Technical specifications of practice 4

Purpose	Establish measurable general objectives and expected results from the effective process implementation.
Description	This practice includes the following activities: **P4.A1. Define the performance limits of the process.** The values obtained from new measurements of the selected process attributes are compared with expected values; from new values it calculates the performance limits and the process capability index. It should be noted that the measurements are collected by staff involved in the specific process being monitored. **P4.A2. Elaborate the report of quality or performance** of the processes supported on statistical control techniques and statistical analysis techniques. With the data obtained in the previous activity, it is possible to characterize the situation of the process by analyzing the control chart and calculating the process capability index. In case of achieving quality objectives, i.e., that the process is under statistical control and the target value of the performance index is achieved, a new value to achieve is defined, or another process is evaluated. In case of failing to obtain all quality objectives, execute again practices 2, 3, and 4.
Responsible	Quantitative Management Agent
Input(s)	New measurements of selected process attributes
Output(s)	Current status report of the process performance, showing if the process is under control and reaches the target value
Related Technique(s)	Control chart Process capability analysis
Technological support	Statistical Package for Social Science (SPSS), Minitab, GenStat, OpenStat.

3.1.3.5. User guide

FQMaP includes a user guide to execute the practices in an individual process. A complete example is presented, showing step-by-step how to carry out the practices defined in the technical guide, applied to the process of "software construction" according to the definition of the ISO12207:2017; the example (originally in Spanish) is fully presented at this URL: https://shorturl.at/hzOZ2. It should be highlighted that a process is evaluated from several attributes; however, to facilitate monitoring the user guide, only the attribute "amount of defects

found" is evaluated. This also indicates how to elaborate the products by using the forms included in the documents and templates component.

Practice 1. Initial performance assessment of a process (P1). The first activity of this practice is to define process performance goals (see P1.A1 from Table 2) and, as indicated at the beginning of this section, the process selected is "software construction". Its first performance goal is being under statistical control, which is determined upon revising the control chart if it passes all the tests indicated in Table 6.

Table 6. Tests definition for a control chart

Test	K	Definition of abnormal situation
a	3	1 Point > K standard deviations from the center line.
b	9	K consecutive points in a row on the same side of the center line.
c	6	K consecutive points in a row, all increasing or all decreasing.
d	14	K consecutive points in a row, alternating up or down.
e	2	K out of K+1 consecutive points >2 standard deviations from the center line on the same side.
f	4	K out of K+1 consecutive points >1 standard deviations from the center line on the same side.
g	15	K consecutive points in a row within 1 standard deviation from the center line (either side).
h	8	K consecutive points in a row > 1 standard deviation of center line (either side).

Source: [53].

The control chart groups the values of the selected process attribute, which in this case is the amount of defects found. That attribute was selected according to suggested by [7], [8] and [69], where it is mentioned the number of defects in a software product is an important measurement because it provides a reference to measure the degree of client satisfaction, efficiency of inspection processes, processes that still require inspection, and the system components prone to presenting errors. This attribute provides evidence of the quality of the product and related processes. As a second goal, it is required for the performance index of the process to have a value of 1.33 or above.

The second activity consists in establishing the baseline of the process' performance (see P1.A2 from Table 2) and, to contextualize the example, it is necessary to have data on the amount of defects found in each software product developed (such as module, class or component), such as those presented in Table 7. Given that software products vary in size, it is required to establish a ratio that permits comparing different products under the same scale, which is why it was necessary to use the metric denominated "defect density" with which we can normalize the amount of defects for a pattern size of 1000 Lines of Code (LOC), expressed as 1000 LOC or 1 KLOC. The expression to calculate the defect density is equal to (amount of defects) / (size in KLOC) and for product 1 from Table 7, we have the following: (21 Defects) / (721/1000) KLOC = 21 Defects / 0.721 KLOC whose result is 29.126214 Defects / KLOC.

Thereafter, a chart should be made where the X values represent each of the products revised (numbered from 1 to 20); the Y values represent each of the values of defect density calculated for each product. The type of most suitable chart is the type U control chart by attributes, also known as "u-chart" because it represents the number of non-conformities found in a unit of product inspected, with variable sample size. The chart corresponding with the data from Table 7 appears in Figure 3.

Table 7. Data for user guide

Product Number	Product Size (LOC)	Defect Quantity	Defect Density (Defect Quantity / KLOC)
1	721	21	29.126214
2	380	11	28.947368
3	235	7	29.787234
4	506	14	27.667984
5	276	8	28.985507
6	598	17	28.428094
7	642	19	29.595016
8	968	28	28.925620
9	412	12	29.126214
10	717	20	27.894003

Product Number	Product Size (LOC)	Defect Quantity	Defect Density (Defect Quantity / KLOC)
11	521	15	28.790787
12	373	11	29.490617
13	811	23	28.360049
14	412	12	29.126214
15	655	19	29.007634
16	520	15	28.846154
17	244	7	28.688525
18	598	17	28.428094
19	848	24	28.301887
20	773	22	28.460543

As third and last activity in practice 1, data of process performance are analyzed and reported (see P1.A3 from Table 2), taking as input the scatter graph, which must be analyzed with respect to the definition of tests to determine if the process assessed is under statistical control, as indicated in Table 6. If at least one of the eight tests is failed, then the process is not under statistical control. The results obtained upon applying the tests mentioned on the scatter plot from Figure 3 appear in Table 8. The results indicate two faults and, hence, the process is not under statistical control.
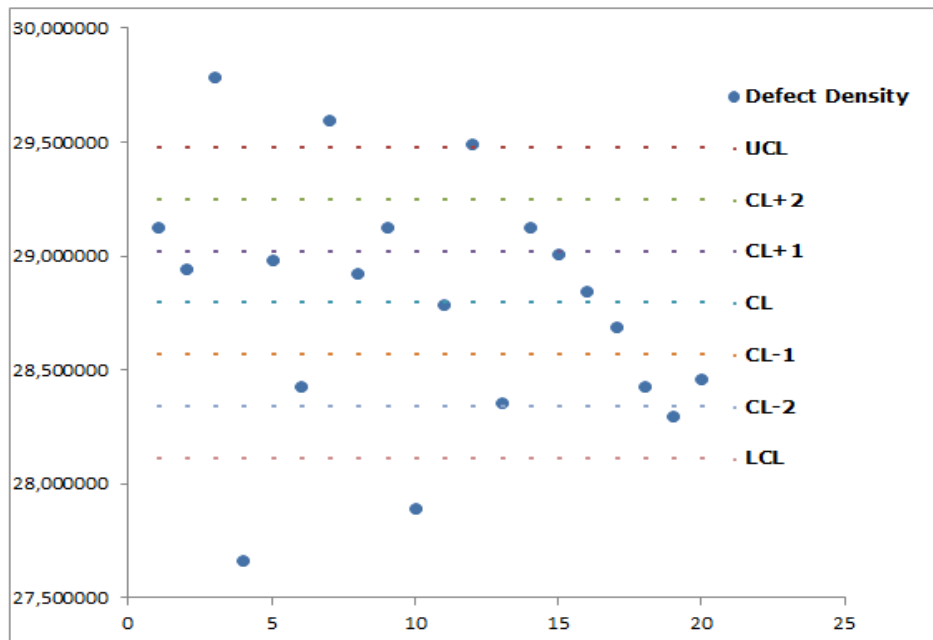

Figure 3. Scatter plot related to data in Table 7

Table 8. Interpretation of test results

Test	Result	Description
a	**Fail**	Higher than 3 standard deviations from center line: Above: Product 3, 7, and 12. Below: products 4 and 10.
b	Pass	Only 4 consecutive points on same side from center line. That series is represented by products 17, 18, 19, and 20
c	**Fail**	There are 6 consecutive decreasing points (products 14, 15, 16, 17, 18, and 19)
d	Pass	The longest series just has 11 consecutive points alternating up or down (products from 1 to 11)
e	Pass	No, there are 2 of 3 consecutive points higher than 2 standard deviations from center line on same side
f	Pass	No, there are 4 of 5 consecutive points higher than 1 standard deviation from center line on same side
g	Pass	There are just 3 consecutive points inside 1 standard deviation from center line (products 15, 16, and 17)
h	Pass	There are just 3 consecutive points higher than 1 standard deviation at both sides of center line (products 12, 13 and 14; products 18, 19, and 20)

Also, a process capability analysis should be carried out and for such, it is necessary to calculate the process capability index (Cpk). It is not acceptable for a process to be under control but its performance index to be lower than the minimum value of 1.33 [66], which means the process is not fulfilling its functional objective. To calculate that index, use the expression that appears in Figure 4.

$$C_{pk} = \min\left[\frac{USL - ubar}{3\sigma}, \frac{ubar - LSL}{3\sigma}\right]$$

Where:
Ubar: average number of incidents per batch (ū = 28.799188)
USL: Upper Specification Limit
LSL: Lower Specification Limit
Min: It chooses the lower value from both quotients

Figure 4. Formula to calculate the process capability index (Cpk)

The USL and LSL values must be established by the organization and indicates the goals to be reached for the process being evaluated. Taking the levels proposed by the Six-Sigma methodology [70], these are expressed in terms of process attribute is being evaluated, to determine the USL and LSL values, as shown in Table 9.

Table 9. Reference values of sigma levels for process

Sigma Level	Defects per million of elements	Percentage of process efficiency	Equivalence in (Defect Quantity/KLOC)
3.3	35 931	96.41	35.93
3.4	28 717	97.13	28.71
3.5	22 705	97.72	22.70
3.6	17 864	98.21	17.86
3.7	13 903	98.61	13.90
3.8	10 724	98.93	10.72
3.9	8 198	99.18	8.19
4.0	6 210	99.38	6.21

From the data in Table 7, the defect density values are between 27.6679 and 29.7872 defects/KLDC; this indicates that sigma level 3.3 is exceeded. Now the organization establishes as a goal to exceed sigma level 3.5. According to that indicated in Table 9, the sigma level of 3.5 is equivalent to a defect density equal to 22.70 defects/ KLOC; thus, if the process yields values above 22.70 defects/ KLOC, it means that it is below the minimum sigma level of 3.5. This means that when the value of the defect density diminishes, the sigma level increases and the process is valued as higher quality.

Upon revising the defect density values presented in Table 7, it may be noted that these are above 27.66 defects/ KLOC, which is above the reference measure of 22.70 defects/ KLOC and, consequently, the sample process does not reach the minimum sigma level. Due to the aforementioned, the value of 22.70 defects/ KLOC would be taken as the first goal to overcome and becomes the USL value. For the LSL value, using the measure of 0.0 defects/ KLOC is recommended, thus, ensuring that the LSL value is always below that obtained as Lower Control Limit (LCL).

This is justified because a process under statistical control and whose products comply with the specifications is characterized because the USL value is higher than Upper Control Limit (UCL) and additionally the LSL value is lower than LCL. Thereinafter, the USL values should start diminishing and reach a measure below 17.86 defects/ KLOC (equivalent to the sigma level of 3.6), which represents a good value for the process, but not world class; a category recognized when there are processes with minimum level 4 in Six Sigma, according to [71]. The example being discussed, if the organization establishes as USL value = 22.70 defects/KLOC and as LSL value = 0.0 defects/KLOC, then we proceed to calculate the necessary values to determine Cpk, as indicated in Figure 5.

$$USL - ubar = (22.70 - 28.799188) = -6.099188$$
$$3\sigma = 0.680023$$
$$(USL - ubar) / 3\sigma = -6.099188 / 0.680023 = \mathbf{-8.969091}$$
$$ubar - LSL = (28.799188 - 0.0) = 28.799188$$
$$3\sigma = 0.680023$$
$$(ubar - LSL) / 3\sigma = 28.799188 / 0.680023 = \mathbf{42.350318}$$
It chooses the lower value from both quotients: Cpk = **-8.969091**

Figure 5. Calculation for the performance index process (Cpk)

Given that the minimum acceptable value for Cpk is 1.33, the value obtained in this example for the magnitude of the index is quite below that minimum value. Thereby, it is concluded that the process is incapable, meaning it does not comply with the functional objective of generating software products with a defect density below 22.70 defects/ KLOC.

The elements obtained upon executing this first practice must be consigned in Form 1 – belonging to the documents and templates component – (Fig. 6). For the example being worked on, it is concluded that it is necessary to execute the other practices defined in FQMaP.

Practice 2. Causal analysis (P2). The first activity belonging to this practice consists in generating the report of results of the analysis of root causes (see P2.A1 from Table 3) in which are consigned the possible causes that keep a process from achieving its performance goals. Those causes are identified through causal analysis techniques such as the cause-effect diagram (also denominated Ishikawa diagram or fishbone diagram), the Pareto diagram, or causal diagrams (that use principles of systems dynamics). The information obtained upon executing this activity must be consigned in Form 2 (Fig. 7). It should be noted that the problems faced by each organization have specific characteristics, so that it is only possible to generically indicate the steps to execute in this practice. However, FQMaP has a quick reference guide on the cause-effect diagram with the basic aspects of this technique.

FQMaP	Process performance baseline report	Form **1**

Version History			
Date	**Author**	**Change description**	

Section A. Identification.

Process name	Software construction	Process ID	
Evaluated attribute	Defect density		

Section B. Include the control chart

Section C. Diagnostics of initial process status

Test	Result	Description
a	**Fail**	Higher than 3 standard deviations from the center line: Above: Product 3, 7, and 12. Below: products 4 and 10.
b	Pass	There are just 4 consecutive points on the same side from the center line. That series is represented by products 17, 18, 19, and 20.
c	**Fail**	There are 6 consecutive decreasing points (products 14, 15, 16, 17, 18, and 19).
d	Pass	The longest series only has 11 consecutive points alternating up or down (products from 1 to 11).
e	Pass	No there are 2 of 3 consecutive points higher than 2 standard deviations from the center line on the same side.
f	Pass	No, there are 4 of 5 consecutive points higher than 1 standard deviation from the center line on the same side.

| g | Pass | There are just 3 consecutive points inside 1 standard deviation from the center line (products 15, 16, and 17). |
| h | Pass | There are just 3 consecutive points higher than 1 standard deviation at both sides of the center line (products 12, 13, and 14; products 18, 19, and 20). |

Diagnostics from the tests evaluation: IS under control ____ IS NOT under control <u>X</u>

Calculation and evaluation of the Process capability index (Cpk):
USL = 22.70 defects/KLOC   LSL = 0.0 defects/KLOC
It calculates the necessary values to determinate Cpk:
USL – ubar = (22.70 - 28.799188) = -6.099188 3σ =   0.680023
(USL – ubar) / 3σ = -6.099188 / 0.680023 = **-8.969091**
ubar - LSL = (28.799188 – 0.0) = 28.799188 3σ =   0.680023
(ubar - LSL) / 3σ = 28.799188 / 0.680023 = **42.350318**
It chooses the lower value from both quotients: Cpk = **-8.969091**.
The process IS NOT capable because it does not comply with the minimum performance index required (1.33)

Elaborated by:_____ Date:_____
Signature:

Approved by:_____ Date:_____
Signature:

Figure 6. Example of Form 1 filled out

FQMaP	Report of root causes (special causes of the process variation)	Form **2**

Version History

Date	Author	Change description

Section A. Identification

Process name		Process ID	
Evaluated attribute			

Section B. Include the cause-effect diagram

Section C. List of prioritized causes (assign an identifier for each cause)

Identifier	Description of cause	Cause type
		Special __ Common __
		Special __ Common __
		Special __ Common __

Elaborated by: _____ Date:_____
Signature:

Approved by: _____ Date: _____
Signature:

Figure 7. Form 2 "Report of root causes"

As a second and last activity associated to Practice 2, the VSE personnel must establish action proposals on the causes identified (see P2.A2 from table 3) and, in the first instance, they must select those which present greater impact upon the onset of the problem, that is, those denominated special causes of variation. The information obtained upon executing this activity must be consigned in Form 3, such as appears in Figure 8.

FQMaP	Report of action proposals to solve identified causes	Form **3**

Version History

Date	Author	Change description

Section A. Identification

Process name		Process ID	
Evaluated attribute			

Section B. List of identified causes and its action proposals

Cause (include the identifier assigned in Form 2)	Action proposal (indicate the criterion that reflects the reduction of the cause's incidence)

Elaborated by: _____ Date: _____
Signature:

Approved by: _____ Date: _____
Signature:

Figure 8. Form 3 "Report of action proposals"

Practice 3. Preparation for quantitative management (P3). The first activity in this practice consists in defining the quality and process performance objectives (see P3.A1 from Table 4), which takes as starting point that obtained in Practice 1. This activity considers that the objectives to pursue are the following:

(a) Make sure the process is under statistical control, whose profile must pass each and every test for a control chart indicated in Table 6.

(b) Obtain a minimum value for the performance index, Cpk = 1.33. This requires the value of defect density to be below the upper limit of specification mentioned in activity P1.A3 (see Table 2) and whose value is USL = 22.70 (defects/ KLOC). The lower limit of specification must be a value below that obtained as LCL.

The information obtained upon executing this activity, along with the description of the specific risks to which the organization is exposed as a consequence of not achieving the objectives mentioned must be consigned in Form 4, such as appears in Figure 9.

FQMaP	Quality objectives of the process	Form **4**
Version History		

Date	Author	Change description

Section A. Identification

Process name	Software construction	Process ID	

Section B. Description of quality objectives of the process
(signals the derivative risks in case of not reaching the objectives)

(1) Accomplish that the process is under statistical control, whose profile must overcome each and every one of the tests for a control chart.
(2) Get a minimum value for the performance index, Cpk = 1.33.
    That requires that the value of defect density be less than the Upper Specification Limit (LSL), mentioned in activity P1.A3 and its value is USL = 22.70 (defects / KLOC). The lower limit of specification must be a value below that obtained as Lower Control Limit (LCL).
Derivative risk: excessive cost overruns and missed deadlines due to the time spent to correct a large amount of defects. It is cheaper to control the process quality instead of inspect the generated products.

Section C. List of selected attributes
For each attribute explain why it has been included

Attribute	Justification
Number of defects per generated product	This attribute is the source for quantitatively determining the efficiency (as a percentage) and the process performance (Cpk index). Is chosen because only counting is required and setting ratios, which can be calculated easily.

Elaborated by: _____ Date: _____ Signature:	Approved by: _____ Date: _____ Signature:

Figure 9. Example of Form 4 filled out

The second activity calls for elaborating the report of sub processes and attributes selected (see P3.A2 from Table 4). It is necessary to specify attributes of the construction process of software products. The example being worked on has as attribute "amount of defects per product generated", which is the source to quantitatively determine the efficiency levels (expressed as percentage) and process capability (Cpk index). The mentioned attribute is selected because it only requires counting and establishes quotients calculated without difficulty. The information obtained upon executing this activity must be included in Form 4.

The third and last activity of Practice 3 is that of elaborating the process performance model (see P3.A3 from Table 4). Upon establishing the parameters in the previous activity, calculate the amount of defects permitted in relation to the size of the software product for the value of defect density to be below the Upper Specification Limit (USL). To obtain those values, an algorithm was used -elaborated by the author – which only needs as inputs the USL and the maximum size of the software product in Lines of Code (LOC). The algorithm generates the amount of defects according to the size of the software product and shows the calculation of defect density below or equal to the USL.

With the LOC values and of defects estimated given by the algorithm a scatter plot is constructed and a regression analysis is applied over this. The equation generated serves to estimate the maximum value of defects for other sizes of software product (in LOC) according to the USL established. The equation generated

represents the performance model of the process with respect to the attribute selected. The information obtained upon executing this activity must be included in Form 5, such as appears in Figure 10.

FQMaP	Process performance model	Form **5**
Version History		

Date	Author	Change description

Section A. Identification			
Process name	Software construction	Process ID	
Evaluated attribute	Defect density		

Section B. Include the diagram related for the model

$y = 0.0225x - 0.4615$
$R^2 = 0.9997$

Estimated Defect Density

Section C. Model description

This model based on linear regression it is considered acceptable for 2 reasons:

(a) The Coefficient of Determination R^2 can take values from 0 to 1; if this value it is close to 1 the model is better, and the reliability of the estimates will be greater. For this model $R^2 = 0.9997$, then the adjustment is very high.

(b) The probability value named "p-value" must be less than 0.05. It means that the X variable is important for predicting the value of the variable Y using linear regression. Generally, if the probability value (p-value) is less than 0.05 then the linear regression model is significative. For this model p-value is $\mathbf{2.603*10^{-86}}$, so that it is significative.

Elaborated by: _____ Date: _____ Signature:	Approved by: _____ Date: _____ Signature:

Figure 10. Example of Form 5 filled out

Practice 4. Execution of quantitative management (P4). The first activity in this practice consists in determining the process performance limits (see P4.A1 from Table 5). From the values obtained through the new measurements made, a new scatter plot should be generated with its corresponding control limits. The second and last activity involves generating a report on quality or process performance backed by statistical control and statistical analysis techniques (see P4.A2 from Table 5). The new scatter plot will be subjected to the tests indicated in Table 6, as well as calculation of the new capability index. The new plot, along with the table of tests that support the process diagnostic and the conclusions must be included in the Form 6, which looks similar as the Form 1.

3.2. Evaluation of FQMaP

This section presents the FQMaP evaluation process, detailing the stages of this process, results obtained, and how these influenced on tuning the proposal.

3.2.1. Execution of the evaluation process

The initial FQMaP version was considered for evaluation by expert judgment using the Focus Group technique according to that proposed by [72], [73], and [74]. According to these authors, activities grouped into four phases are involved:

(a) Planning of the evaluation session
(b) Selection of participants

(c) Conduct session

(d) Analysis of information and report results

This technique was selected because it provides elements to plan, articulate, and execute a set of activities that permit systematically evaluating a proposal such as FQMaP. Additionally, it offers mechanisms to obtain innovative information that enables debugging and tuning the proposal. With the feedback obtained, that initial FQMaP version was refined to, thus, generate the definite version of the Framework; the following presents in detail each of the phases executed.

3.2.1.1. Plannning phase

The activities in this phase were as follows:

Problem definition. Obtain feedback to develop a new concept represented in the FQMaP proposal. The aim upon applying the Focus Group technique was to evaluate, from a conceptual point of view, the initial version of the "FQMaP framework for quantitative management of software development processes in small organizations". As base for planning and preparation, the following were used: (i) a synthesized document of FQMaP, which summarizes in three pages the general structure, along with its components; (ii) the initial version that describes in greater detail the three framework components.

Preparation of materials. The materials filled out by the participants during the debate session were:

(a) Participant file. This form collects data from each participant during the evaluation session; among others, their academic formation and experience in improving software development processes.

(b) Component evaluation form. In this document, each participant consigns the positive aspects, aspects to improve, or observations they believe convenient to include regarding the FQMaP proposal. This form provides writing spaces to express the assessment of each framework element.

(c) General aspects of the evaluation survey. It is a questionnaire with 15 questions that seeks to provide an opportunity for participants to assess aspects of pertinence, validity, and utility of the framework. The questions inquire if the FQMaP components, practices, activities, roles, and products are adequate; they also permit evaluating the clarity and conciseness of the guides that make up the Framework and, finally, offer a space to evaluate possible missing elements, weaknesses or evaluate the ease of application of FQMaP.

The procedures to carry out the focus group session were defined, as well as the means to obtain the information required. In the first place, the session protocol was defined as shown in Table 10, which allows defining the agenda for the debate session.

Definition of information capture and registry. The models selected were: (i) audio files of the session, (ii) participant file, (iii) components evaluation form, and (iv) the general aspects evaluation survey.

Table 10. Focus Group session protocol

Subject	Evaluation of "FQMaP framework for quantitative management of processes in small software development organizations".
General Objective	Evaluate the FQMaP framework to measure the perception of acceptance or rejection by the participants, who are experts in Software Process Improvement and Quantitative Process Management.
Specific Objectives	(a) Show the Framework components. (b) Collect the observations on each FQMaP component. (c) From the information obtained refine the components.

Definition of information analysis methods to generate processing of that generated during the session. The method selected was that of frequency distribution, which is used to describe the values obtained in each item subjected to evaluation. This was accomplished from the tabulation of results and from synthesizing the participant observations during the session. After the session, the information was revised by the moderator and the supervisor to identify the most adequate aspects to obtain an improved version of FQMaP, according to the scope and objectives established for this work.

3.2.1.2. Participants selection phase

These activities were executed:

Definition of participant profile. Two categories were established for participant selection: (i) professionals assigned to academia and with knowledge on improving software development processes and quantitative management of processes; (ii) professionals assigned to software development organizations, familiarized with process improvement and quantitative management of processes.

Identification of probable participants. The most important aspect was for participants to show knowledge and/or experience in improving software development processes and, finally, six professionals participated. Four of them are assigned to academia; two have Ph.D. and two have Master's degrees. The two remaining professionals worked in software development and have studies at the Masters level.

3.2.1.3. Conduction phase

The activities were the following:

Basic sequence. The session combined face-to-face and virtual modalities, coordinated by the moderator and the supervisor, and integrated by the participants. The defined session protocol was followed and documents prepared for said session were used; these are described in section 4.1.1. The information generated during the debate session was captured through audio recording along with forms filled out by each participant.

Definition of the role of moderator. This role was fulfilled by the first author of this paper, who was in charge of introducing FQMaP and moderating participant speaking times during the debate, as well as other activities associated to the documents to be filled out, so that the agenda was executed by following the established plan:

(a) Presentation of FQMaP, which through an executive exposition described each Framework components.

(b) The second and longest point on the agenda is the debate session, where each of the participants presented their contributions and observations for each of the FQMaP components, with critical constructive approach. With respect to concerns formulated by each participant (which could be made at any moment of the session), these were answered by the debate moderator.

(c) Lastly, each participant filled out the components evaluation form and the survey on general aspects.

3.2.1.4. Data analysis and results reporting phase

From the revision of the "evaluation form", the "general aspects evaluation survey", and the audio files, the information collected was analyzed during the session to identify and synthesize participant observations. Table 11 gathers the positive aspects identified by participants, Table 12 gathers the aspects to be improved, and Table 13 shows the remaining contributions and observations.

Table 11. Positive aspects about FQMaP identified during the Focus Group session

Positive aspects	Indicated by participant					
	P1	P2	P3	P4	P5	P6
It is a simple proposal, easy to understand and useful for small software development organizations	✔	✔	✔	✔	✔	✔
Components are clearly described	✔	✔		✔	✔	✔
Practices and activities are appropriate and easy to understand	✔	✔		✔	✔	✔
Products generated are few and are easily understood		✔	✔	✔	✔	✔
The user guide presents a clear relationship between techniques and activities	✔	✔		✔		✔
Reference guides are an excellent reference tool; they are simple and clear	✔		✔	✔		✔
Forms are simple and easy to fill out. They are suitable in terms of form and number and support the use of both practices and techniques. They facilitate traceability and support the improvement activities.	✔	✔	✔	✔		✔

Table 12. Aspects to improve about FQMaP identified during the Focus Group session

Aspects to improve	Indicated by participant					
	P1	P2	P3	P4	P5	P6
Specify the minimum maturity aspects of the organization.	✔	✔	✔	✔	✔	
Define the required profile for the "Quantitative Management Agent" role.		✔	✔	✔	✔	✔
Specify better the relationship between inputs and outputs of each FQMaP practice.		✔		✔	✔	
Determine attributes of various processes that can be evaluated with FQMaP and the related set of metrics required by those attributes.	✔					✔
Show control of documents; the forms presented should consider management attributes of the work products.	✔	✔				

Table 13. General observations about FQMaP identified during the Focus Group session

General observations	Indicated by participant					
	P1	P2	P3	P4	P5	P6
It is suggested to make a model described in levels allowing the staged implementation of the metrics and measures defined.					✔	✔
Develop management software to support FQMaP practices.			✔		✔	
Consider basic training in the use of statistical tools for those executing the "Quantitative Management Agent" role.	✔			✔		✔

The result of the qualitative-nature evaluation, conducted through the Focus Group, is the identification of the most relevant aspects of FQMaP, which are shown by the following, which identified the positive aspects:

(a) It is a simple proposal with useful elements for small software development organizations, besides, it is considered that the activities are few and specific;

(b) The FQMaP components are clearly specified and their structure is familiar with other process patterns, which would facilitate their application;

(c) The practices and activities are considered adequate to support quantitative management in improvement projects;

(d) The products required are suitable for small organizations because, given that they are few without much complexity, it is estimated that the effort required to generate them does not exceed the capability of these types of organizations;

(e) The user guide offers a good relationship between techniques and activities;

(f) The quick reference guides contain clear and precise information;

(g) The forms are considered simple and easy to fill out.

In second place, the following aspects to be improved were identified:

(a) Need to define the minimum maturity conditions of the organization to apply the FQMaP practices;

(b) Clearly define the characteristics required to perform the role of "Quantitative Management Agent"; this aspect was solved and consigned in section 3.3.3 of this paper;

(c) It is not noted that the product of a practice serves as input for the following; it is necessary to indicate the input and output relationships of the products generated during each activity to avoid confusion upon implementing the practices and activities;

(d) It is recommended to include an artifact that permits organizations to identify the most suitable statistical techniques in some general cases, thus, identifying more easily the application case;

(e) It is suggested to improve control and follow up of the forms of the documents and templates component, considering work product management attributes, such as definition of requirements, identification, and

control of versions.

All the aspects previously mentioned were addressed and the corresponding modifications were made to FQMaP, which are described in section 4.2 of this paper. Finally, a set of additional observations was gathered and considered elements for future work; these are included in section 5 of this paper.

3.2.2. Modifications made to FQMaP from the evaluation

This section shows the FQMaP elements modified as a result of the evaluation process to improve the framework proposed. Regarding the component of the technical guide, modifications were made and are shown by the following:

(a) information was included on the minimum maturity conditions of the organization seeking to implement FQMaP practices;

(b) specification of the characteristics required to perform the role of "Quantitative Management Agent" was added;

(c) a section was added on the attributes associated to diverse processes that can be evaluated with FQMaP and the metrics corresponding to those attributes;

(d) Information was included on the nature of the relationships between the input elements and the products generated during each practice.

With respect to the documents and templates component, the forms were refined including control and follow up elements, considering work product management attributes, such as definition of requirements, identification, and control of versions.

3.2.3. Limitations of evaluation

In first place, the risk exists that the participants did not contribute complete information or that it is biased due to the following:

(a) Insufficient preparation. It is possible that some participants might attend the session without the proper preparation, which would be reflected in poor contributions. To mitigate this factor, each participant was sent, one week in advance, the three-page synthesized document and a detailed 25-page document on FQMaP; the 15-minute executive presentation was also included as the first point of the evaluation session.

(b) Participant inhibition, given that they are required to publicly express their concepts and appreciations. This would keep them from fully contributing on the aspect sought to address. To reduce the impact of this factor, turns were assigned for each participant to speak.

Secondly, logistics risks exist that affect negatively the Focus Group session, such as the following:

(a) Difficulty to synchronize the agendas of those wishing to participate in the Focus Group session, including the case of confirmed participants who decline at the last minute when it is impossible to reschedule the session.

(b) Reduction or loss of control by the moderator during the session. Characteristically, a Focus Group session is more difficult to control than the individual interviews, hence, the moderator must maintain control of the session to avoid wasting time or to keep the participants from arguing over aspects barely related to the session topic.

(c) Greater difficulty in analyzing the information gathered. Synthesis of qualitative information represented in comments and observations expressed in oral and written manner is difficult given that the same idea may be expressed in diverse ways.

The evaluation process supported on the Focus Group technique is a pertinent means to assess proposals such as FQMaP because it offers flexibility to explore aspects not proposed previously, unlike other techniques such as interviews and surveys; additionally, it permits gathering contributions on diverse themes presented by each of the participants, using information capture media such as the "evaluation form", the "general aspects evaluation survey", and the audio files, making them the fundamental input to recognize positive aspects and aspects to be improved within the proposal of the framework.

4. Conclusions and future work

The principal product presented in this paper is the proposal denominated FQMaP, which is aimed at VSEs and seeks to incorporate quantitative management techniques to their software development processes. This proposal was defined with the following characteristics: few roles involved; few activities and products; definition of specific guidelines to appropriate quantitative management practices; and reference guides integrated with a user guide, hoping they suit the characteristics of VSEs and of their software development projects.

The main characteristics that describe FQMaP as a proposal aimed at VSEs, which permits incorporating practices and techniques that support quantitative management are:

(a) Technical guidelines to obtain a quantitatively managed process. This characteristic would allow FQMaP users to follow it correctly to carry out the selected process to the desired status. This is accomplished from the information the framework includes on how to use SPC tools, statistical analysis techniques, and the documents to determine, with reasonable effort, the baseline of the process performance, as well as the quality and performance objectives of processes selected by the organization.

(b) Examples of using SPC tools and statistical analysis techniques. To help those using FQMaP to understand how these are used and the application of those tools and techniques and, thus, articulate them with the organization's tasks.

The practices indicated in FQMaP are considered the same ones to execute and have been included bearing in mind the profile of the VSEs and the types of projects they manage. These were defined so that they imply quality and efficiency when required to quantitatively manage processes a VSE considers most important without incurring in high costs of time and resources, and to achieve the goals established for those processes in the short term.

Regarding SPC tools, it is essential to use control charts as base tool; but it should not be the only one, which is why the cause-effect diagram was included as key tool to perform causal analysis when, from the information given by the control charts, evidence shows the process it is not under statistical control. With respect to statistical analysis techniques, the process capability analysis was included, which determines if a process fulfills its functional objective. Regression analysis was selected too, serving to elaborate the performance model of a process.

As future work, FQMaP would include the following elements: broadening of the user guide with examples on other attributes of the process initially proposed or examples on other processes, establishing a training mechanism to permit assuming the role of "quantitative management agent" by a member of a VSE, designing basic training processes on statistical techniques and management of software tools that support said techniques, and including information on how an organization establishes the values of specification limits for the attributes of its processes.

Additionally, creating a FQMaP version that describes capability or maturity levels that permit gradual implementation of practices; this would bring benefits for the software industry, given that it would establish an order to follow based on the current status of the organization seeking to apply the framework. FQMaP could rely on AI tools to support the required data volumes, and thus drive research related to Quantitative Management of software development processes.

Finally, exploring the development of a software management tool that supports the FQMaP practices. Automation is an important element to increase effectiveness in obtaining and analyzing information, in addition to facilitating the execution of the practices.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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