

Quantitative Analysis of Best Practices Models in the Software Domain

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Abstract— Organizations are adopting multiple best practices models to improve overall performance. Their objective is to capture the cumulative added value of each model into one single environment. These multimodel environments raise several challenges; selection and composition of models are not straightforward tasks. This paper proposes an approach to help address these challenges by comparing models at a quantitative level. We propose a characterization of size of a model as a measure of scope coverage and detail of descriptions when compared to a reference model and model complexity in terms of architectural structural connectedness. An example of applying the proposed approach is described in an Industrial context where a multimodel process solution was evolved from CMMI-Dev level 3 to level 5.

Multimodel improvement taxonomies; Software Process Improvement; Software Engineering Management;

I. INTRODUCTION

Organizations are adopting multiple best practices models to improve overall effectiveness and efficiency. Market pressure, competitiveness, regulatory compliance or the need to solve a particular issue are general business drivers for organizations to adopt multiple models (hereafter used interchangeably as improvement technologies or simply models). The goal is to obtain the cumulative added value of each model into one single environment.

These multimodel environments are characterized for having several models being implemented concurrently at different hierarchical levels and across different organizational functions. Usually, adoption decision rests at different levels of authority and is motivated by different needs and perspectives of distinct business units. Additionally, models are likely to accumulate over the years, being adopted one after the other. These efforts, if not supported and coordinated appropriately carry significant risk of failure [1].

This integration effort often results in misalignment of models implemented creating additional reconciliation costs. Unclear relationships between models lead to operational problems and reduced productivity. This results in excessive costs and erosion of benefits when compared to single model environments. Additionally, the overall picture of capability and cost of quality for each model is difficult to attain when combined into a single environment. Organizations need help in getting started effective and efficient in using multiple quality models and adopting the proper set of models requires some guidance [2] [3] [1].

To mitigate these risks of failure and inefficiency, organizational process improvement groups need the ability to compare models effectively before these are adopted for implementation. A fact is that comparing model is not straightforward. Firstly, the number of models is considerably high across multiple domains and disciplines covering a diverse set of subjects. Secondly, comprehensiveness of descriptions and structural differences need to be considered for effective comparison.

Selection and composition of models are two challenges that organizations need to tackle when considering the adoption of multiple models [4]. Selection occurs prior to the composition effort and represents one important step. At this stage, the most suited model or set of models is expected to be identified. Selection decisions may derive from common industry patterns of adoption or regulatory requirements.

Approaches to guide selection and adoption of models are affinity groups, taxonomies, mappings, selection and implementation patterns and formal decision methods [5]. These approaches provide different levels of comprehensiveness for model comparison. Taxonomies enable a high level comparison, generally to compare a considerable set of models. Conversely, mappings are often used to compare two models with increased level of detail. These approaches focuses on a comparative qualitative analysis of models content that fails to provide a summary and extended of the differences between models.

Improvement groups considering a multimodel approach often need to justify the decision to adopt or reject a specific model. A comparative added value of a model with possible cost estimates of integration effort as well as clear synergies and dependencies with other models are not easy to derive from a qualitative analysis. Measures characterizing and detailing differences between models would provide additional information to inform better decision making on model adoption and/or re-engineering existing multimodel environments.

This paper details an approach proposed in [6] to compare models at a quantitative level. It characterizes size and complexity attributes for comparing models as an extension to a taxonomy for improvement frameworks described in [1]. We applied it in a joint effort with a Portuguese software house to evolve a multimodel process solution for compliance with CMMI-Dev [7] (hereafter shortened to CMMI) level 5 requirements.

The following sections are organized as: section 2 provides an overview of existing approaches available to compare improvement technologies. Section 3 proposes the

definition of size and complexity measures for characterizing improvement technologies. Section 4 presents the results of measuring size and complexity of Software best practices used in an Industrial context. Section 5 concludes on the proposed approach and its possible implications.

II. COMPARISON OF BEST PRACTICES MODELS

This section provides a summary on approaches currently available for comparison of models (an extended analysis is available in [6]). Halvosen and Conradi [8] identified several approaches for model comparison, namely: comparison based on characteristics, comparison based in needs mappings and comparison based on models or bilateral mappings.

Characteristics based approaches are proposed as taxonomies of characteristics or attributes. Each model subject for comparison is classified according to the set of attributes considered in the taxonomy. The comparison is based on the resulting classification of each attribute for each model. Examples of taxonomies based on characteristics are available in [1] and [8]. A simpler approach is proposed in [9] using an affinity matrix defined by a pair of attributes.

Heston and Phifer [2] introduce the concept of ‘process DNA’ and ‘Quality Genes’ that summarise concepts or quality characteristics from several key industry standards. Classification is based in an analysis of each model contents to gauge its depth and coverage of each quality gene. Each model is classified for each quality gene as *high correlation*, *some correlation* or *no correlation*. Organizations may interpret quality genes as needs and assess which models are more suitable to meet their process improvement objectives.

A models or bilateral mapping process requires two models and a mapping function. The goal of the mapping exercise is to find similarities and differences between models contents. Examples of models mappings are available in [11] and [13].

The approaches presented evidence operational differences when selection of models is to be carried out. Characteristics based comparisons are useful in providing a high-level overview of models content. Characteristics based comparisons are seen as properties or attributes that are useful to understand and compare a diverse set of models. Conversely, bilateral or model mappings are applicable to pairs of models and imply a deeper analysis of models content to find differences and similarities.

Selection and composition of models are two challenges organizations face when adopting multimodel environments [14]. Characteristics and/or needs mapping approaches are helpful for model selection, allowing to compare a diverse set of models. Models or bilateral mappings are useful in the composition step. Composition may benefit from a lower-level comparison resulting of a deeper model analysis.

Lower level comparisons require consideration of model structural differences and elaboration of descriptions. Often, gaps exist as a direct result of different elaboration levels and

structural differences may also difficult comparisons. A common ground for reconciliation of these differences would enhance the model mapping process, providing deeper insights into models content. In the next section we address this issue of reconciliation.

III. ARCHITECTURAL ATTRIBUTES: SIZE AND COMPLEXITY

In [6] the authors introduced and discussed a conceptual overview, without formalizing it, on how to measure size and complexity of best practices models.

The analysis focused on the structure used by best practices models to describe their content. The authors highlighted that every model focuses on a certain subject that can be broader or narrower and that the internal structure for describing the subject is based on textual components that are organized hierarchically. The notion of hierarchy is used to encapsulate descriptions that are further elaborated as the level in the hierarchy increases, providing additional levels of detail with a bounded scope or subject. An elaboration hierarchy comprises an ordering of detail levels (see Figure 2): level zero is at the lower level of elaboration. Lower levels form part of components at higher hierarchical levels.

Based on this conceptual perspective, a proposal for measuring size and complexity was introduced. The characterization of size aimed to translate the notion that scope of a model can be measured if one considers a reference scope for comparison and that, within a shared scope the amount of information present may vary, introducing the concept of elaboration of descriptions.

Two challenges were identified for these measures of scope size and elaboration of descriptions. The first challenge was: how to find a reference scope for comparison and secondly how to measure detail of descriptions of a model.

To overcome the challenge of finding a reference scope the authors proposed the use of a model of interest to provide the reference scope, which intuitively serves the best interest of the comparison. To overcome the second challenge (translating the notion of elaboration of descriptions), the authors proposed comparing the number of model architectural components used by each model to describe a shared scope. The argument is that simply counting overall number of components will not provide a correct notion of elaboration of descriptions. In their perspective, the number of components describing a shared scope is indicative of differences in detail provided by each model.

In summary, two dimensions were considered when conceptualizing size of a model: scope shared when compared to a reference model and the level of elaboration present within a shared scope by considering the number of architectural components present in each model.

Complexity (or the perception of complexity) appears to be generated by three factors working in combination:

variety, connectedness and disorder [15]. The authors considered structural connectedness to assess architectural complexity and deliver an objective measure of architectural components linkage of a model. Structural connectedness aims not to provide an indicator of the complexity of implementation but rather identify which models have a ‘systemic’ view for their requirements definition. By linking components models are explicitly integrating components rather than listing requirements.

The best practices models mapping technique mentioned in section 2 enables the identification of a shared scope between two models. We developed our approach to compare models at a quantitative level based on this technique and defined the concept of elaboration of descriptions to compare the detail of shared content.

The next sub-sections formalize our method of measuring size and complexity of best practices models, detailing the initial approach proposed in [6].

A. Mapping models

The goal of mapping a model to another is to identify similarities and differences of models content. Figure 1 represents two models being mapped, a mapped model (M_p) and a reference model (M_r). Area 2 represents the similarities or shared scope and area 1 the differences resulting from the mapping exercise. A typical mapping focuses on finding the shared scope of M_r and M_p (area 2 in Figure 1) no special attention is given to area 1 and area 3. We believe it is possible to obtain extra information by extending the analysis to areas 1 and 3 and consider the dimension of elaboration of descriptions on the shared scope (area 2). A quantitative analysis of models size is possible by relating areas 1, 2 and 3, and considering differences in the level of information present in the shared scope.

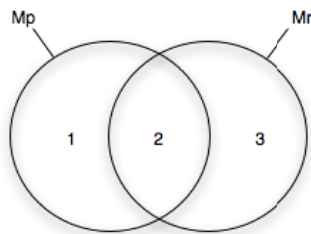


Figure 1 - Mapping Models

A mapping process requires two models and a mapping function. A model is chosen to be the reference model M_r and the other to be the mapped model M_p . In a mapping process the scope of the mapped model M_p is analysed for coverage by establishing a mapping between architectural component of the mapped model and the reference model M_r . An example may consider the reference model CMMI and the mapped model ISO9001. The mapping identifies the ISO9001 requirements coverage that is attained if an existing CMMI model is in place. The mapping function F establishes a relation between architectural components of

M_r and M_p . It is important to notice that no assessment for coverage of the reference model is being considered. In fact, the total scope of the reference model is not evaluated in this setting, it provides only the reference base to which overlapping and gaps are identified against the mapped model.

As mentioned earlier, models use components to define the scope of their content descriptions and a hierarchical relation is established to provide a progressive level of detail in descriptions. The mapping function F is defined to compare architectural components scope at specific levels of detail. Figure 2 depicts this relation of the mapping function. In a mapping process the mapping function characterizes the level of scope shared between model components. Coverage is established at L_{Px} of M_p to a level L_{Ry} of M_r , where $x \in [0, N_x]$ and $y \in [0, N_y]$ and N_x and N_y are the number of elaboration levels present in M_p and M_r , respectively.

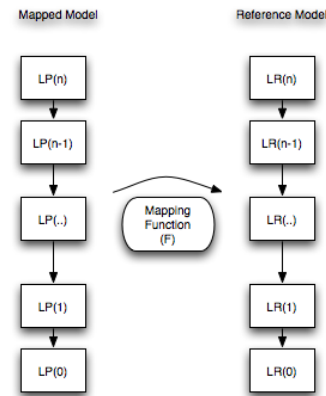


Figure 2 – Model Elaboration Hierarchy

B. Model Size

Models used in the Software Engineering Domain vary in the scope they cover and the level of elaboration they use in their descriptions. One may argue that ISO9001 is broader and less detailed than CMMI or that CMMI is broader than ISO15939 [16] but the latter is more detailed than CMMI. Narrowing the scope often results in increased detail of descriptions. Increased detail is achieved by using a greater number of components at a similar level of elaboration or further elaborating by creating new levels of elaboration. An objective measurement of this perception would help to clarify the subjective nature of these assertions.

Defining an elaboration hierarchy of model descriptions (relating model architectural components) provides the scope boundary crucial for performing an evaluation of shared scope and level of detail in descriptions.

As stated previously, comparing models scope size requires the use of a normalizing size reference. Effective comparison implies that a shared characteristic is found to derive a relative measure of size. Scope shared will provide

the link to objectively compare scope's size and the scope of the reference model will be used for this purpose. The number of architectural components, at specific levels of elaboration, covering a shared portion of scope will be used to measure detail of descriptions.

The following concepts are relevant to characterize the attribute of size of a model.

1) Shared Scope

Scope shared is a measure of the degree of coverage of the mapped model M_P relative to a reference model M_R . It can be expressed using the following notation:

$$(M_P, M_R, \varphi), \forall \varphi \in [0,1] \text{ in } \mathcal{R} \quad (1)$$

The coverage factor φ is the result of a mapping performed at a chosen level of granularity, e.g. ISO9001 is covered by a factor of φ by CMMI when *shall statements* are compared to CMMI *practices* or, considering as reference a full implementation of CMMI, one can attain φ coverage of ISO9001 requirements. The following concepts are enunciated regarding scope coverage.

Mapping function. A coverage function F establishes the degree of coverage between a pair of models components. It receives as input a component element C_R of M_R at a desired level of elaboration L_{Ry} and a component element C_P of the mapped model M_P at the desired level of elaboration L_{Px} .

$$\varphi = F(C_P, C_R) \quad (2)$$

The mapping function often assumes the use of a categorical ordinal scale that characterizes the level of coverage that one component has over the mapped component. The scale can be recoded to assume values that translate the meaning of each category into a discrete numeric scale, where the recoded φ assumes values between $[0,1]$ where 0 represent no mapping and 1 a total map.

Component mapping. A component C_i of a model M_P at a desired level of granularity L_{Px} is compared using a mapping function F to every component C_j of M_R at the desired level of detail L_{Ry} .

$$(C_i, C_j, \varphi_j), i \in [0..nx] \text{ and } j \in [0..ny] \quad (3)$$

where nx is the number of components of M_P at L_{Px} , ny is the number of components of M_R at L_{Ry} and φ_j is the coverage factor resulting from applying F . The value of φ_j is the coverage obtained for C_i of M_P by each C_j of M_R .

Component coverage. A component is covered if exists at least one component in M_R that shares some scope with a component of M_P otherwise is not covered. The highest value obtained in a mapping is the maximum coverage obtained for that component of M_P considering all

components of M_R . Thus, a component C_i of a model M_P is said to be covered by M_R by a factor of φc if, $\exists C_j \in M_R$ that:

$$(C_i, C_j, \varphi_j), \varphi_j > 0 \quad (4)$$

and $\varphi c = \max(\varphi_j), j \in [1..n]$ where n is the number of elements that satisfy (4) for each C_i .

Scope coverage (Sc) of a mapped model M_P . The shared portion of the mapped model is obtained by identifying architectural components with shared scope. These include components that satisfy $\varphi c > 0$ in (4).

$$Sc = \frac{\sum_{i=1}^n \varphi c(i)}{n * \varphi(max)} \quad (5)$$

In (5), n is the total number of component maps considered in the mapping and $\varphi(max)$ is the maximum possible coverage for each component.

Scope coverage of a reference model M_R . Concerning the reference model, it is only feasible to say that a portion of its scope is shared with the mapped model. A component of a mapped model may be covered totally by a component of the reference model, but the opposite may not occur. The reflexive property does not apply in this setting. Still, an approximate measure of scope coverage can be derived considering the cardinality of the set of components present in the mapping, where:

$$\theta = N/N_t \quad (6)$$

where, N is the number of components of M_R at L_{Ry} referenced in the mapping process, N_t is the total number of components of M_R at L_{Ry} and θ is the reference factor.

2) Elaboration of descriptions

Elaboration of descriptions uses a measure of the number of architectural components of M_R that are referenced in the mapping process for a scope bounded by each architectural component of M_P e.g., a requirement from ISO9001 maps to x practices of CMMI. The level of elaboration of a component C_i from M_P regarding M_R is given by the cardinality βi of the set of components S_R from M_R that satisfies the condition in (4), where, n is the number of components of M_P at L_{Px} .

$$(C_i, \beta i, S_R), i \in [0..n] \quad (7)$$

Elaboration of descriptions of M_P (Mpd) is given by the central tendency mean of frequencies of βi (n is the number of components of M_P at L_{Px} , f_i is the number of occurrences of each different group of βi and f_t the total number of occurrences of f_i 's)

$$Mpd = \frac{\sum_{i=1}^n \beta i * f_i}{f_t} \quad (8)$$

Values of β in (7) vary from zero, indicating that a mapped component with any degree of coverage is absent of M_R . The opposite extreme case occurs when a component maps to all components of M_R . Large values of β indicate significant differences in the elaboration of descriptions for a shared scope.

The inverse relation is also considered for the mapped components of M_R . It measures the cardinality of the set of components C_i of M_P that reference a component C_j of M_R . The relation is expressed as follows: the level of elaboration of a component C_j of M_R regarding M_P is given by the cardinality γ_j of the set of components C_i from M_P that satisfies (4).

$$(C_j, \gamma_j), j \in [0..n] \quad (9)$$

In (9), n is the number of components of M_R at L_{Ry} . Elaboration of descriptions of M_R (M_{Rd}) is given by the central tendency mean of frequencies of γ_i , where n is the number of components of M_R at L_{Ry} , f_i is the number of occurrences of each different group of γ_i and f_t is the number of total occurrences of f_i 's.

$$MRd = \frac{\sum_{i=1}^n \gamma_i * f_i}{f_t} \quad (10)$$

The difference of elaboration in models descriptions is given by the elaboration factor (E_f):

$$E_f = \frac{MPd}{MRd} \quad (11)$$

When E_f approximates 1 it indicates the overall shared scope is described on average by the same number of architectural components at the chosen level of granularity. It is expectable that, in the assumption of similar levels of detail not every component map translates to a one to one relation, some variation may occur. But, if the level of elaboration is similar between models both measures are expected to have the same order of magnitude on an average case. Values greater than one indicate that M_P is less elaborated than M_R for the shared scope at specific levels of elaboration. Values inferior to one indicate more elaboration in M_P .

The notion of balance in elaboration of descriptions for a shared scope is given by the value of standard deviation for (8) and (10). High values indicate considerable differences in elaboration of descriptions when describing specific subjects within a shared scope. We aim to capture this intuition for values of (7) and (9) and evaluate homogeneity between models descriptions.

C. Complexity

In order to establish a measure of model complexity we considered structural connectedness. Every model has its component structural variety, with explicit connections

between defined components. Structural connectedness considers any reference that an architectural component has by definition to any other architectural component of the same type. Connectedness as a complexity characterization aims to measure the number of internal links that models have in their descriptions. These links are associated with information flow between architectural components and provide a measure of structural intra-dependence. Structural connectedness ($StrC$) is defined as:

$$StrC = \frac{n}{N*(N-1)} \quad (12)$$

where, N is the number of architectural components in the model and n is the number of unidirectional references between architectural components.

In this perspective complexity will measure architectural component interconnectedness of a model. If models are used to define systems of processes as result of tactical composition of model as enunciated in [17], an analysis of the level of interconnectedness in the model is relevant to inform a composition and integration effort or to assess component intra-dependence of an existing system of processes.

The next section describes the applicability of this method to support the design and evolution of a multimodel process quality management system.

IV. MEASURING SIZE AND COMPLEXITY

Critical Software S.A (CSW) is a Portuguese software house that recently achieved a CMMI maturity level 5 rating. CSW has a multimodel Quality Management System (QMS) that complies with standards like ISO9001, Allied Quality Assurance Publications (AQAP), ISO12207, ISO15504 and CMMI.

As a former CMMI level 3 organization, an analysis gap to bridge level 3 to 5 was performed to identify the necessary changes to implement level 5 requirements. Bridging the gap required an evolution of the existing QMS to include new practices. Having a multimodel process solution we needed to identify the set of QMS practices already implemented that could relate to required practices of CMMI Level 5.

Figure 3 depicts the exercise carried out to identify gaps between the QMS (CMMI level 3 compliant) and CMMI level 5.

We performed a map between the QMS and ISO9001 and CMMI level 5. In order design and implement new practices we were interested in understanding also how ISO9001 related to CMMI level 5. We needed to harmonize or reconcile these models before architecting new practices for the QMS. This need motivated the development of our approach to map models at a quantitative level and use it to compare ISO9001 and CMMI.

The process of deriving the relative size of a model described next was used to, firstly: compare size and complexity of ISO9001 and ISO12207 and improve our

understanding on how these models relate to CMMI. Secondly, compare ISO15288 with CMMI as an exercise of applicability of the approach for comparison purposes with aforementioned ISO models.

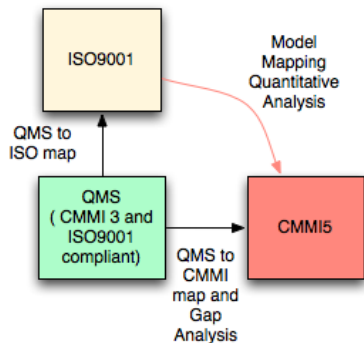


Figure 3 - QMS and Model Mappings

As stated in section 3, our approach for comparing prescriptive models is supported in the models mapping technique. In a mapping technique, three factors may influence the result of the final model coverage, namely: the mapping function chosen to carry out the mapping, the subjectivity of the author evaluation and, when considering a pair of models, the level of elaboration chosen to apply the mapping function also influences the result of the coverage. In order to control these variables and have a meaningful comparative scenario, three mappings provided publicly by Mutafelija and Stronberg [13] [18] [19] were used to perform the quantitative analysis. The mappings were performed by the same authors and applied the same mapping function. The third aforementioned factor does not apply in our experimental setting (this implied having mappings of two models with maps at different elaboration levels). An architectural analysis of models considered is described next.

The central architectural component in CMMI is the *process area*, it groups related practices that together help achieve a set of goals that are important to implement with success the respective process area. Process areas are grouped using *maturity levels* or *process categories*. Each process area is elaborated using *goals* which can be *specific* or *generic*. Each specific goal is detailed using *specific practices*. For each practice, further detail is given in the form of *typical work products* and *sub-practices*. Generic goals and associated practices follow the same configuration, but apply to all process areas and are denominated institutionalizing practices.

ISO12207 central component is the *process*, grouped into two major *divisions*. These two divisions are further divided into 7 *sub-divisions* of groups of processes. For each sub-division process descriptions are proposed. Each process description defines the *scope*, *purpose*, *outcomes* and *activities*. Each activity is detailed using *tasks*. ISO15288 uses the same structure of ISO12207 but one division is suppressed. An additional difference between these models is the use of *shall statements* in ISO12207 to mark standard requirements, which is absent in ISO15288.

ISO9001 focus its content on *requirements* to be met during appraisals. These are to be met by organizations for standard conformance. The standard uses what could be characterized as a decomposed requirement structure. It evidences five levels of elaboration. Requirements are grouped in *categories*. These categories define the scope of requirements that are detailed using *requirement items*. Each item is elaborated using textual descriptions in the form of *shall statements*. These can assume the form of *shall clauses*. Shall statements are the core architectural component of ISO9001 standard.

The following procedure describes the steps required to compare size of considered models. The first four items refer to the mapping steps, the remaining refer to the quantitative analysis steps.

- i. The process of computing size of a model begins by identifying the models to be considered for comparison. One of the models is chosen to be the reference model (M_R) and the other the mapped model (M_P).
- ii. For each of the models an elaboration hierarchy is defined.
- iii. A coverage function (F) is then defined using a coverage scale to map models components at specific levels of elaboration.
- iv. The mapping process is carried out and scope coverage is obtained for each component using criteria described in (2).
- v. With the mappings available, the scope shared and component coverage is obtained using (1), (4) and (5).
- vi. Scope coverage indicator of the reference model is obtained using (6)
- vii. Elaboration factor is calculated using (7), (8), (9) and (10).

A. Size: Scope Shared

We computed the shared scope between ISO9001 and CMMI and repeated the process for ISO12207 and ISO15288. As an example, the shared scope calculation is described next for ISO9001 and CMMI.

We first computed the component coverage for each ISO9001 requirement keyword (shall statement) map. Table 1 shows a partial table of the mapping available in [13]. Table 2 shows the results of computing $\varphi_c = \max(\varphi_j)$ using (4). For each requirements keyword in Table 1 the maximum coverage is determined considering each map established, e.g., Establish QMS requirement maps to 29 CMMI practices (22 practices correspond to one generic practice of all 22 process areas and an additional 7 practices from 2 specific process areas) with a maximum coverage of 100 for each CMMI practice, fully covering the ISO requirement statement. The result of this calculation is depicted in Table 2 for each requirement map in Table 1.

With all values computed for individual component coverage the mapped model coverage is obtained computing (5). Each value in the *coverage* column of Table 2 is added

and then divided by the number of architectural components multiplied by the maximum coverage for each component. Using notation in (1), shared scope for ISO mappings and CMMI is, (see also Figure 4): (ISO9001, CMMI, 0.83), (ISO15288, CMMI, 0.77), (ISO12207, CMMI, 0.74).

Scope coverage indicator of the reference model

An additional calculation was performed to have an indicator of the shared scope of the reference model, in this case CMMI. The indicator translates a measure of the percentage of CMMI scope that is addressed by ISO9001.

Sect.	ISO 9001:2000 Requirement Keywords	CMMI PAs	CMMI Practices	Conf
4	Quality management system			
4.1	General requirements			
	Establish QMS	All PAs OPD OPD OPD OPF OPF OPF OPF	GP 2.1 SP 1.1 SP 1.2 SP 1.3 SP 3.1 SP 3.2 SP 3.3 SP 3.4	100 100 100 100 100 100 100 100
	Identify processes	OPD	SP 1.1	100
	Determine sequence	OPD	SP 1.1	100
	Effective operation	OID OPF	SP 2.1 SP 3.3	30 30
	Resources	All PAs	GP 2.3	100
	Monitor processes	All PAs All PAs	GP 2.8 GP 2.9	100 100
	Implement actions	OPF OPF	SP 2.1 SP 2.2	100 100
	Manage using ISO standard	All PAs	GP 2.1	60
	Control outsourced processes	SAM SAM SAM	SP 1.3 SP 2.1 SP 2.2	100 100 100
	Outsourced process control in QMS	SAM SAM SAM SAM	GP 2.2 SP 1.3 SP 2.2 SP 2.3	100 100 100 100

Table 1 - Component Mapping (ISO9001 to CMMI)

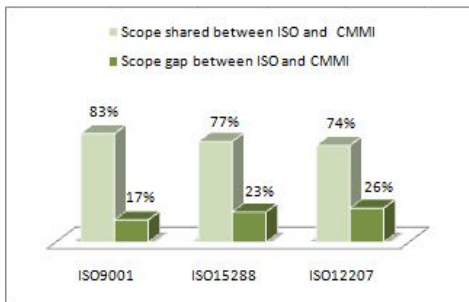


Figure 4 - Coverage of ISO standards by CMMI

We defined two groups of CMMI practices, the first with practices referenced in the ISO mappings with a shared scope ($\varphi_j > 0$ in (3)) and a second group of practices with no reference ($\varphi_j = 0$ in (3)). Table 3 shows an example of this exercise for the CMMI Requirements Management Process Area (PA).

In the Reference column of Table 3 a value of 1 indicates the practice is referenced by a shall statement of

ISO9001 and a value of 0 indicates that no reference exists. This exercise was replicated for all 22 PAs of CMMI. We used (6) to obtain an indicator of scope shared with CMMI, using the number of elements of the first group as N in (6) and the total number of practices as Nt in (6) by adding elements of the first and second groups. This calculation was replicated for ISO12207 and ISO15288 mappings.

ISO9001:2000 Requirement Keywords (Ci)		Coverage max(φ_{ij})	Number of CMMI associated practices
4.1 General requirements	Establish QMS	100	29
	Identify processes	100	1
	Determine sequence	100	1
	Effective operation	30	2
	Resources	100	22
	Monitor processes	100	44
	Implement actions	100	2
	Manage using ISO standard	60	22
	Control outsourced processes	100	3
	Outsourced process control in QMS	100	4

Table 2 - Component Coverage Table

The results show that in ISO9001 to CMMI map, 68% of overall CMMI practices are referenced in the mapping and a total of 88% under the scope of a maturity level 3 scenario (see Figure 5). ISO15288 map references 53% of total CMMI practices against a 66% of practices under a maturity level 3 scope. ISO12207 map references 56% of all CMMI practices and 72% of practices under a maturity level 3 scope.

We considered also how ISO models are referencing generic practices (GP) and specific practices (SP) practices, separately. ISO9001 map establishes references to 88% and 82% to GPs and SPs, respectively (see Figure 6). In ISO15288 map a total of 53% and 80% practices are referenced, respectively. For ISO12207 a total of 61% and 77% practices are referenced, respectively. The scope of GP's considered is bounded for a Capability Level 3 as no references for level 4 and 5 GP's occurs in any of the maps considered.

B. Size: Elaboration of Descriptions

To understand the difference in elaboration or detail of descriptions we computed (7) for each shall statement in ISO9001 to CMMI mapping and the opposite relation for each CMMI practice, using (9).

Figure 7 shows that exists a single occurrence (y-axis) of a shall statement making reference to a group of 67 CMMI practices (x-axis) and that exists 57 occurrences of a shall statement making reference to a single CMMI practice. Figure 8 shows the opposite relation. Two occurrences of a CMMI practice referenced by a group of 12 shall statements and above 80 occurrences of a CMMI practice referenced by a group of single shall statements.

PA	Goal	Practice	Reference
Requirements Management Process Area	Specific	1.1	1
		1.2	1
		1.3	1
		1.4	1
		1.5	1
	Generic	1.1	0
		2.1	1
		2.2	1
		2.3	1
		2.4	1
		2.5	1
		2.6	1
		2.7	1
		2.8	1
		2.9	1
2.1	1		
3.1	1		
3.2	1		
4.1	0		
4.2	0		
5.1	0		
5.2	0		

Table 3 - Generic and Specific Practices Referenced by ISO

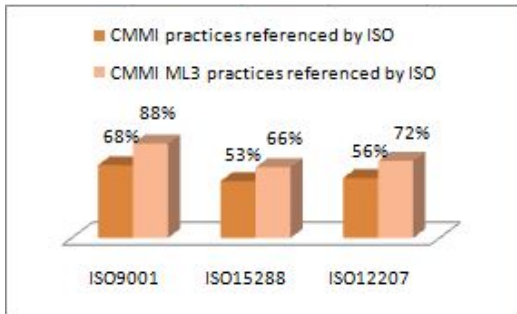


Figure 5 - CMMI Practices Referenced in the Mapping Process.

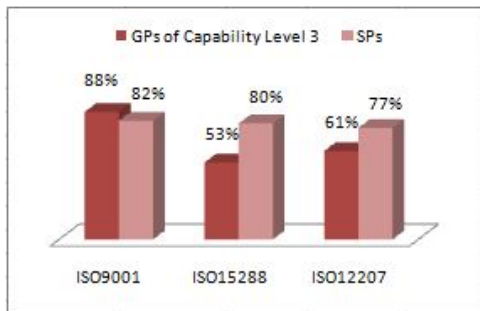


Figure 6 - CMMI GP and SP Referenced by ISO Standards

Computing (8) and (10) based on the frequency analysis we obtain the central tendency of architectural components referenced for each model. The values are summarized in Figure 9 with values of E_f applying (11).

An average value of 7 CMMI practices are referenced by each shall statement with 10.2 units of standard deviation. Conversely, each CMMI a practice is referenced by an average of 3.6 shall statements with 2.5 units of standard deviation, with an E_f of 1.95. ISO15288 tasks make reference

on average, to 3 CMMI practices with 5.4 units of standard deviation and each CMMI practice is referenced, on average, by 2.1 tasks with 1.5 units of standard deviation, resulting in an E_f of 1.38. Thirdly, ISO12207 shares, on average, each task scope with 3.2 CMMI practices with 6 units of standard deviation. Each CMMI practice is referenced on average by 2.7 tasks with 2 units of standard deviation. This leads to a 1.16 elaboration factor between ISO12207 and CMMI.

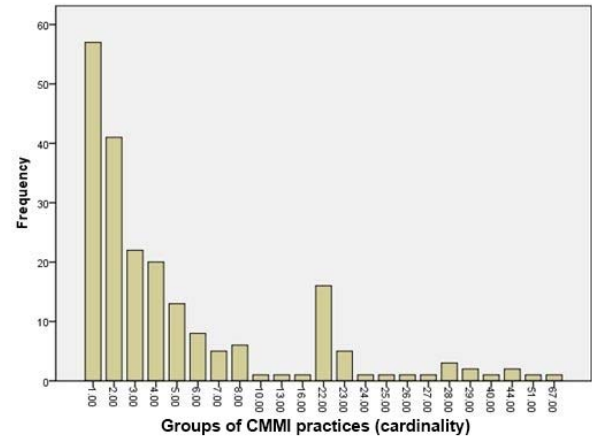


Figure 7 - Frequency Analysis of Shall Statements Referencing to CMMI Practices

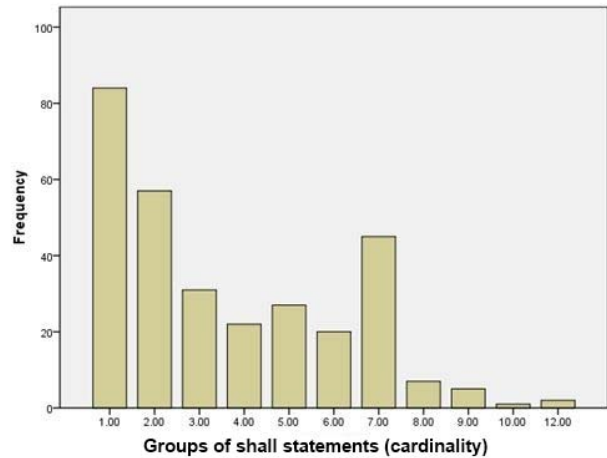


Figure 8 - Frequency Analysis of CMMI Practices Referenced by Shall Statements

C. Complexity: structural connectedness

Both ISO12207 and CMMI define explicit links at process level. ISO15288 has no inter-process or any other type of internal references. For ISO12207, internal references origin at the task level but the ending reference is a process architectural component. For simplicity and not jeopardizing the semantics of the connection defined, when links are established from task to process it will be considered the process to which task belongs, resulting in process to process link.

A similar scenario occurs in ISO9001, it defines internal links that originate at shall statement level but reference an ending requirement item. It will be considered a link between the originating item requirement that has a shall statement referencing another item requirement. Table 4 show a reference matrix elaborated to identify and count the number of links between CMMI PA's. Figure 10 depicts the values obtained using (12) for each of the models considered (each value is multiplied by a factor of 100 for readability).

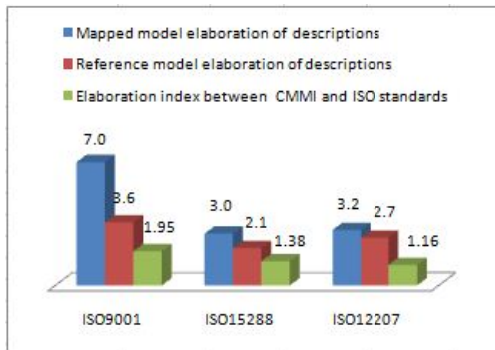


Figure 9 - Elaboration Factor between ISO Standards and CMMI

V. DISCUSSION OF RESULTS

Our study helped to understand that there is a significant (above 74%) shared scope between the mapped models and CMMI (Figure 4). The majority of ISO9001 requirements out of scope of CMMI are relative to the ISO clause Control and monitoring of measuring devices that justifies 50% of scoped out shall statements mapped to CMMI (area 1 in Figure 1). The majority of tasks out of scope in ISO15288 are relative to the Operation Process tasks fulfilling 33% of total task not addressed by CMMI. The remaining are associated with single tasks spread across other processes. In ISO12207 about 50% of scoped out tasks relate to the Software Operation Process and Software Reuse Process areas.

The analysis of scope coverage of the reference model showed that high maturity practices of CMMI are poorly addressed by ISO standards (Figure 5). Generic Practices of high maturity levels (level 4 and 5) of CMMI are completely out of scope of ISO standards. Also, four PAs of CMMI level 4 and 5 are significantly out of scope of ISO12207, scoring below 25% on referenced practices with the Causal Analysis and Resolution (CAR) process area totally absent of ISO12207. A similar scenario occurs in ISO15288 with three of the high maturity PAs with less than 40% referenced tasks and with Organizational Innovation and Deployment PA referenced only at 7%.

Additionally, from the data is possible to evidence higher similarity in terms of scope between ISO9001 and CMMI when compared to the other ISO standards considered (Figure 6). ISO9001 shall statements make reference to 88%

of practices of CMMI maturity level 3, scoring higher than ISO15288 and ISO12207. It also seems to be more balanced when considering GP's and SP's. ISO9001 covers both SP's and GP's in a similar degree with 82% and 88% of practices referenced, respectively. The other ISO standards are significantly less oriented to cover GP's. Two process areas of CMMI are completely absent of ISO9001: CAR and Decision Analysis and Resolution.

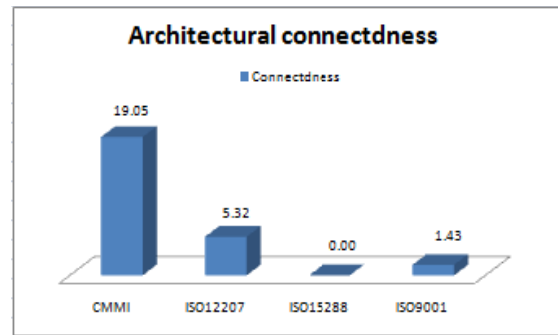


Figure 10 - ISO and CMMI Structural Connectedness

Maturity Level	REQM	PP	PMC	SAM	MA	PPQA	CM	RD	TS	PI	VER	VAL	OPF	OPD	OT	IPM	RSKM	DAR	DEP	OPM	OID	CAR	
REQM	REQM																						
PP		PP																					
PMC			PMC																				
SAM				SAM																			
MA					MA																		
PPQA						PPQA																	
CM							CM																
RD								RD															
TS									TS														
PI										PI													
VER											VER												
VAL												VAL											
OPF													OPF										
OPD														OPD									
OT															OT								
IPM																IPM							
RSKM																	RSKM						
DAR																		DAR					
DEP																			DEP				
OPM																				OPM			
OID																					OID		
CAR																						CAR	
	6	9	7	1	0	4	8	0	1	5	3	2	0	1	3	5	5	2	3	3	1	88	

Table 4 - CMMI Process Area Reference Map

Concerning elaboration of descriptions (E_f values), we may argue that CMMI, within the shared scope, is more detailed than any of the model considered in the mappings (Figure 9). Comparatively, ISO9001 is less elaborated followed by ISO15288 and thirdly ISO12207. The measures of E_f seem to translate the intuition that ISO9001 being a general purpose standard is less elaborated. Also, ISO12207 could be considered the most similar model to CMMI with a smaller E_f value, indicating the level of information describing the shared scope is somehow similar. Finally, within the shared scope, ISO9001 is more heterogeneous in addressing elaboration of requirements comparatively to ISO12227 and ISO15288 tasks. The values of standard deviation indicate that subsets of requirements are considerable less elaborated then others. This variation is less significant in the other ISO standards.

Links between architectural components in model descriptions provide information to guides the development

and implementation of process architectures. On this subject the differences between models are considerable. CMMI is the only model that includes in its structure an architectural component to define links between process areas. ISO standards establish links when these are considered convenient, but the approach is not systematic as in CMMI. The result is that CMMI is more informative on this matter, delivering relevant information to guide the development of systems of processes.

VI. CONCLUSION

In this paper we proposed an approach to measure size and complexity of best practices models in a context where selection and composition of models can benefit from explicit insights in terms of size and complexity. Our approach is based on the models mapping technique to compare models. We extended the level of information that can be derived of a mapping exercise by defining a method to have a quantitative analysis of models size. We also considered structural connectedness to assess model complexity.

We used the method to deliver a quantitative analysis of models that target or are being used in the Software Engineering domain. CMMI-Dev, ISO12207 and ISO15288 emphasis is on life cycle processes, ISO9001 focus on governance and requirements for a quality management system. This exercise of measuring size and complexity was motivated by the need to evolve a multimodel quality management system of a Portuguese software house, bridging the gap from CMMI-Dev level 3 to level 5. We needed to understand gaps and overlapping between CMMI-Dev level 5 with ISO9001 and ISO12207. Our analysis revealed that ISO standards share a high percentage of scope with CMMI-Dev and CMMI-Dev is well ahead of ISO standards in terms of prescribing relations between architectural components.

As part of an organizational process improvement group we used the quantitative information derived from applying the method to develop a clear understanding into models similarities and differences. We felt the model mapping technique did not deliver a simplified view on contributions of models of interest to the organizational system of processes. It also provided quantitative information of the impact of evolving the system of processes to CMMI-Dev level 5 in the remaining supported models. This was possible by quantifying how much the change impacted the percentage of scope covered of several supported models. Additionally, a more insightful view on which models are influencing which areas of the system was obtained using the details of descriptions size perspective.

This approach can be used by improvement groups to develop a quantitative analysis of model comparisons and justify their adoption and evolution with quantitative information. Additionally, for Standard Bodies and Organizations prescribing best practices models allows building comparative quantitative charts of their models, which may be used to evolve or reconcile content with other models.

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