Bridging the Gap between Security/Risk and Quality

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Abstract. An IT security vulnerability can be considered as an inherent weakness in a target system that could be exploited by a threat source. The underlying hypothesis in our proposal is that each identified attribute associated with the target entity to be controlled should show the highest quality satisfaction level as an elementary indicator. The higher the quality indicator value achieved per each attribute, the lower the vulnerability indicator value and therefore the potential impact from the risk standpoint. In the present work, we discuss the added value of supporting the IT security and risk assessment areas with measurement and evaluation (M&E) methods and strategy, which are based on metrics and indicators. Also we illustrate excerpts of an M&E case study for characteristics and attributes of Security, and their potential risk assessment.

1   Introduction

There exist widespread sayings such as "you cannot control what you cannot measure" meaning –as a possible interpretation- that the lack of data e.g. numbers jeopardizes the very basic engineering and management principles of being systematic and disciplined. Also, "if you do not know where you are, a map will not help to reach the destination" meaning for instance that the lack of data and information for understanding the current situation of an entity vanishes any effort –even having enough resources- to meet the ultimate goal such as improvement. In other words, we cannot improve what we cannot understand, and we cannot appropriately understand without analyzing consistent data and information. So data and information are basic inputs for different processes; while data usually come from facts, measures, etc. information is the meaningful interpretation of data for a given purpose, user viewpoint and context.

In the present work, we state that metrics and indicators are basic, yet key organizational assets for providing suitable data and information for analyzing and monitoring. With the aim to systematically carry out M&E projects and programs, software organizations should establish clearly a set of principles, activities, methods and tools to specify, collect, store, and use trustworthy metrics and indicators and their values. Moreover, in order to make the analysis and decision-making process more robust, it is necessary to ensure that measures' and indicators' values are repeatable and comparable among the organization's projects. Therefore, it should be mandatory to store not only M&E data but also metrics and indicators metadata as for example metric and indicator ID, version, measurement method, scale, scale type, unit, indicator model, etc.

In fact, metrics and indicators should be seen as designed and versioned by-product or resources stored in organizational repositories. Particularly, the metric is the sound specification of a measurement process which transforms an entity attribute –the input- into a measure i.e. data –the output; and the elementary indicator is the sound specification of an evaluation process, which has as input a metric's measure and produces an indicator value i.e. information. However, looking at recognized literature [4, 7, 10, 12, 16] what a metric or indicator means and fits in a given process, and issues such as *why*, *what*, *who*, *when*, *where* and *how* (*W5H* for short) to measure and evaluate are often poorly linked and specified. To make things a bit more complicated, we have observed very often a lack of consensus among M&E terminological bases in different recognized standards and manuscripts or, sometimes, absent terms [17].

Ultimately, metrics and indicators are part of our integrated GOCAME (*Goal-Oriented Context-Aware Measurement and Evaluation*) strategy [18, 19], which can be used to understand and improve the quality of any organizational entity or asset. Particularly, we emphasize in this work metric and indicator specifications for vulnerability attributes regarding the *Security* characteristic [8] for a system, as the target entity.

Note that a vulnerability is an inherent weakness in a target system that could be exploited by a threat source. Most vulnerable capabilities/attributes of a system can be identified for instance with security controls. Therefore, understanding the current quality acceptability level achieved for vulnerability attributes can help in turn assessing the risk and planning actions for improvement, i.e. the risk reduction by implementing the risk treatment from the impact viewpoint. The underlying hypothesis is that each meaningful attribute associated with the target entity to be controlled should show the highest quality satisfaction level as an elementary nonfunctional requirement. The higher the quality indicator value achieved per each attribute, the lower the vulnerability indicator value and therefore the potential consequence on the target entity.

So the main contributions of this paper are: *i*) the awareness of the added value of supporting the IT security/risk assessment area with a quality evaluation strategy, which is based on metrics and indicators; *ii*) a thorough discussion about the specification of metrics and indicators as informational, reusable resources for M&E process descriptions, highlighting the importance of recording not only data but also the associated metadata of information needs, context, attributes, metrics and indicators to ensure repeatability and consistently; and *iii*) the illustration of metrics and indicators from excerpts of an actual IT security and risk evaluation case study.

Following this introduction, Section 1 provides an overview of the GOCAME strategy, focusing on its M&E conceptual framework and process for better understanding the modeling of metrics and indicators. Also a summary of risk assessment is made in order to see where M&E fit. Section 3 elaborates on the GOCAME framework and process to see where the above mentioned W5H rule fits in the M&E process; then, concrete metric and indicator templates for security attributes are fleshed out, following a discussion of our approach contributions. Section 4 addresses related work and, finally, Section 5 outlines the main conclusions and future work.

2 Background

Measurement and Analysis is a basic CMMI process area at level 2 for the staged re-

presentation [4] that gives support to other process areas by means of measures. Thus, measures and their interpretation for a given information need are considered a key supply to assist and analyze the rest of all other process areas. Moreover, in order to support consistency in different M&E projects, well-established M&E strategies are needed as well. For instance, GOCAME [18] is based on three main principles: i) an M&E *conceptual framework*; ii) an M&E *process*; and iii) *M&E methods* and *tools*.

GOCAME's first principle is that designing and implementing an M&E project/program requires a sound *M&E conceptual framework*. Often times, organizations conduct measurement programs that start and stop because they don't pay enough attention to the way nonfunctional requirements, contextual properties, metrics and indicators should be designed, implemented and analyzed. Any M&E effort requires an M&E framework built on a rich conceptual base as an ontology. Then, we built the C-INCAMI (*Contextual-Information Need, Concept model, Attribute, Metric and Indicator*) framework [18] based on our metrics and indicators ontology [17].

GOCAME's second principle requires a well-established *M&E process* in order to guarantee repeatability in performing activities and consistency of results. A process prescribes a set of phases, activities, inputs and outputs, sequences and parallelisms, roles, and so forth. Finally, GOCAME's third principle is *M&E methods and tools*, which can be instantiated from both the conceptual framework and process. While activities state 'what' to do methods, on the other hand, describe 'how' to perform these activities. Next, we outline GOCAME's M&E conceptual framework and process for better understanding the metric and indicator modeling in Section 3.

2.1   GOCAME Strategy Overview

GOCAME is a multi-purpose strategy that follows a goal-oriented and context-sensitive approach in defining M&E projects. Regarding the abovementioned first principle, C-INCAMI is structured in six components, namely: i) *M&E project*, ii) *Nonfunctional Requirements*, iii) *Context*, iv) *Measurement*, v) *Evaluation*, and vi) *Analysis and Recommendation*. The components shown in Fig. 1 are presented below. Also some key terms are defined –see [17] for more details.

The *Requirements* component (`requirements` package in Fig. 1) allows specifying the *Information Need* of any M&E project. It identifies the *purpose* (e.g. "understand", "improve", etc.) and the *user viewpoint* (e.g. "security administrator", etc). Also, it focuses on a *Calculable Concept* –e.g. "quality", "security"- and specifies the *Entity Category* to evaluate –e.g. a resource, product, system, etc. The leaves of an instantiated model (a requirements tree) are *Attributes associated* with an *Entity Category*. From the quoted terms, **Information Need** is defined as "*insight necessary to manage objectives, goals, risks, and problems*"; **Entity Category** is defined as *"object category that is to be characterized by measuring its attributes or properties*", and, **Attribute** is "*a measurable physical or abstract property of an entity category*".

Regarding the *Context* component (`context` package), one key term is **Context**, which is defined as "*a special kind of entity representing the state of the situation of an entity, which is relevant for a particular information need*". Context is a special kind of *Entity* in which related relevant entities are involved. Related entities can be resources –as a network or security infrastructure-, organization or the project itself, among oth-

ers. To describe the context, Attributes of the relevant entities are used for further quantification, which are called *Context Properties* (see details in [13]).

The Measurement component allows specifying the metrics that quantify attributes. To design a *Metric*, *the Measurement and Calculation Method* and the *Scale* should be defined. Whereas a measurement method is applied to a *Direct Metric*, a calculation method is applied to the formula of an *Indirect Metric*. A *Measurement* produces a *Measure*. **Measurement** is defined as "*an activity that uses a metric definition in order to produce a measure's value*", while a **Measure** is "*the number or category assigned to an attribute of an entity by making a measurement*", and the **Metric** is "*the defined measurement or calculation method and the measurement scale*". Hence, for designing a direct metric two aspects should be clearly specified as metadata, namely: its measurement method and scale. The **Measurement Method** (i.e. procedure) is "*the particular logical sequence of operations and possible heuristics specified for allowing the realization of a direct metric description by a measurement";* and the **Scale** is "*a set of values with defined properties*". Note that the *scale type* depends on the nature of the relationship between values of the scale, such as keeping the order and/or distances among categories, in addition to the existence of the zero category meaning absence of the measured attribute. The scale types mostly used in Software and Web Engineering are classified into "nominal", "ordinal", "interval", "ratio", and "absolute". Each scale type determines the choice of suitable mathematical operations and statistics techniques that can be used to analyze the data.
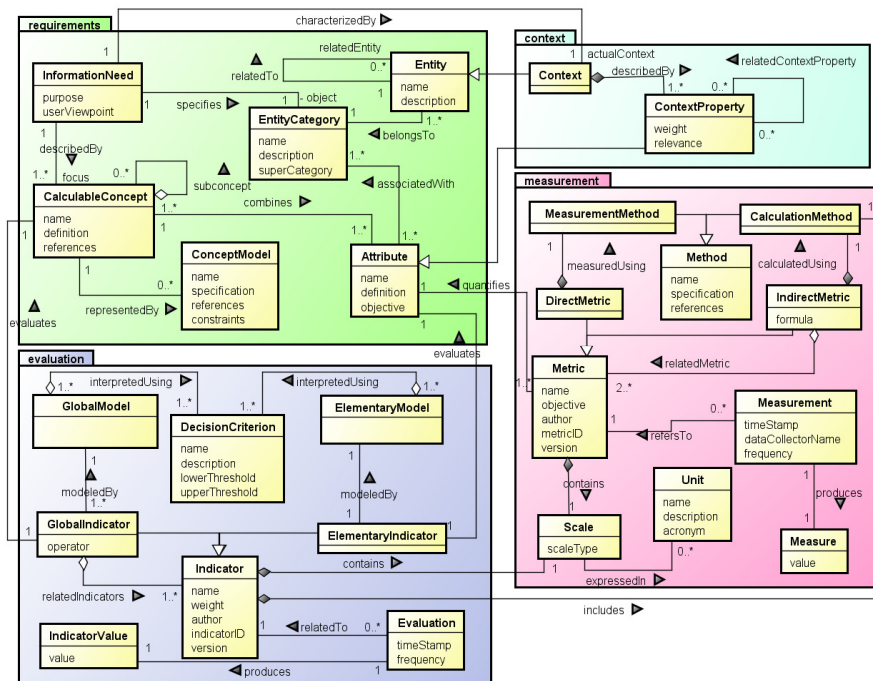

Fig. 1. Main concepts and relationships for the C-INCAMI components

The *Evaluation* component includes the concepts intended to specify the design and implementation of elementary and global evaluations. It is worthy to mention that the selected metrics are useful for a measurement process as long as the selected indicators are useful for an evaluation process. *Indicato*r is the main term, which allows specifying how to calculate and interpret the attributes and calculable concepts of a requirements tree. There are two types of indicators. First, *Elementary Indicators* that evaluate lower-level requirements, namely, attributes. Each elementary indicator has an *Elementary Model* that provides a mapping function from the metric's measures (the domain) to the indicator's scale (the range). The new *Scale* is interpreted using agreed *Decision Criteria* (also called Acceptability Levels), which help to analyze the level of satisfaction reached by each elementary nonfunctional requirement, i.e. by each attribute. Second, *Partial/Global Indicators*, which evaluate mid-level and higher-level requirements, i.e. sub-characteristics and characteristics in a concept model (e.g. a security model). Different aggregation models (*Global Model*) can be used to perform evaluations. As for the implementation, an *Evaluation* represents the activity involving a single calculation, following a particular indicator specification –either elementary or global-, producing an *Indicator Value*. In our ontology **Evaluation** is defined as "*activity that uses an indicator definition in order to produce an indicator's value*", and **Indicator** as "*the defined calculation method and scale in addition to the model and decision criteria in order to provide an estimate or evaluation of a calculable concept with respect to defined information needs*".

Taking into account the GOCAME's second principle, its general process embraces the following activities: i) *Define Nonfunctional Requirements*; ii) *Design the Measurement*; iii) *Design the Evaluation*; iv) *Implement the Measurement*; v) *Implement the Evaluation*; and vi) *Analyze and Recommend.* These high-level activities as well as sequences, parallelisms, inputs and outputs are shown in Fig. 2.
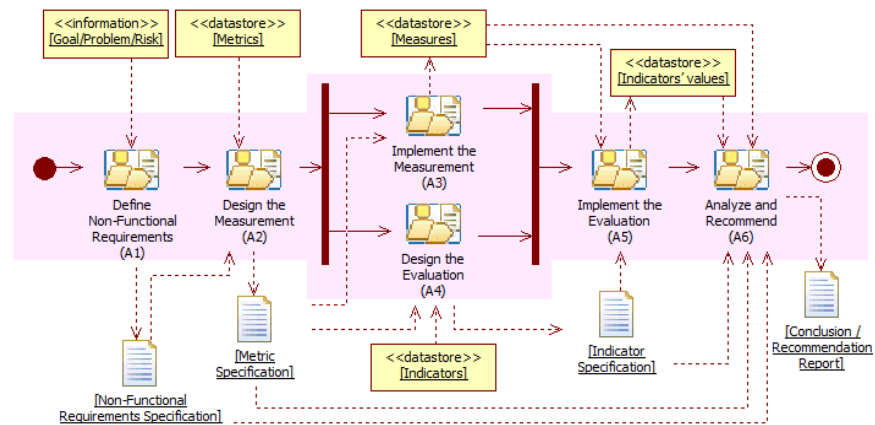

Fig. 2. High-level activities for the GOCAME M&E process. Legend *A* means *Activity*

The proposed M&E process [3] follows a goal-oriented approach. Once the requirements project has been created, first, the *Define Nonfunctional Requirements* activity has a specific goal or risk as input and a Non-functional Specification docu-

ment as output (which contains the M&E purpose, user viewpoint, focus, entity, instantiated characteristics and attributes, and context information). Then, the *Design the Measurement* activity allows identifying the metrics from the Metrics repository (*<<datastore>>* stereotype in Fig. 2) to quantify attributes: the output is a Metrics Specification document. Once the measurement was designed, the evaluation design and the measurement implementation activities can be performed –in any order or in parallel. The *Design the Evaluation* activity allows identifying Indicators.

The *Implement the Measurement* activity uses the chosen metrics to obtain the measures that are stored in the Measures repository, and then *Implement the Evaluation* can be carried out. Lastly, *Analyze and Recommend* activity has as inputs the measure and indicator values (i.e. data and information), the metric and indicator specifications (i.e., metadata) in order to produce a Conclusion/Recommendation report.

Since the M&E process includes activities such as specify the requirements tree, identify metrics, analyze and recommend, and so on, it is necessary to have a methodology that integrates all these aspects and tools that automate them. To this aim the WebQEM (*Web Quality Evaluation*) methodology and its tool [18] were instantiated from the framework and process, and used in different academic and industrial cases. It is important to remark that some GOCAME methods for evaluation are based on multi-criteria (attribute) decision analysis, which can also be used for risk assessment [11].

2.2   Risk Assessment Issues regarding M&E

There are abundant standards and research (e.g. [1, 4, 9, 11, 15], to quote just a few) in areas of risk management, risk assessment techniques and processes as well as risk vocabularies –however, an ontology for the risk domain is still missing. In this paper, without entering in specific discussions of the risk terminological base, we use some terms defined in the previous sub-section as entity, attribute, amongst others.

Categories of entities as software projects, products and systems or some of their components, involve risks at different development or operative stages which should be identified, prevented, controlled, treated and monitored through a well-defined and systematic risk management approach. A risk can be defined as an undesirable consequence of an event on a target entity, which can represent an organizational asset – where an asset is an entity with (added) value for an organization. The potential losses affecting the asset are also called impact of the risk. Besides, the term vulnerability is commonly used in the security area, which briefly means a weakness in an entity attribute/capability that can be exploited by a threat source.

Software Risk Management (SRM) suggests actions e.g. to prevent risk or reduce its impact on the target entity instead of dealing with its further consequences. Thus, we can identify relevant attributes associated to an entity that can be vulnerable (weak) from triggered external/internal events. Then, by understanding the current attributes' strengths and weaknesses –e.g. by using the GOCAME strategy-, actions for change can be recommended and planned for further treatment implementation.

In general terms, SRM includes a set of policies, processes, methods and tools to analyze risks, understand weaknesses, prepare preventive/perfective actions, and control risks on the target entity. Particularly, for risk assessment three processes are proposed in [11]: i) *Risk identification*; ii) *Risk analysis*; and iii) *Risk evaluation*. In addition, *Establishing the context*, *Risk treatment*, *Risk monitoring and review*, and *Com-

munication are also common processes for a well-established SRM strategy. Basically, the *Risk identification* activity aims at gathering information about all risks that can affect the system or resource (i.e. the target entity), such as risk category, possible causes and outcomes, etc. In [9] it is defined as "the process of finding, recognizing and describing risks". Also a note indicates "risk identification involves the identification of risk sources, events, their causes and their potential consequences". In the *Risk analysis* activity, the identified risks are prioritized according to the probability of occurrence and loss/undesirable consequences associated to the entity attributes to set how many risks will be treated. It is defined as "the process to comprehend the nature of risk and to determine the level of risk". *Risk evaluation* activity is defined as "the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable". Risk evaluation assists in the decision about risk treatment, which is defined as "the process to modify risk" [9]. For example, risk treatment can involve: i) taking or increasing risk in order to pursue an opportunity; ii) removing the risk source; iii) changing the likelihood (probability); and iv) changing the consequences, amongst other choices.

In this work, we propose, for brevity reasons concentrating just on the iv) above item –particularly, in the vulnerabilities- for designing the M&E and ulterior improvement plan. The plan should describe actions to reduce the vulnerability/impact on the target entity. Particularly, regarding our proposal, system attributes, metrics and indicators should be selected to manage the risk status, showing whether the risk is reduced. The interpretation of evaluations is made by the used indicators and their acceptability levels met, which in turn make use of metrics that quantifies the attributes associated to the entity as per plan. Therefore, target entities can be measured and evaluated by means of their associated attributes and calculable concepts (characteristics). The underlying hypothesis is that each meaningful attribute to be controlled (related e.g. to the Security characteristic) should show the highest quality level of satisfaction as an elementary nonfunctional requirement. The higher the quality indicator value achieved for each attribute, the lower the vulnerability indicator value. Then:

Vulnerability Indicator value (for Attribute A_i) = 100 – Quality Indicator value A_i;   (1)

where in the percentage scale there are acceptability levels for the elementary quality indicator, representing 100% a totally satisfied (achieved) requirement, and 0% totally unsatisfied –so implies that an urgent change action must be planned. So per each relevant attribute Ai, we can calculate the risk indicator value (magnitude) before and after improvement changes were performed using the often quoted formula:

Risk value A_i = Probability of Event occurrence for A_i * Vulnerability Indicator value A_i;   (2)

and then calculate the risk reduction per each vulnerable attribute. Or even the risk reduction calculated as an aggregated indicator value e.g. for Security. We argue that without the well-established support of metrics and indicators and their values SRM is more craftwork than science. The proposal of looking at vulnerabilities as attributes and then using metrics and indicators for their M&E is illustrated in sub-section 3.2.

3   Metric and Indicator Specifications for Security

From the specification standpoint, metrics and indicators can be considered as de-

signed and versioned by-products stored in organizational repositories, which are (re-)used by M&E activities. Nevertheless, regarding the state-of-the-art literature, what metrics and indicators mean and where fit in a given M&E process as well as issues such as *why, what, who, when, where* and *how* to measure and evaluate have often been poorly related and specified.

3.1 The W5H rule: Why, What, Who, When, Where, How?

Nelson [14] asserts that a "discussion of the *why*, *who, what, where*, and *when* of security metrics brings clarity and further understanding because it establishes a framework for implementing a framework to implement security metrics in your organization" (cf. p.14). We want to reinforce this idea and try to strengthen it. GOCAME's three principles outlined before will help us to illustrate the rationale for the W5H mnemonic rule. Particularly, in the following summary, we rely on the general process depicted in Fig. 2, which in turn is compliant with the terminological framework shown in Fig. 1.

Why an organization should tackle the M&E endeavor might be represented in the *M&E project definition* and instantiation. Basically, there is an issue (the *goal/problem /risk* input in Fig 2) that requires a solution driven by analysis. For instance, the organization needs to reduce some particular entity vulnerabilities; however, as commented above, it cannot improve what cannot understand, and it cannot appropriately understand without consistently analyzing data and information. The why aspect therefore embraces the concrete *Information Need* and *purpose* for M&E such as understand, improve, and control some relevant objective, regarding a *specific user viewpoint.*

What is to be measured and evaluated? This embraces the concrete target *entity* – and related entities including *Context* that *belongs to* an *Entity Category*. Also, a given information need is described by a *focus* (e.g. the security *Calculable concept*) to which attributes are combined. Moreover, entities cannot be measured directly but only through their attributes and *Context properties*. So, the *non-functional requirements specification* artifact (see Fig. 2) documents to a great extent the why and the what.

How basically deals with the metric and indicator specifications. *Metrics and Indicators* are organizational assets stored in repositories (as depicted in Fig. 2), which are selected respectively by the A2 and A4 activities at design time, and then implemented by the A3 and A5 activities accordingly. As we show in sub-section 3.2, metric and indicator specifications should be considered metadata that must be kept linked through *metricID*, *indicatorID* and *version* –for consistency reasons- to measure and indicator values produced for the A3 and A5 activities. Further, metadata and datasets are consumed by the A6 activity or by inter-project analysis tasks.

Who is responsible for the different stages of an M&E project? Certainly, there are different levels of responsibilities and roles. In the C-INCAMI *M&E project definition* component (not shown in Fig. 1) related project concepts allow recording the responsible information. In addition, *author* name is a common field for both metric and indicator specifications which represents their creator as a piece of design. Besides, the *data collector* name –see *Measurement* term in Fig. 1- allows recording the responsible for data gathering in the A3 activity.

When is recorded for each M&E project and also per each enacted M&E task. Basic questions supported are, among others: When do you collect metric measures? How

often do you collect them? When do you perform evaluations and analysis? For example, the *time stamp* and *frequency* fields in the *Measurement* and *Evaluation* terms allow recording them accordingly when A3 and A5 are executed.

Where is the M&E project running? Where is the entity under evaluation placed? In which context is the target entity measured and evaluated? Where is data collection activity for metrics performed? Some of these raised issues can be taking into account by the C-INCAMI M&E *project definition* component including the recorded *Context* and its associated *Context properties* and *values*. Next, using the W5H rule we illustrate the *Security* characteristic emphasizing mainly the **how** aspect, for space reasons.

3.2 Security Characteristic for an Information System: Proof of Concept

In this sub-section, excerpts of a case study we have performed are used as proof of concept. One issue of the W5H rule is **what** is to be measured and evaluated? The concrete entity is named "XYZ"–with fictitious name-, a real student management WebApp widespread used in Argentinean universities. XYZ is a system –from the *Entity Category* standpoint- commonly used by students, professors and faculty members. Moreover, **why** should it be evaluated? Because a concrete information need was raised by the IT department responsible in the ABC organization (again, a fictitious name for confidentiality reasons), which is related to security risks due to different potential threats, e.g. students changing the bad marks of subjects due to system vulnerabilities. So the *purpose* of the information need is firstly to "understand" the current external quality satisfaction level achieved, particularly for the non-vulnerabilities regarding the "Security" feature, from the "security administrator" *user viewpoint*.

Once the current security satisfaction level is understood, secondly the purpose is to "improve" the WebApp in those weakly performing indicators. That is to say, the ultimate purpose is to reduce the risk (i.e. security vulnerabilities) on the XYZ entity.

Fig. 2 shows as output of the A1 activity the non-functional requirements specification artifact, which mainly documents the why and what aspects. Specifically, Table 1 represents the requirements tree instantiated for the *Security* characteristic and its sub-characteristics such as *Confidentiality* (coded 1.1), *Integrity* (1.2) and *Authenticity* (1.3), which are the ones prescribed in the ISO 25010 system quality model [8]. For instance, *Confidentiality* is defined as "degree to which a product or system ensures that data are accessible only to those authorized to have access" [8]. Additionally, we have identified new sub-characteristics such as *Access Schema Protectability* (1.1.1) which is defined as "degree to which the system ensures the confidentiality of data by providing access protection capabilities". Moreover, 20 measurable attributes were specified for *Security* as shown in Table 1, which are highlighted in italic.

For example, the objective of the 1.1.1.1 attribute is "to find out the degree to which bypassing the authentication schema is avoided". While most WebApps require authentication for gaining access to private information or to execute tasks, not every authentication method is able to provide adequate security.

In Table 2 this attribute is also defined and its indirect metric –and related direct metrics- is thoroughly represented in the metric template. The W5H rule's **how** issue deals basically with the metric and indicator specifications. Once the nonfunctional requirements were specified, the next A2 activity consists in selecting the meaningful metrics from the Metrics repository (see Fig. 2) to quantify attributes. One metric

should be assigned per each attribute of the requirements tree respectively; e.g., the indirect metric named *Ratio of Protected Pages Accessed via Forced Browsing* was selected for quantifying the *Authentication Schema Bypass* (1.1.1.1) attribute.

Table 1. Requirements tree specification for the *Security* characteristic and sub-characteristics

1.   Security (see definition in [8])
1.1.   Confidentiality [8]
1.1.1.   Access Schema Protectability
1.1.1.1.   Authentication Schema Bypass
1.1.1.2.   Login Schema Protectability
1.1.2.   Session Data Protectability
1.1.2.1.   Session Data Disclosure Protectability
1.1.2.2.   Session Data Theft Protectability
1.2.   Integrity [8]
1.2.1.   Cross-Site Scripting Immunity
1.2.1.1.   Reflected Cross-Site Scripting Immunity
1.2.1.2.   Stored Cross-Site Scripting Immunity
1.2.1.3.   DOM-based Cross-Site Scripting Immunity
1.2.1.4.   Cross-site Request Forgery Immunity
1.2.2.   *Session Data Tampering Protectability*
1.3.   Authenticity [8]
1.3.1.   Session ID Protectability
1.3.1.1.   Session ID Theft Protectability
1.3.1.2.   Session ID Tampering Protectability
1.3.2.   Session Impersonation Protectability
1.3.2.1.   Session Management Protectability
1.3.2.1.1.   Session ID Expiration
1.3.2.1.2.   Session Expiration Due to Idle Timeout
1.3.2.1.3.   Re-authentication Mechanism Availability
1.3.2.1.4.   Session ID Regeneration Availability
1.3.2.1.5.   Keep-me-logged-in Mechanism Availability
1.3.2.2.   Session Non-Replay Protectability
1.3.2.3.   Session Fixation Protectability
1.3.3.   Password Protectability
1.3.3.1.   Password Aging Policy
1.3.3.2.   String Password Strength

While an indirect metric has a calculation method (procedure) for its formula specification, a direct metric has a measurement procedure. For instance, the measurement procedure for #PF direct metric is objective, i.e. it does not depend of human judgment when the measurement is performed. The measurement procedure represents the counting rule and its specification for #PF indicates "using an unauthenticated browser session, attempt to directly access a previously selected protected page URL through the address bar in a browser. Add one per each successful access which bypasses the authentication". In addition, its measurement procedure can be automated by a software tool, so this field can be added to the metric template as well. Ultimately, the metric –as informational resource for the A2 and A3 activities- embraces metadata such as metric ID, scale, scale type, value type, measurement/calculation procedure specification, tool, version, and author, among others. These metric metadata allow therefore repeatability among M&E projects and consistency in the ulterior analysis of data sets.

Once metrics were selected for quantifying all attributes then the A4 activity should be performed, which deals with designing the evaluation. While an elementary indicator evaluates the satisfaction level reached for an elementary requirement, i.e., an

attribute of the requirements tree, a partial/global indicator evaluates the satisfaction level achieved for partial (sub-characteristic) and global (characteristic) requirements.

Table 2. Indirect and direct metric specifications to the *Authentication Schema Bypass* attribute

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Attribute Name: *Authentication Schema Bypass*   **Code**: 1.1.1.1 in Table 1
Definition: Due to negligence, ignorance or understatement of security threats often result in authentication schemes that can be bypassed by simply skipping the login page and directly calling an internal page that is supposed to be accessed only after authentication has been performed;
Objective: To find out the degree to which bypassing the authentication schema is avoided.

Indirect Metric Name: *Ratio of Protected Pages Accessed via Forced Browsing* (%PPA); **Objective**: To determine the ratio between the number of successful attempts accessing protected pages by forced browsing and the total number of attempts performed; **Author**: Dieser A.; **Version**: 1.0; **Reference**: OWASP Testing Guide 2008 V3.0 (available at https://www.owasp.org/index.php/OWASP_Testing_Project);
Calculation Procedure (Method) / Formula: %PPA = (#PF / #TPP) * 100
Numerical Scale: Representation: Continuous; **Value Type**: Real;   **Scale Type**: Ratio;
     Unit Name: Percentage; **Acronym**: %
     Related Metrics: 1) Number of successful attempts to access protected pages by forced browsing (#PF); and 2) Total number of attempts to access protected pages by forced browsing (#TPP)

Related Direct Metric Name: *Number of successful attempts to access protected pages by forced browsing* (#PF) ; **Objective:** The number of successful attempts bypassing the authentication schema for the protected page population using the forced browsing technique; **Author**: Dieser A. ; **Version**: 1.0;
     Measurement Procedure: Name: Direct page request; **Type**: Objective; **Specification**: Using an unauthenticated browser session, attempt to directly access a previously selected protected page URL through the address bar in a browser. Add one per each successful access which bypasses the authentication;
     Numerical Scale: Representation: Discrete; **Value Type**: Integer; **Scale Type**: Absolute;
     Unit Name: Successful attempts on Protected pages; **Acronym**: Pp

Related Direct Metric Name: *Total number of attempts to access protected pages* (#TPP); **Objective**: The total number of protected pages (i.e. the given population) to be attempted for access by a given technique; **Author**: Dieser A.; **Version**: 1.0;
     Measurement Procedure: **Type**: Objective; **Specification**: As precondition, log into the website with a valid user ID and password. Browse the site looking for the URL population of protected pages, which are those that must be accessed only after a successful login. Add one per each protected page URL selected.
     Numerical Scale: **Representation**: Discrete; **Value Type**: Integer; **Scale Type**: Absolute;
     Unit Name: Protected pages; **Acronym**: Pp

Table 3. Elementary indicator specification to the *Authentication Schema Bypass* attribute

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Attribute: *Authentication Schema Bypass*   **Code**: 1.1.1.1 in Table 1
Elementary Indicator:
          Name: *Performance Level of the Authentication Schema Bypass* (P_ASB)
          Author: Dieser A. **Version**: 1.0
     Elementary Model:
          Specification: the mapping is: P_ASB = 100 iff %PPA=0; P_ASB = 90 iff %PPA< %PPA$_{MAX}$;
P_ASB = 0 iff %PPA >= %PPA$_{MAX}$ where %PPA is the indirect metric in Table 2.
     Note that the %PPA$_{MAX}$ is an agreed parameter (threshold) of 2% for the XYZ case study.
     Decision Criterion [Acceptability Level]:
          Name 1: Unsatisfactory **Description**: indicates change actions must be taken with high priority
               Range: if $0 \leq P\_ASB \leq 80$
          Name 2: Marginal   **Description**: indicates a need for improvement actions
               Range: if $80 < P\_ASB \leq 98$
          Name 3: Satisfactory   **Description**: indicates no need for current actions
               Range: if $98 < P\_ASB \leq 100$
     Numerical Scale / Scale Type: Ratio   **Unit Name**: Percentage

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As commented in sub-section 2.1, indicator is the main concept for evaluation, which can be elementary or partial/global. In Table 3 the elementary indicator named *Performance Level of the Authentication Schema Bypass* is specified. This elementary indicator will determine the quality satisfaction level reached by the 1.1.1.1 attribute considering the measured value of its indirect metric. Conversely to metrics, indicators have decision criteria for data interpretation. In Table 3, three acceptability levels useful for the interpretation of indicator values in the percentage scale are designed.

With regard to the **how** for a global indicator, it has similar metadata as shown for an elementary indicator. But instead of an elementary model it has a global or aggregation model. An example of global model is LSP (*Logic Scoring of Preference*) [5], which was used e.g. in [18, 19]. LSP is a weighted multi-criteria aggregation model, which has operators for modeling simultaneity (C conjunctive operators) and replaceability (D disjunctive operators) relationships among attributes, sub-characteristics and characteristics of a requirements tree. For instance, the C+ strong conjunction operator lets modeling the simultaneity criterion among the 1.1, 1.2 and 1.3 sub-characteristics, yielding zero if one input were zero.

Next, it is the specification of the LSP aggregation model:

$$P/GI\ (r) = (W_1 * I_1^{\ r} + W_2 * I_2^{\ r} + ... + W_m * I_m^{\ r})^{1/r}\ ; \tag{3}$$

where *P/GI* represents the partial/global indicator to be calculated, and I_i stands for elementary indicator value and the following holds $0 <= I_i <= 100$ in a percentage scale; W_i represents the weights, where: $W_1 + W_2 + ... + W_m = 1$, and $W_i > 0$ for $i = 1$ to m, in an aggregated block of elements; and, *r* is a parameter selected to achieve the desired logical simultaneity, neutrality or replaceability relationship.

Lastly, as result of the whole design and selection process –activities A1, A2 and A4-, the following documents are yielded: the non-functional requirements specification, the metrics specification and the indicators specification.

Aspects of **when** and **where** are related to great extent to *Implement the Measurement and Evaluation* activities, as commented in sub-section 3.1. Particularly, for each executed M&E project, the A3 and A5 activities produce measure and indicator values accordingly at given moments in time and frequencies.

3.3 Added Value of Metrics and Indicators for Bridging the Gap

We have illustrated above the specification of a security metric and elementary indicator both regarded as resources for M&E process descriptions. Therefore, it is worthy to remark again that metric and indicator specifications should be considered metadata that must be kept linked by IDs –for reasons of analysis comparability and consistency- to measure and indicator values produced by the A3 and A5 activities.

Let's suppose for example that the same *Authentication Schema Bypass* (1.1.1.1) attribute can be quantified by two metrics (recall in Fig. 1 that an attribute can be quantified for many metrics, but just one must be selected from the Metric repository for each M&E project). So one metric (M1) in the repository is that specified in Table 2, and the other metric (M2) is one which has different measurement procedure and scale type; e.g. M2 considers the predictability of the session identifiers (IDs) as procedure,

and a categorical scale, particularly, an ordinal scale type with values ranging from 1 to 3, where 3 represents the highest difficulty to predict the ID session, and 1 the lowest. After many M&E projects using the same security attributes are executed, all data and datasets from measurement are recorded in the Measure repository (Fig. 2). In some projects were used M1 and in others M2 for quantifying the 1.1.1.1 attribute. Therefore, if metadata of recorded data were not linked appropriately, e.g. to the measured value 3 which can come from both metrics in different projects, the A6 activity will produce inconsistent analysis if takes as inputs all these related projects. This inconsistency is due to the 3 value, depending on the used metric, has different scale properties recalling that each scale type determines the choice of suitable mathematical and statistics techniques that can be used to analyze data and datasets. In summary, even if the attribute is the same, both metric measures are not comparable.

On the other hand, regarding the elementary indicator shown in Table 3, its specification is in terms of quality satisfaction levels –since the Security characteristic in Table 1 is based on the ISO quality model-, so each vulnerability indicator value can be obtained as per Eq. 1. Recall that the underlying hypothesis is that each security attribute to be controlled for the target entity should show the highest quality level of satisfaction as an elementary nonfunctional requirement. But as the reader can surmise, the elementary indicator template in Table 3 could also represent the vulnerability level almost straightforwardly, under the premise that the higher the quality indicator value achieved per each attribute, the lower will be the vulnerability indicator value. Hence, the risk magnitude per each vulnerable attribute can be calculated using Eq. 2.

Lastly, the aggregation model in Eq. 3 can be used for calculating the current state of the security global risk based on risk elementary indicator values. Also the risk reduction can be calculated after improvement actions (risk treatment) and re-evaluation were performed. These issues will be thoroughly illustrated in a follow-up paper.

4   Related Work

Considering the state-of-the-art research literature, what metrics and indicators mean and where they properly fit in with regard to specific M&E processes and strategy have often been understated or neglected. Furthermore, there are abundant research and standards in areas such as measurement and analysis [2, 4, 7, 12], IT security and risk assessment [1, 10, 11, 15, 16], but issues such as *why, what, who, when, where* and *how* to measure and evaluate have very often been poorly intertwined and specified.

For instance, as quoted in sub-section 3.1, Nelson states that a "discussion of the *why, who, what, where*, and *when* of security metrics brings clarity and further understanding because it establishes a framework for implementing a framework to implement security metrics in your organization". Nevertheless, in our opinion Nelson fails in discussing the W5H mnemonic rule with more robust conceptual grounds as we did based on the GOCAME first and second principles introduced in sub-sections 2.1 and 2.2. Moreover, the *how* issue –which precisely deals with the key aspect of metric and indicator specifications- is also left aside, when the author remarks "*How* is left as an exercise for the reader" (cf. p.14).

On the other hand, we have developed an integrated M&E strategy so-called GOCAME, which is made up of three capabilities, i.e. the conceptual framework, the

process, and the methodology, as overviewed in Section 2. The metric and indicator ontology used by the C-INCAMI conceptual framework has similarities to the one presented in [6]. However in [17] we have modeled some terms e.g., elementary indicator, global indicator, etc., and some relationships e.g., measurement and measure, metric and indicator, among others, which differ semantically with those proposed in [6]. In addition, we have enlarged the metric and indicator ontology with context terms and relationships [13] while in [6] these are missing. Moreover, GOCAME exhibits a terminological correspondence between the C-INCAMI conceptual framework and the process specifications; for example, the activity diagram of Fig. 2 shows many of the same terms defined in the ontology and depicted in Fig. 1. Note that a more explicit representation about this correspondence will be documented apart.

Lastly, in order to support repeatability and consistency of results among different M&E and analysis projects and programs, well-established strategies are needed as well. In [19] two integrated M&E strategies –which can also be used for risk assessment- namely GQM$^+$Strategies [2] and GOCAME were assessed and analyzed thoroughly. The study drew GQM$^+$Strategies performs lower than GOCAME regarding the suitability of the conceptual base and framework. Ultimately, the sound and complete specification of metrics and indicators as shown in the previous templates (tables 2 and 3) outperforms the examined ones in the related work.

5   Conclusion and Future Work

Finally, we would like to highlight the three contributions listed in Section 1. The first one that says "the awareness of the added value of supporting the IT security/risk assessment area with a quality evaluation strategy, which is based on metrics and indicators" was one driver of the paper. We have discussed our approach helps bridging the gap between the IT security/risk assessment area and existing quality M&E methods. The entrance gate –as described in sub-section 2.2- is based on identifying vulnerability attributes of a target entity, which can be quantified by metrics and interpreted by indicators. Hence, by using GOCAME, we can apply for quality and risk assessment its multi-criteria (attribute) decision analysis methods.

To the second contribution that says "a thorough discussion about the specification of metrics and indicators as informational, reusable resources for M&E process descriptions…" we have stated that metrics and indicators are basic, yet key organizational assets for providing suitable data and information for analyzing, and ultimately decision-making tasks. Also we have remarked that a metric is the sound specification of a measurement process that transforms an entity attribute –the input- into a measure –the output, i.e. data-; and the elementary indicator is the sound specification of an evaluation process, which has as input a metric's measure and produces as output an indicator value –i.e. contextual information. Besides, we have highlighted throughout the paper the importance of recording not only data sets and information but also the associated metadata, giving clues of a potential wrong analysis in sub-section 3.3.

Lastly, the third stated contribution "the illustration of metrics and indicators from excerpts of an actual IT security and risk evaluation case study" has been made mainly in sub-section 3.2. The purpose of the information need is firstly to understand the current quality satisfaction level achieved to the Security characteristic for the XYZ

entity, from the security administrator user viewpoint. Once its current state is understood, the following purpose is to improve the XYZ system in those weakly performed indicators; that is, to reduce its security risks. The whole results and analysis of this case study will be documented in a separate paper.

Regarding future work, an ontology for risk assessment is to the best of our knowledge missing yet, so we are considering its further development as we did for M&E. Currently, there exist vocabularies such as in [9], but we are aware that an ontology supports a richer conceptual modeling than a glossary of terms; hence, this can benefit the instantiation of SRM strategies, processes and methods as well.

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