Integración de la teoría de la ingeniería de software y la metodología de despliegue de función de calidad para apoyar la medición del estado de progreso en proyectos software

Integration of the Software Engineering Theory and the Quality Function Deployment Methodology for Supporting the Measurement of the State of Progress in Software Projects

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Resumen. Una práctica fundamental para cumplir los objetivos en un proyecto software es medir su estado de progreso de tal forma que se puedan tomar acciones correctivas a tiempo. La mayoría de los enfoques que apoyan los procesos de medición se enfocan en describir técnicas para tratar dichas mediciones desde la perspectiva de gestión de proyectos. Sin embargo, dichos enfoques carecen de estrategias que faciliten una adecuada integración, entendimiento y aplicación por parte de los profesionales en el área de desarrollo de software. Además, la falta de rigor de dichas propuestas dificulta el establecimiento de prácticas comunes y genera resultados poco confiables. Este artículo proporciona un enfoque que satisface la necesidad de usar marcos estandarizados y fácilmente adoptados con el propósito de apoyar la medición en el desarrollo de software. Para logar esto se hace uso de elementos provistos por SEMAT y QFD, generando una propuesta que incluye una representación estandarizada y un método para analizar las necesidades de medición desde la perspectiva del cliente. Para validar la confiabilidad de los hallazgos presentados en este artículo, se realizó un mapeo de literatura y un estudio basado en entrevistas. Como resultado, este artículo expone un marco para apoyar la medición del estado de progreso de proyectos software y su importancia radica en la capacidad de superar las debilidades, previamente mencionadas, integrando el punto de vista de la gestión de proyectos y la fundamentación de la ingeniería de software.

Palabras Clave. Proyectos software, estado de progreso, calidad, SEMAT, QFD.

Abstract. A fundamental practice to fulfill the objectives in a software project, is to measure its state of progress so that corrective actions can be taken timely. Most of approaches supporting measurement processes are focused on describing techniques to deal with these measurements from a project management perspective. However, these approaches lack of strategies that facilitate an adequate integration, understanding and application by professionals in software development area. In addition, the lack of rigor of such proposals hinders the establishment of common practices and give rise to unreliable results. This paper is aimed at providing an approach that satisfy the need of using frameworks standardized and easily adopted in order to support the measurement in the software development. To do this, we use the elements provided by SEMAT (Software Engineering Method and Theory) and the procedures established by QFD (Quality Function Deployment) by generating a proposal which includes a representation standardized and a method to analyze the needs of measurement from customer perspective. Also, a mapping review and a study based on interviews intended to assure the reliability of the findings exhibited in this paper were done. As a result, this paper exposes a frame to support the measurement of the status of progress in the development of software projects and its importance lies in the capability to overcome the previously mentioned weaknesses by integrating the project management point of view with the foundation of the software engineering.

Keywords. Software Projects, Progress Status, Quality, SEMAT, QFD.

I. Introducción

Studies exhibit that the works focused on software engineering measurement are oriented mainly towards product measurements and in a lower proportion towards the process executed to obtain said product. Measurement of the product is much easier than the measurement of the process and the latter serves to better decision-making about possible changes in business and operating model [1]. According to [2], the monitoring and measurement of the processes are necessary to know if the results are compliance with was planned, including corrective measures. In this sense, the improvement actions require documentation and knowledge of the performance of the processes by defining a set of indicators that supply relevant information, regarding the execution and results of one or several processes in an adequate and representative manner.

Various practices that support the measurement of different entities related to the area of software engineering, have been proposed [3]. Both academics and industry use these practices and empirical studies to generate a variety of proposals aimed at supporting the control of progress in the development of software projects. However, most of these approaches lack theoretical foundations and a common ground that facilitates their implementation, integration, and understanding. Thus, the lack of rigor in most of these approaches encourages the need to introduce languages that assist the stakeholders to compare, evaluate, analyze, simulate, adapt, and compose methods [4].

SEMAT (Software Engineering Method and Theory) supports the representation of modern practices by providing a set of elements to systematically obtain information from the engineering processes and control the activities developed during the software engineering process [5]–[7]. For example, stakeholder management, requirements elicitation, and development of software systems, among others. Such proposal, adopted by the OMG (Object Management Group), was conceived with the purpose of facing a wide variety of problems, including the lack of theoretical bases, lack of consensus, and fashion prevalence the field of software engineering [4]. On the other hand, QFD (Quality Function Deployment) is a method that allows customers to transform qualitative needs into quantitative characteristics, facilitating the deployment of quality functions in subsystems and component parts. Besides, provides a quality framework which considers the assessment and concepts that the client deems appropriate to achieve the satisfaction of their needs, including a sequence of steps and processes for this purpose [8]. QFD is focused on the integration of each of the management processes and the responsibility of each of the stakeholders, obtaining a quality management in all the phases and processes that are involved in the development of a product, including software development [9].

This paper is aimed at providing an approach that satisfy the need of using frameworks standardized and easily adopted to support the measurement in the software development. Particularly, this work is targeted to take advantage of the benefits of QFD to structure a set of indicators for supporting the control of progress in the development of software projects and mainly. These indicators were selected from a literature review and a survey applied to several representative companies related to software development. Then, these indicators are used as input to populate the matrices that make up the QFD quality house. In the same way, we intended to use the capacity provided by the kernel of the essence of SEMAT to supports the representation and theoretical foundation of the developing of software projects. In this sense, an extension to such kernel, related to the measurement of progress, is proposed, and described. This extension is based on the specification provided by QFD, which will be integrated into the framework described by SEMAT.

II. Materials and methods

According to [10], a methodological framework refers to the set of methodological elements, which are required to plan the way in which the development of the research will proceed. Based on the methodological aspects described by [11], a methodological approach for the development of this work is established by following the steps illustrated in Figure 1.

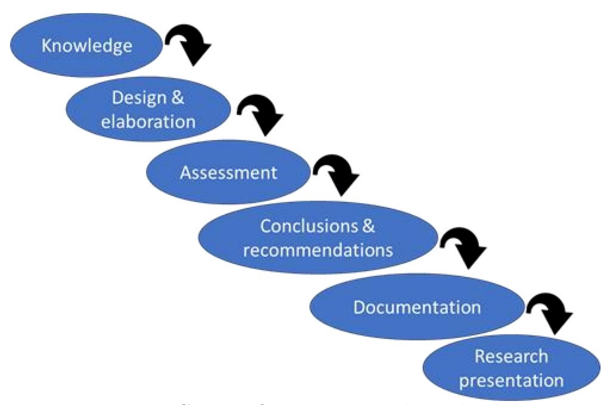


Figure 1. Steps of the proposed methodology.
Source: the authors based on [11]

Knowledge. In this step, a rigorous search, collection and synthesis of information about SEMAT and QFD was carried out in order to characterize such frameworks and to demonstrate their application in both the academic and business field aimed at supporting the progress measurement in the development of software projects.

Design & elaboration. According to [12], the research design is defined as a general strategy assumed by the researcher to respond to the problem posed. Besides, the design also involves the decisions that are made regarding data collection [13]. In this way, it is necessary to indicate the methodological aspects related to the population and sample that will serve as base in the collection of information.

According to [13], the population and sample establishes the study units as the set of beings that have the characteristic or event to be studied and that are framed in the inclusion criteria that make up the population. In this case, the population refers to those actors who play professional roles in software development, which are related to processes of measuring the state of progress in the development of their software projects and who work in companies dedicated to develop software with national coverage.

Once the population is identified, a representative sample is taken to carry out a survey where the respondents were selected based on their willingness to collaborate, the type of experience, attitude, and necessary knowledge, which resulted in obtaining the maximum benefit from the information collected. A set composed by 11 companies in the software sector was selected. Thus, a technique known as convenience sampling was carried out, which consists of selecting the available cases to which there is access [14]. The selection of the sample was made considering the national and even international coverage of the software projects that are developed by said companies [15]. Data collection techniques were based on direct observation and documentary review supported by instruments such as files, bibliographic reviews, and surveys. The operationalization of the objectives included the establishment of relations between specific objectives and research variables. According to [13], this operationalization process allows the researcher to identify those perceptible aspects of an event that make it possible the recognition of its presence or intensity. For this purpose, tools and resources provided by SEMAT and QFD facilitate the aforementioned operationalization in a clear and precise manner.

Assessment. The assessment of the results of the project was made through a laboratory study intended to validate the answers given by the respondents. This validation was based on the integration of the elements of SEMAT kernel to represent the practice used in the process of measuring the progress status of software projects and the application of the QFD methodology to configure the quality house matrix whose purpose is addressed to identify and analyze the answers given in the survey.

Conclusions & recommendations. In this step, the results obtained and the findings related to measure the state of progress in the development of software projects are presented. In this case, these conclusions and recommendations were based on the characterization of the elements provided by SEMAT kernel and integration of QFD to ensure quality in the processes related to the measurement of the state of progress in the development of projects. Thus, some recommendations are made by providing a diagnosis of the impact of this proposal in relation to the measurement of the state of progress in the development of software projects.

Documentation. The documentation of a research allows the researches to maintain evidence of the activities carried out and achieve their reproducibility, as well as to support the results obtained.

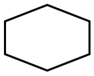
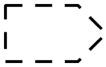
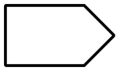
Research presentation. The results in concordance with the objectives of the research are presented. This presentation is intended to demonstrate the degree of impact and importance that this proposal provides regarding to measure the progress status in software projects.

Essence kernel promoted by SEMAT includes a set of elements that are universal to all software engineering efforts. Through the states defined by its elements, Essence kernel [7] provides a novel and effective instrument for reasoning about the progress and health of software development efforts in a method independent manner [5], [6]. The growing number of software projects requires the development of methods that guarantee quality assurance and effective management. Traditionally, proposals to guide changes in project management are based on approaches such as: waterfall model, incremental spiral model, prototype, and rapid application development, among others. In addition, it can be used to increase customer satisfaction by incorporating the voice of the stakeholder in the software development process. Potential defects correspond to the sum of errors found in requirements, design, coding, user documents, and bad corrections. So, the use of QFD to support defect prevention is recommended [16].

In this case we propose a setting of SEMAT according to the specifications required in this study. The elements of SEMAT included in this study are shown in Table 1.

Additionally, QFD is used as a method for developing quality designs to satisfy customer needs by translating consumer desires into key design and quality assurance targets [17]. Voice of Customer (Customer Needs) as input data and information can be obtained from the results of a customer survey conducted. In this case, we use QFD in order to support the identification and analysis of the measures and measure units that were identified by using the mapping review and the surveys practiced to the respondents. The basic steps included by QFD are related to the determination of stakeholder requirements, engineering characteristics, matrix of relationships, roof of the quality house, and target values. However, considering the scope of our research project, we selected the following steps of QFD:

Table 1. SEMAT elements

Notation	Name
	Practice
	Alpha
	Activity space
	Activity
	Work product
	Competency

Source: [7]

A. Determine stakeholder requirements

Different leaders of companies dedicated to develop software projects were selected as stakeholders who represented the voice of the stakeholder.

B. Determine engineering characteristics

These characteristics correspond to the technical specifications that form the section called "HOW" of the House of Quality described by QFD.

C. Determine matrix of relationships

Based on the information that was registered in the "WHAT" and the "HOW" sections of the House of Quality, the relationships between them are established.

III. Results

SEMAT was used to represent the practice associated with the measurement process of the progress status in software projects. To do this, SEMAT defines three areas of interest involved in the development of a software project: Stakeholder, Solution, and Effort. Once these areas were analyzed, it was established that this research work is based on the area of interest known as Effort. According to [7], this area of interest contains everything that has relation with the team and the way they approach their work. In addition, such area considers those practices aimed at planning, guiding, and monitoring team efforts. In this way, we propose a new practice called "Measure progress status" for supporting the characterization of a specific set of activities and its respective work products. Figure 2 illustrates the representation of this practice with its respective work products. By the other hand, the description of the method to apply QFD in the context of the measurement of the state of progress in the development of software projects is presented. It is important to clarify that the definition of the concepts of measure and measurement are conform to the ISO/IEC/IEEE 15939:2017 standard.

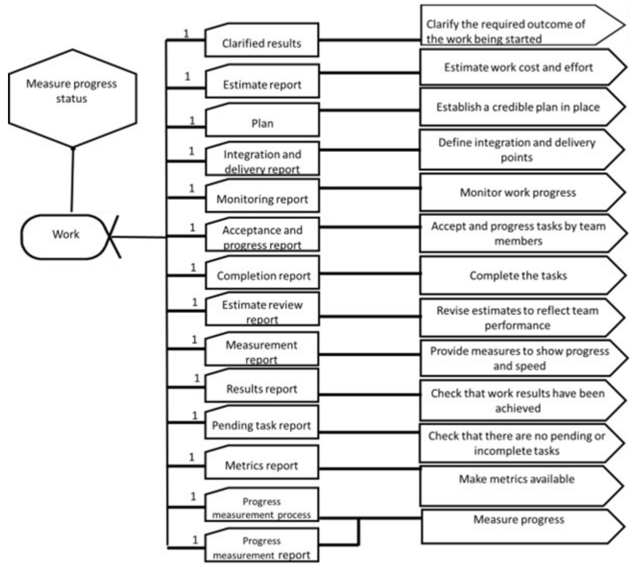


Figure 2. Practice "Measure progress status"
Source: The authors

In Figure 2, an activity called "Provide measures to show progress and speed" is proposed. This activity is crucial since it involves the essential measures to measure the state of progress in the development of software projects. Therefore, an association with a space activity "Integrate QFD into the measurement process" is established. Thus, QFD is used to support the process by grouping a set of key activities. Such activity space is connected to a set of activities, and these activities are linked to their corresponding competencies. Then, such activities are linked to work products, as illustrated in Figure 3 and Figure 4.

In order to demonstrate the applicability of our proposal, in this section the first three activities related to "Integrate QFD into the measurement process" are executed:

A. Determine stakeholder requirements

Such activity consists of selecting the necessary measures to satisfy the measurement process of the state of progress. Consequently, these measures correspond to the requirements or needs of the stakeholder. These needs arise in a first phase, from a literature review that allowed identifying some common characteristics considered essential to measure the progress of a software project. Based on this information a survey was designed which was applied to the stakeholders selected. In such survey, we asking to stakeholders for their opinion on the measures that they consider relevant to measure the state of progress of software projects. The response options for the respondents corresponded to the various alternatives found during the literature review, and they also had the possibility of adding other alternatives from the point of view of their professional experience. This was done with the purpose of complet-

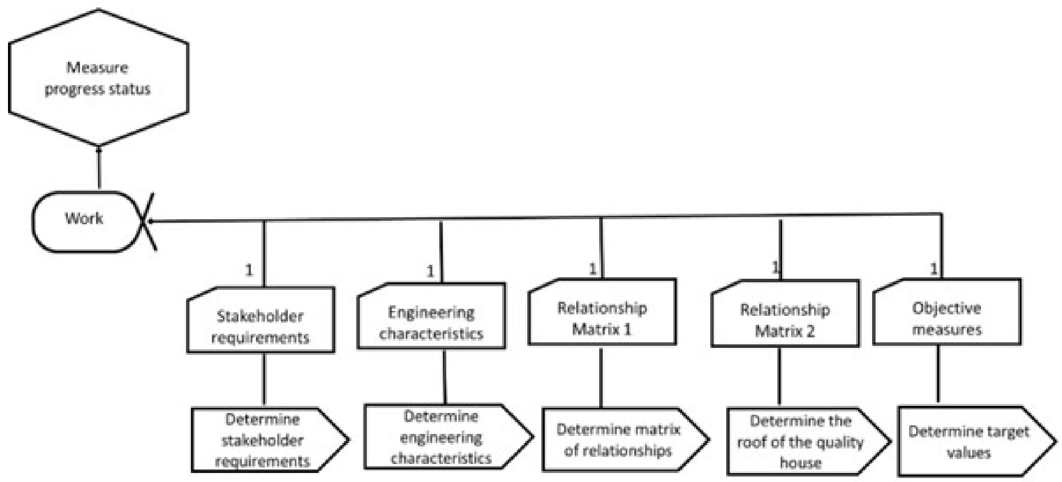


Figure 3. Activity space "Integrate QFD into the measurement process"
Source: the authors

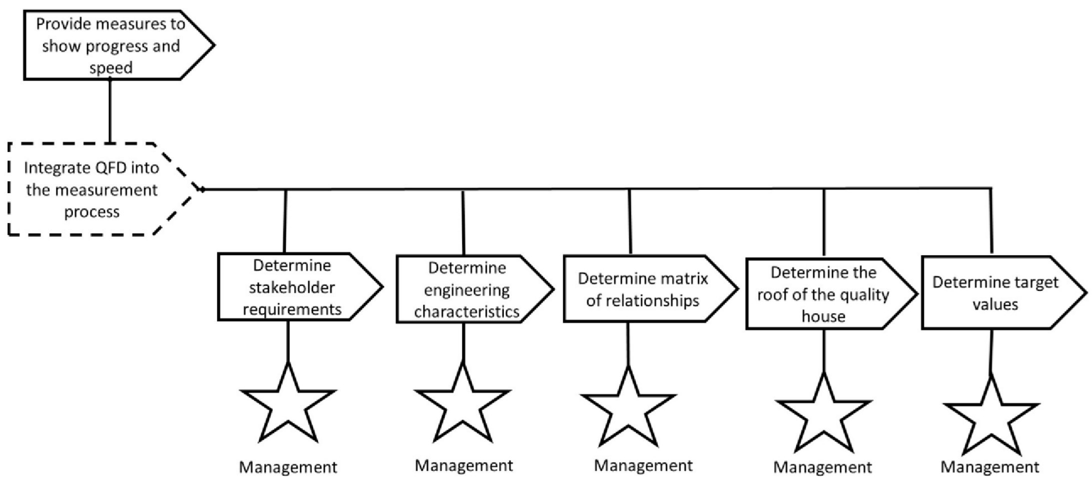


Figure 4. Work products related to activities.
Source: the authors

ing the first qualitative phase based on the analysis of the information and data obtained through the data collection instrument. This information represents the needs from a viewpoint of the clients and is used to create the section called "WHAT" of the House of Quality described by QFD, as illustrated in Table 2.

Table 2. Characteristics contained by the section "WHAT" within de House of Quality

Stakeholder requirements – "WHAT"
Software defects
Project size
Effort
Project duration
Developer performance
Development team performance
Productivity
Project planning
Internal customer satisfaction Errors in production

Source: the authors

B. Determine engineering characteristics

This section refers to identify how the needs of the stakeholder can be faced from the view point of the technical experts. In this case, the activity refers to specify the units of measures or technical specifications necessary to satisfy the measurement of the state of progress. So, these units of measurement correspond to the engineering characteristics. Such characteristics, as well as the needs selected in the previous stage, were identified based on review of the literature and later to the elaboration of the survey that was applied to the stakeholders in terms of their opinion about the relevant units of measures to measure the progress status of software projects. These resulting characteristics are illustrated in Table 3.

C. Determine matrix of relationships

It is possible to illustrate a characterization to measure the progress status of software projects. In this case, the needs of the stakeholders and the technical spec-

Table 3. Characteristics contained by the section HOW within de House of Quality

Engineering characteristics – "WHAT"		
Group of units	**Units**	**Abreviation**
Software defects	Number of defects per phase	Ndf
	Number of defects in pre-launch	Ndp
	Number of components with errors	Nce
Frequency of measure use	Number of people year of effort	Npe
	Commited tasks	Tco
	Lines of code / development effort	Lc/Ed
	Amount of errors reported	Cer
	Number of customer complaints	Nqc
Project size	Amount of lines of code	Clc
	Amount of people - year	Cpa
	Amount of people - month	Cpm
Effort	Amount of estimated hours	Che
	Amount of real hours	Chr
	Amount of people - year	Cpa
	Amount of people - month	Cpm
	Months per development phase	Mf
Project duration	Number of iterations (Time in weeks)	Ni
	Months per development phase	Mf
Engineering characteristics – "HOW"		
Group of units	**Units**	**Abreviation**
Developer performance	Number of lines of code	Nlc
	Number of defects / LOC (lines of code)	Nd/Lc
	Average of hours of weekly tasks	Phts
Development team performance	Hours of project to date Hpf	
	Tasks developed to date	Trf
	Earn value to date	Vg
	Total of lines of code	Tlc
Productivity	Lines of code / Hour	Lc/H
	Number of requirements / man month	Nr/Hm
	Number of designs / man month	Nd/Hm
	Size of output (lines of code) / man month	Ts/Hm
	Number of test suit / man month	Np/Hm
Project planning	Current duration / estimated duration	Da/De
	Current effort / estimated effort	Ea/Ee
	Total time of development (people month)	Ttd

Source: the authors

ifications are considered from two key points of view. The first point corresponds to the measures that are considered relevant for the stakeholders and the second point corresponds to the units of measures to satisfy the needs identified. Figure 5 shows the relationships between the WHAT and the HOW.

After the stakeholder requirements and the engineering characteristics are selected and assigned to the quality house, the next step is to qualify the relationships between them [18]. To do this, it should be noted that the characteristics can affect the requirements in a positive or negative way. Then, a weighting process must be carried out in a joint effort by the roles corresponding to the stakeholders and the technical staff. In this work, the two roles can be performed by the same staff or by different staff, this decision depends on the conditions and characteristics of the development of the software project. This step facilitates the common understanding about the effect of the engineering characteristics on the stakeholder requirements. It is important to mention that the scale to evaluate the answers given according to the level of importance is included in the range from 1 to 5, where each value represents the level of importance to the stakeholders. Such values are: 1 (Not important), 2 (Little important), 3 (Neutral), 4 (Important), and 5 (Very important).

Once the degree of importance of the WHAT's has been identified, the relationship matrix of the "WHAT" vs "HOW" is calculated. This matrix indicates how much impact the engineering characteristics can have on the stakeholder requirements. Each grid is filled with a score $C_{ij} = \{0, 1, 3 \text{ or } 9\}$ to estimate the impact.

The relationships between these dimensions are not always 1:1, there may be complex relationships, as well as different levels of relationship. A single "engineering characteristic" can influence several "stakeholder

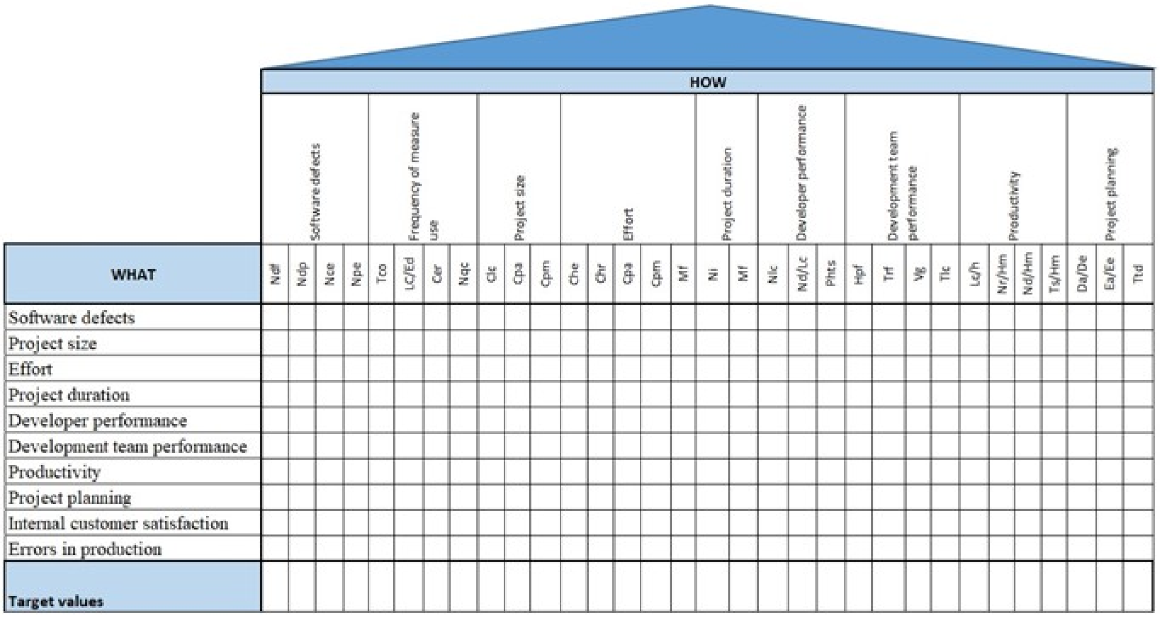


Figure 5. Relationships matrix.
Source: the authors

Table 4. Weighting process

WHAT'S	Importance degree	Raised quality	Improvement rate	Abuse weight	Relative weight
Software defects	4.45	5.0	0.89	22.25	1.09
Project size	4.09	4.5	0.91	18.405	0.90
Effort	4.45	5.0	0.89	22.25	1.09
Project duration	4.09	4.5	0.91	18.405	0.90
Developer performance	4.33	4.5	0.96	19.485	0.95
Development team performance	4.58	4.5	1.02	20.61	1.01
Productivity	4.36	4.5	0.97	19.62	0.96
Project planning	4.52	5.0	0.90	22.60	1.11
Internal customer satisfaction	4.12	4.5	0.92	18.54	0.91
Errors in production	4.39	5.0	0.88	21.95	1.08

Source: the authors

requirements". This matrix shows the relationships between the "WHAT" and the "HOW", which are defined considering three levels of relationship: weak relationship, medium relationship, and strong relationship. Based on [19], the values suggested in this process are: 0 (No relationship), 1 (Weak), 3 (Medium), and 9 (Strong). A blank cell indicates that the engineering characteristic has no influence on any stakeholder requirement. This means that the interpretation of "WHAT" and "HOW" was not performed properly. The results obtained from such matrix are shown in Figure 6.

IV. Discussion

The frame provided by SEMAT allows the stakeholders to represent adequately any practice related to software development. In particular, the practice related to measure the progress status during the development of a software project. In this way, we exhibited an approach that support the stakeholders to compare, evaluate, analyze, simulate, adapt, understand, and compose practices in this study area. Then, the integration with a frame aimed at assuring quality in the processes by involving the voice of client was demonstrated. Thus, the collected information was useful for validating the integration and demonstrating the application of the proposal described in this paper. A review more detailed of the results in this study allow to us highlight some aspects. By one hand, according to Table 4, the analysis of the statistical process based on the answers given to the requirements in the section "WHAT" within the quality house demonstrates that the requirements raised by the stakeholders (respondents) have a high-level priority relative to the measurement of the state of progress in software development. An example of this assessment is evidenced

	HOW																																
	Software defects				Frequency of measure use				Project size			Effort					Project duration		Developer performance			Development team performance				Productivity				Project planning			
WHAT	Ndf	Ndp	Nce	Npe	Tco	LC/Ed	Cer	Nqc	Clc	Cpa	Cpm	Che	Chr	Cpa	Cpm	Mf	Ni	Mf	Nlc	Nd/Lc	Phts	Hpf	Trf	Vg	Tlc	Lc/h	Nr/Hm	Nd/Hm	Ts/Hm	Da/De	Ea/Ee	Ttd	Relative weight
Software defects	9	1	1	3	3	1	1	9	3	3	0	0	3	3	3	3	1	0	9	3	3	3	9	3	3	3	3	3	3	1	9	3	1,09
Project size	9	3	3	3	9	1	0	0	0	9	3	9	9	3	3	9	3	9	3	0	9	3	1	3	0	1	9	3	3	9	9	9	0,9
Effort	9	9	9	9	9	9	1	0	3	9	3	3	9	9	9	3	9	9	9	3	9	3	3	3	0	1	3	3	3	3	9	9	1,09
Project duration	9	1	9	9	9	3	3	3	0	9	3	9	9	9	9	9	9	9	9	0	9	9	9	3	3	1	9	3	3	9	3	9	0,9
Developer performance	9	9	3	9	3	3	1	0	3	3	0	3	9	3	3	9	3	3	9	3	3	3	3	3	1	3	3	9	3	3	9	9	0,95
Development team performance	9	3	3	9	3	0	1	0	3	3	1	3	9	3	3	9	3	3	9	3	3	3	3	3	1	3	3	9	3	3	9	9	1,01
Productivity	3	3	9	3	9	3	3	9	3	9	3	9	9	9	9	9	9	9	3	1	3	1	3	3	0	1	3	3	3	9	9	9	0,96
Project planning	9	9	9	9	9	3	9	3	3	9	9	9	9	9	9	9	9	9	3	0	9	9	9	9	1	3	9	3	3	9	3	9	1,11
Internal customer satisfaction	9	9	9	3	3	3	3	3	3	1	0	9	9	3	3	3	3	3	3	0	3	3	3	3	0	3	3	3	3	9	9	9	0,91
Errors in production	9	1	9	3	1	1	9	9	9	3	0	9	3	1	1	1	3	3	1	9	1	0	0	1	1	3	1	3	1	3	3	3	1,08
Impact degree	84	48	64	60	58	27	32	37	31	58	23	62	77	52	52	63	52,2	56	58	23	52	37	43,6	35	10	22	45	42	28	57	71	77	1
Relative weight	84	48	64	60	58	27	32	37	31	58	23	62	77	52	52	63	52,2	56	58	23	52	37	43,6	35	10	22	45	42	28	57	71	77	
Relative importance	2	13	4	7	12	22	19	17	20	8	23	6	3	11	1	5	11	10	8	23	11	17	15	18	25	24	14	16	21	9	4	3	

Figure 6. Relationships “WHAT” vs “HOW”.
Source: the authors

in such Table 4, where the degree of importance and quality raised has a rating between “Important” and “Very important”. By other hand, the Figure 6, allow us to identify and make a diagnosis of the degree of importance and degree of impact of the diverse components related to the measurement of the progress status during the development of software projects. This relevance is demonstrated by identifying and relating the requirements of the interested parts and the technical characteristics considered in the development of software projects. These tasks facilitate the establishment of controls to be carried out and decisions making to be made to improve quality and progress level in projects. Figure 7 illustrated a greater degree of impact related to Ndf (number of defects per phase), Chr (amount of real hours), Ttd (Total time of Development - peoplemonths), Ea/Ee (Current Effort / Estimated Effort), Nce (number of components with errors), Mf (months per development phase), Che (amount of estimated hours) and Npe (number of peopleyears of effort).

V. Conclusion

This work constitutes a valuable contribution in the field of software engineering in particular related to measuring the progress status in the development of software projects. There is a diversity of measurement approaches, as well as various methods used to develop software projects. Some of these approaches are based on empirical experience and others are framed in globally recognized standards, norms, and frameworks. It was found that not only this variety represents a matter of concern, but also the informal and subjective way in which many of these measurement processes are carried out, cause uncertainty and lack of confidence both in the process and in the results obtained. With the purpose of facing these difficulties, SEMAT was proposed as a representation framework based on a kernel that provides a series of elements leading to the establishment of a common base that facilitates the understanding, analysis, and integration of diverse approaches. To achieve the above, a characterization of the elements provided by the SEMAT that could support the measurement of the progress status of software projects was described. Also, the way in which these characteristics are integrated into the measurement process was described. Additionally, the lack of rigor in the application and configuration of the measurement process, which was evidenced in the review of studies, made it possible to demonstrate the usefulness of integrating QFD (Quality Function Deployment) in this work. The use of QFD for the purpose of supporting the development of software products is widely demonstrated in the literature, however, in this work it was innovatively demonstrated that QFD, can also support the execution of software development processes.

VI. Acknowledgement

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