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Investigation Correspondence between CMMI-DEV and ISO/IEC 15504

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***Abstract*—**CMMI and ISO/IEC 15504 are two main models for software process assessment and improvement. Both models have staged and continuous representations but these are different. Continuous representations of the models propose the different sets of processes (process areas). The differences of staged representations are even more essential. CMMI staged representation is based on the ideas of a classic staged maturity framework with 5 levels introduced by W. S. Humphrey back in 1988. ISO/IEC 15504, formerly known as SPICE, has promoted a continuous model for process capability assessment. However, not long ago SPICE community recognized the benefits of a staged representation. As a result, the organizational maturity framework with 6 maturity levels has been introduced in ISO/IEC 15504-7:2008. This paper investigates relationship between CMMI-DEV and ISO/IEC 15504 maturity levels and processes capability profiles. It presents the mapping approach and ISO/IEC 15504 processes capability profiles as well as maturity levels ensured by all CMMI maturity levels. Also reverse mapping is performed and CMMI processes capability profiles and maturity levels ensured by all ISO/IEC 15504 maturity levels are presented.

***Keywords*—**CMMI, ISO/IEC 15504, models mapping, organizational maturity, processes capability profile.

I. Introduction

Most software development projects face the following problems: projects are delayed; they overrun budget; and/or customers are dissatisfied with the quality of the software delivered. This phenomenon is so widespread that it is even being named as a software crisis [1]. Almost twenty years ago it was understood that there is no silver bullet for the solving of software related problems [2] and the research emphasis was shifted to organizational and methodological matters.

Software process engineering is accepted as a most achieved software engineering area during last decade. Investigations in software process maturity provided a deep insight into software activities and introduced various software process models which helped assess and improve both software process capability and maturity of organization producing software.

The research achievements are noticeable but the problems of the software projects are still very actual and sharp. Organizations seek to benefit from different process models that stimulate harmonization of different models and investigation of process improvement in multi-model environments [3, 4, 5 and 6].

There are introduced various process models [7, 8, and 9] emphasizing different aspects but evolution of general software process models has stabilized two main frameworks widely known as CMM and SPICE with their current revisions: CMMI and ISO/IEC 15504. These two models are prevalent and the most important worldwide [10, 11]. ISO/IEC 15504 is of an international standard and CMMI has become a standard "de facto. The same occurs in Lithuania. Software companies, as a rule, select CMM/CMMI [12, 13] when government supported projects promote ISO/IEC 15504 based models [14, 15].

Another reason for CMMI and ISO/IEC 15504 research relationships is that almost 10 years ago requirements for appraisal method according CMMI [16] had indicated the option of supporting the conduct of 15504-conformant appraisals but no such appraisal method has been published yet.

The purpose of this paper is investigation how these two models are related. How CMMI maturity levels can be expressed by ISO/IEC 15504 processes capability profiles and what ISO/IEC 15504 maturity level is guaranteed by each CMMI maturity level? Also reverse mapping is performed and CMMI capability profile as well as maturity level guaranteed by each ISO/IEC 15504 maturity level is determined.

II. Background and Related Works

This chapter provides the key concepts of software process models and the motivation for the mapping between the models. The research performed is presented and explained in the next chapters.

A software process model defines the standard process that provides the basis for organization's process assessment and improvement. It should ensure the usage of the same concepts, relevance with the best software engineering practices and compatibility with internationally accepted standards.

Software process modeling examines two aspects: the activities of software product development or services provision; and the soundness of how well these activities are performed, i.e. ability to meet the defined schedule, cost, scope, and quality goals.

Software process models could have either a staged and/or continuous representation.

The staged representation model is designed to provide the assessment of the maturity of an entire software process (organization). It defines the stages (maturity levels) with each serving as a required foundation for the next one. The assessment result for the organization is a single rating (maturity level) that allows comparisons among organizations.

The continuous representation model is intended for the assessment of the capability of each named process (process area), such as requirements elicitation, software design, configuration management etc. In this case, the assessment result for the organization is the processes capability profile that consists of capability levels for each named process (process area). This approach allows the selection of a set of named processes (process areas) to be improved and the order of improvements that best meets an organization's

business objectives. Though the capability of each process is assessed separately but this does not mean that processes are not related to each other and it is not possible to improve one process without improving associated processes.

Models of each representation have their own advantages. The criteria for which model should be employed should be carefully considered. The staged representation model is more suited for marketing purposes as it provides the single process maturity rating that is easy to advertise and to compare different organizations. However it is not detailed or flexible enough as it offers a solitary sequence of improvements. It also does not allow to measure software improvement in sufficient detail. This is particularly advantageous for organizations that have little or no experience in process improvement as this model provides guidance on the order of improvement. The continuous representation model provides enough detailed assessment on how well the organization's processes are performed. Although it allows the selection of its own methods of improvement, it is more complicated to compare the capability of different organizations.

All software process models summarize the best practices of software development and services worldwide. But although the source is almost the same, the resulting models are different. Therefore, organizations face the double problem of selection in that they will need to choose both the process model and the representation that is most suitable for their main goals. The solution is made further complicated because organizations want to benefit of the advantages of different models and the different representations. Therefore research that establishes the relationships between software process models and their different representations is important. Most investigations are devoted to the mapping of CMM/CMMI staged representation and SPICE/ISO 15504 continuous model as staged representation has been introduced in ISO 15504 only two years ago.

Each maturity level defines the set of key process areas to be performed. However, it is important to emphasize that this set of key process areas cannot be treated as true processes capability profile. This is because the processes performed could either be outside of the particular maturity level related activities or that some processes could have a higher capability level than required for the maturity level. Therefore, mapping of the maturity level defines minimal (necessary) processes profiles [17, 18].

An analysis of the conceptual relationship between two main software process assessment models CMM and SPICE is performed during their evolution [19, 20, 21, and 22]. Taxonomy and approaches for comparison of software process improvement models is provided in [23]. An attempt to integrate staged and continuous approaches in software process improvement is taken in [24].

The idea of establishing relations between maturity levels and processes capability profiles has been proposed in [25] that provides mapping of CMMI v. 1.1 staged representation to the draft of ISO/IEC 15504-2:1998. These relationships have been detailed in [26] by introducing achievement of capability levels expressed in grades and adjusting mapping of maturity levels 4 and 5.

The work [27] investigates relationships between continuous representation CMMI v. 1.1 and Measurement Framework defined in ISO/IEC 15504-2 and the Process Reference Model described in ISO/IEC 12207 Amd 1/2.

The current versions of the models have been investigated in [28] and the relationships between maturity levels of CMMI-DEV [29] and capability profiles of ISO/IEC 15504 [30, 31] have been established. Recently ISO/IEC 15504 has also introduced maturity levels [32].

III. Mapping CMMI-DEV to ISO/IEC 15504

A brief discussion and presentation is provided so as to understand the mapping of the models' structure.

CMMI staged representation [29] is based on classic staged maturity framework that was introduced by W. S. Humphrey in 1988 [33]. It defines 5 maturity levels: from initial (level 1) to optimizing (level 5). Each of the maturity levels (except maturity level 1) comprises a number of process areas which collectively ensures manageability and predictability of the organization process and forms a base for the next process improvement stage. Capability dimension defines 6 capability levels: from incomplete process (level 0) to optimizing process (level 5). The rating elements in the CMMI are the specific and generic goals; however, the rating of goals is performed on the basis of evidence recorded against each specific and generic practice. Therefore, the practices are "indicators" of process performance and process capability.

ISO/IEC 15504, former SPICE, has always promoted a continuous model for process capability assessment. However, not long ago SPICE community has recognized the benefits of staged representation. As a result, the organizational maturity framework was recently introduced in ISO/IEC 15504-7:2008. It should be noted that instead of classic 5 maturity levels this new framework defines 6 levels: from immature (level 0) to optimizing (level 5). Each of the maturity levels (except maturity level 0) comprises the defined process capability profile. So for the determination of an organization's maturity level, its process capability profile should first be obtained.

The same steps should be performed for mapping maturity levels: first, process capability profile corresponding maturity level should be determined then this profile should be transformed into a maturity level.

ISO/IEC 15504 model has 2 dimensions. The process dimension consists of processes and each process is defined in terms of its purpose and outcomes (i.e. results of the successful implementation of the process). Capability dimension defines 6 capability levels: from incomplete process (level 0) to optimizing process (level 5). Each capability level (except level 0) has the set of process attributes (PA) that define the particular aspects of process capability. The process attributes are defined by stating the achievements to be implemented. The process attribute of level 1 (PA1.1) requires special consideration because its single achievement is related to the outcomes defined for the process. The achievement of this attribute is measured in terms of process outcomes. Consequently, the mapping should address for each process the "process outcomes" (for level 1) and the "achievements" (for levels 2-5).

So, the specific and generic practices of CMMI process areas are mapped into outcomes and achievements of ISO/IEC 15504 processes.

Such a mapping scheme has been used in [25, 26]. It should be noted that mapping of such enough high level elements leaves too much leeway for personal judgment. Therefore, more detailed elements of the models have been examined as candidates for mapping.

Although subpractices in CMMI are informative components meant only to provide ideas that may be used for process improvement, they provide guidance for interpreting specific or generic practices. Therefore, CMMI subpractices have been included into mapping, the same as in [21]. Additionally typical work products and generic practice elaborations have been included in the mapping. An organization's processes assessment conformant ISO/IEC 15504 is based on a Process Assessment Model (PAM). Thus it has been decided to employ into mapping an exemplar PAM defined in ISO/IEC 15504-5 [25]. It expands the process definitions by including a set of base practices that serve as process performance indicators. PAM also defines a second set of indicators of process performance by associating work products with each process. The capability dimension, defined in ISO/IEC 15504-2 [24], is expanded with generic practices, generic resource indicators, and generic work product indicators. All these models elements have been included in the presented mapping.

A. CMMI-DEV Maturity Levels and Corresponding ISO/IEC 15504 Capability Profiles

The relationship between CMMI maturity level and ISO/IEC 15504 processes capability profile assumes an implication: if an organization possesses maturity level N, then processes capability profile of such organization is not "lower" than established by mapping the models.

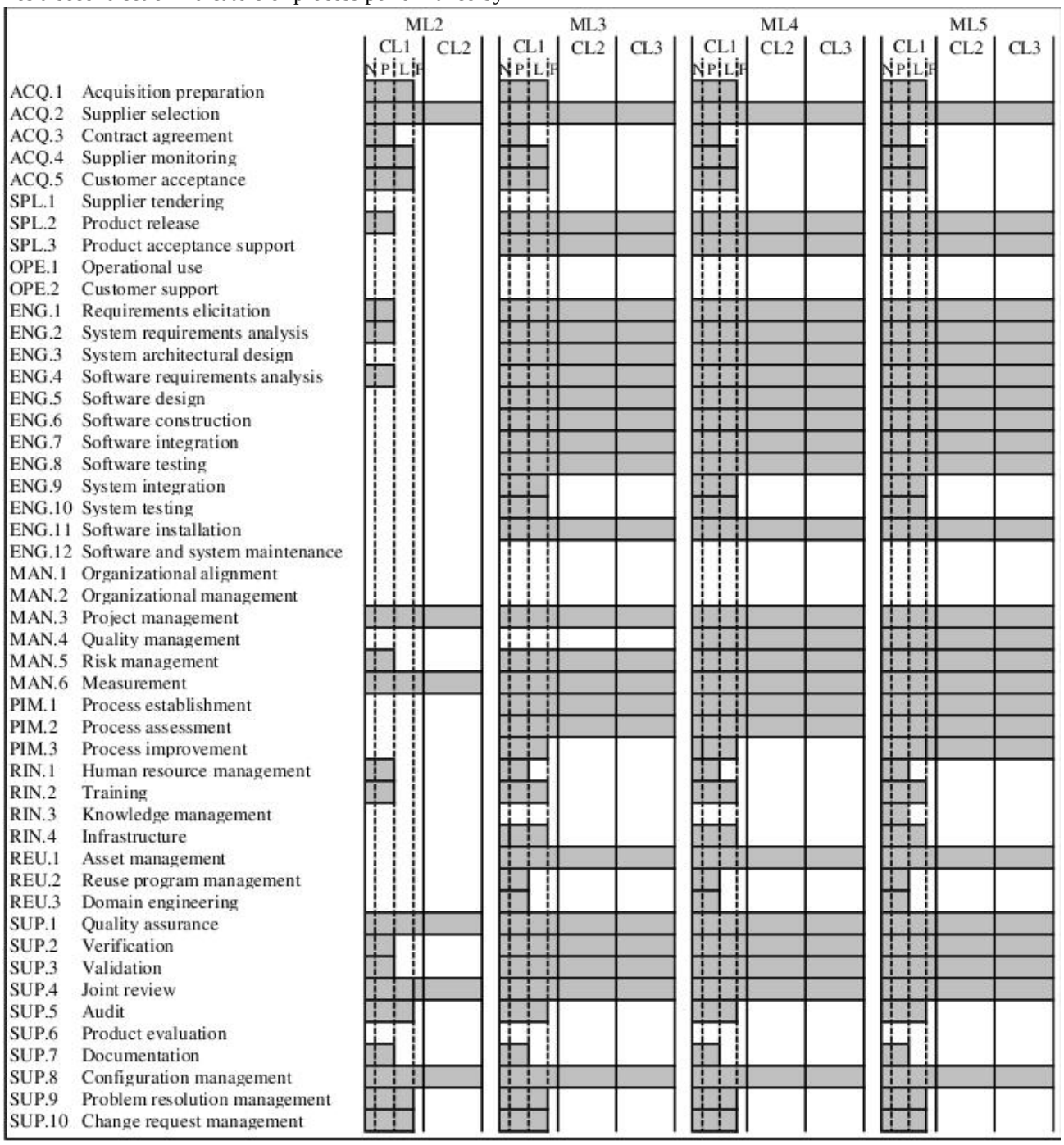

Fig. 1 ISO/IEC 15504 processes capability profiles corresponding to CMMI maturity levels

The following mapping approach has been employed:

- Informative CMMI elements are mapped into ISO/IEC 15504-5 process indicators;
- Mappings obtained are summarized at traditional mapping scheme: CMMI specific and generic

practices into ISO/IEC 15504 process outcomes and achievements;
- ISO/IEC 15504 Processes Attributes (PA) rates in percents are calculated.

Process capability levels are expressed also in grades using the scale:
- up to 15 % – N (Not performed/achieved),
- more than 15 % and up to 50 % – P (Partial),
- more than 50 % and up to 85 % – L (Large),
- more than 85% – F (Full performance/achievement).

Ratings of process attributes required for capability levels are presented in table 1.

Table 1 PA ratings for capability levels

Level	Process Attributes	Rating
1	PA 1.1. Process performance	L or F
2	PA 1.1	F
	PA 2.1 Performance management	L or F
	PA 2.2 Work product management	L or F
3	PA 1.1, PA 2.1, PA 2.2	F
	PA 3.1 Process definition	L or F
	PA 3.2 Process deployment	L or F
4	PA 1.1, PA 2.1, PA 2.2	F
	PA 3.1, PA 3.2	F
	PA 4.1 Process measurement	L or F
	PA 4.2 Process control	L or F
5	PA 1.1, PA 2.1, PA 2.2	F
	PA 3.1, PA 3.2, PA 4.1, PA 4.2	F
	PA 5.1 Process innovation	L or F
	PA 5.2 Continuous optimization	L or F

Established relationship between CMMI-DEV and ISO/IEC 15504 allows to state that if an organization is CMMI, for instance, level 2 organization then ISO/IEC 15504 processes capability profile of such organization will contain processes capability "maturity level 2" profile also this instance is the right in the reverse direction. These profiles should be treated as minimal ones, i.e. processes of the particular maturity level organization will have capability levels not lower than in the corresponding profile obtained by models mapping.

Although models mapping is not able to provide the exact ISO/IEC 15504 processes capability profile for an organization the CMMI assessment results can be used and translated into ISO/IEC 15504 assessment to avoid full reassessment.

It is important to note that CMMI and ISO/IEC 15504 do not require capability level 4 and 5 for all processes. This means that set of processes performed at capability level 4 and 5 can be introduced by organization depending on its activity and business goals. Capability level 4 and 5 are not included in corresponding capability profiles.

The resulting ISO/IEC 15504 processes capability profiles corresponding to CMMI maturity levels are presented in Figure 1: "ML2"- "ML5" are the maturity levels in the CMMI-DEV staged representation and "CL1"- "CL3" are capability levels in ISO/IEC 15504.

1) Capability profile for maturity level 2

Processes capability profile ML2 consists of 6 processes of capability level 2 and 6 processes of capability level 1. Also 12 processes are partially addressed.

It can be noticed that this capability profile includes the processes of support and management categories only. This indicates the gap or too big step in staged CMMI based process improvement. The process improvement path should explicitly include primary processes from the beginning. Such element is absent in staged CMMI improvement path – primary processes are outside of the scope of maturity level 2.

It seems that this minimal capability profile is not only necessary but also sufficient condition for maturity level 2. However, this issue requires explicit investigation to evaluate the influence of CMMI maturity level 2 items not covered in ISO/IEC 15504 model.

2) Capability profile for maturity level 3

Specific practices of maturity level 3 key process areas cover some outcomes of new processes in ISO/IEC 15504 process dimension and supplement outcomes of processes (partially) covered by specific practices of maturity level 2 key process areas.

Maturity level 3 in the staged CMMI suppose performance at this level (generic goals of maturity level 3) key process areas of both maturity levels –level 2 and 3. Generic practices of maturity level 3 ensure full coverage of attribute PA3.1. But process attribute PA3.2 is achieved by specific practices mostly.

As a result processes capability profile ML3 consists of 23 processes of capability level 3 and 11 processes of capability level 1.

3) Capability profiles for maturity levels 4 and 5

Processes capability profile ML4 additionally includes Quality management (MAN.4) process and ML5 - Process improvement (PIM.3) process also.

Because CMMI does not require capability level 4 and 5 for all process areas, an organization could select a set of processes performed at capability level 4 and 5 depending on its activity and business goals.

B. ISO/IEC 15504 Maturity Levels Assured by CMMI-DEV

The relationship between maturity levels assumes an implication: if an organization possesses maturity level N in one model, then the maturity level in another model of this organization is not "lower" than established by the mapping presented.

As it is described in the previous chapter, mapping for each CMMI-DEV maturity level has been done by the following steps:
- Informative CMMI elements of process areas assigned to this maturity level are mapped into ISO/IEC 15504-5 process indicators;
- Mappings obtained are summarized at traditional mapping level: CMMI specific and generic practices into ISO/IEC 15504 process outcomes and achievements;
- ISO/IEC 15504 Processes Attributes (PA) rates in percents are calculated;
- Process capability is expressed in grades (N – Not performed, P – Partially, L – Largely, F – Fully);
- ISO/IEC 15504 process capability profile is established;
- ISO/IEC 15504-7 organizational maturity level assured by CMMI-DEV maturity level is determined.

The results of the mapping are presented in Figure 2. ML2 - ML5 are CMMI-DEV maturity levels. CL1 - CL3 are ISO/IEC 15504 capability levels. Bold frames show the

minimum process capability profiles required for corresponding ISO/IEC 15504 maturity levels.

Although models mapping is not able to provide the exact ISO/IEC 15504 maturity level for an organization the CMMI assessment results can be translated into ISO/IEC 15504 assessment data so avoiding full reassessment.

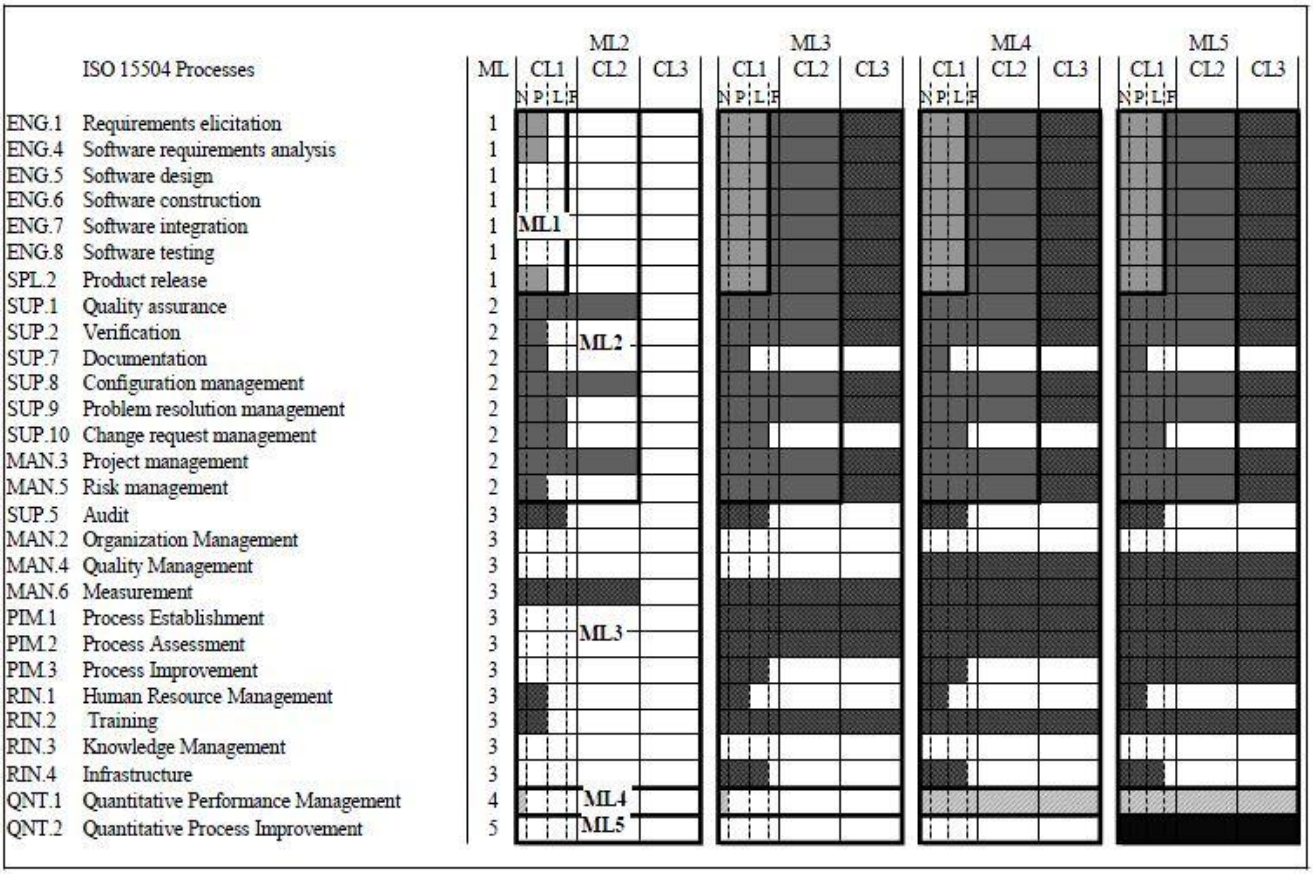

Fig. 2 ISO/IEC 15504 maturity levels coverage by CMMI-DEV maturity levels

CMMI-DEV maturity level 2 only partially addresses 3 of 7 processes forming ISO/IEC 15504 maturity level 1. So CMMI level 2 organization could be immature (level 0) according ISO/IEC 15504. It can be noted that CMMI ML2 includes the processes of support and management categories only, while ISO/IEC 15504 ML1 consists of the processes of support and engineering categories. This indicates a gap in staged CMMI based process improvement. The process improvement path should explicitly include primary (engineering) processes from the beginning.

CMMI-DEV maturity level 3 addresses the processes of engineering, management and support categories. Thus all 7 processes forming ISO/IEC 15504 maturity level 1 get capability level 3 (when only CL1 is required for ML1). ICO/IEC 15504 maturity level 2 adds 8 processes of a basic process set and requires all its processes to be performed at capability level 2. All these processes are already addressed by CMMI ML2 but even CMMI ML3 does not assure capability level 2 for all of them: Change request management gets CL1 when Documentation gets CL0. So CMMI level 3 organization has ISO/IEC 15504 basic maturity level (level 1).

Unfortunately **CMMI-DEV maturity levels 4 and 5** do not cover more outcomes of ISO/IEC 15504 maturity level 2 because they do not include the processes of the support category. Therefore they can only assure ISO/IEC 15504 basic maturity level (level 1) for an organization.

The mapping results show that the ISO/IEC 15504 scope is wider than CMMI-DEV that does not include organization management and knowledge management practices.

Audit, infrastructure, documentation, and human resource management processes are weakly addressed in CMMI-DEV: first two processes get CL1 only when the other two do not satisfy even CL1 requirements.

IV. Mapping ISO/IEC 15504 to CMMI-DEV

Reverse mappings of the models are based on the same ideas as CMMI-DEV mapping to ISO/IEC 15504.

A. ISO/IEC 15504 Maturity Levels and Corresponding CMMI-DEV Capability Profiles

The following mapping approach has been employed:

- ISO/IEC 15504-5 process indicators are mapped into informative CMMI elements;
- Mappings obtained are summarized at traditional mapping scheme: ISO/IEC 15504 process outcomes and achievements into CMMI specific and generic practices;
- CMMI-DEV generic goals ratings are determined;
- Capability levels for CMMI-DEV process areas are established.

Ratings of generic goals required for capability levels are presented in table 2.

Table 2 PA ratings for capability levels

Capability level	Generic goals	Rating
1	GG1 Performed process	Satisfied
2	GG1 GG2 Managed process	Satisfied Satisfied
3	GG1 GG2 GG3 Defined process	Satisfied Satisfied Satisfied
4	GG1 GG2 GG3 GG4 Quantitatively managed process	Satisfied Satisfied Satisfied Satisfied
5	GG1 GG2 GG3 GG4 GG5 Optimizing process	Satisfied Satisfied Satisfied Satisfied Satisfied

The goal is rated Satisfied if and only if [34]

- all associated practices are characterized at the organizational unit level as either Largely Implemented or Fully Implemented, and
- the aggregation of weaknesses associated with the goal does not have a significant negative impact on goal achievement.

Practice is rated Fully Implemented if:

- one or more direct artifacts are present and judged to be adequate,
- at least one indirect artifact and/or affirmation exists to confirm the implementation, and
- no weaknesses are noted.

Practice is rated Largely Implemented:

- one or more direct artifacts are present and judged to be adequate,
- at least one indirect artifact and/or affirmation exists to confirm the implementation, and
- one or more weaknesses are noted.

The resulting CMMI-DEV capability profiles corresponding to ISO/IEC 15504 maturity levels are presented in Figure 3: "ML1"- "ML5" are the maturity levels in the ISO/IEC 15504 staged representation and "CL1"-"CL3" are capability levels in CMMI.

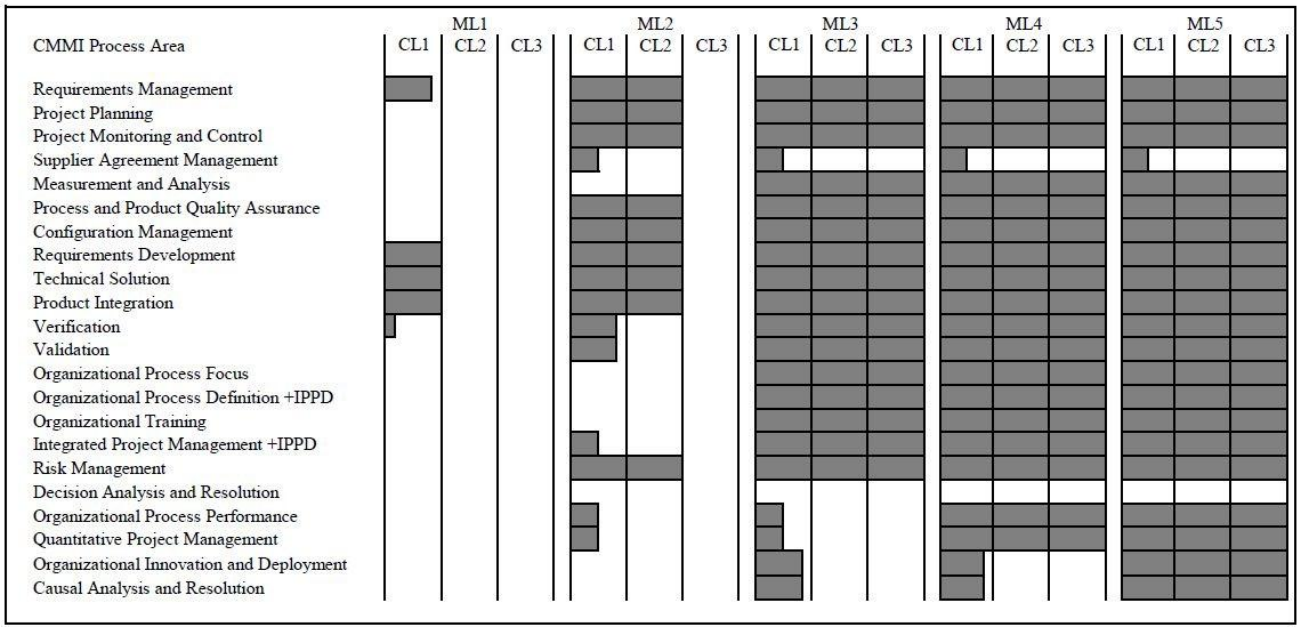

Fig. 3 CMMI capability profiles corresponding to ISO/IEC 15504 maturity levels

1) Capability profile for maturity level 1

Achievement profile ML1 consists of 3 process areas of capability level 1. Additionally 2 process areas are partially achieved their specific goals. ML1 addresses process areas of engineering category only.

2) Capability profile for maturity level 2

Achievement profile ML2 additionally includes 5 new process areas of capability level 2. Also it assures capability level 2 for Requirements Manager process area partially addressed by ML1, because its generic goals for capability levels 1 and 2 and all specific goals are rated Satisfied. Additionally 5 new process areas are partially achieved. It also addresses more specific practices of Verification process area providing rating Largely Implemented but there are some practices not addressed still. ML2 at least partially covers all process areas of project management category.

3) Capability profile for maturity level 3

Achievement profile ML3 additionally includes 4 new process areas of capability level 3. Also it assures capability level 3 for three process areas already addressed. Additionally 2 new process areas are partially achieved.

4) Capability profile for maturity levels 4 and 5

Organizational Process Performance and Quantitative Project Management process areas are assigned capability level 4 by ISO/IEC 15504 ML4.

Maturity level 5 in the ISO/IEC 15504 covers all CMMI process areas, except Decision Analysis and Resolution and Supplier Agreement Management.

B. CMMI-DEV Maturity Levels Assured by ISO/IEC 15504

CMMI-DEV maturity levels are determined from capability profiles obtained by mapping to CMMI continuous representation that has been discussed in the

previous chapter. CMMI-DEV maturity level is achieved if the capability profile is at or above the target profile for all process areas for that maturity level and all lower maturity levels in the equivalent staging.

The results of the mapping are presented in Figure 4. The bold frames show the minimum capability profiles required for corresponding CMMI-DEV maturity levels.

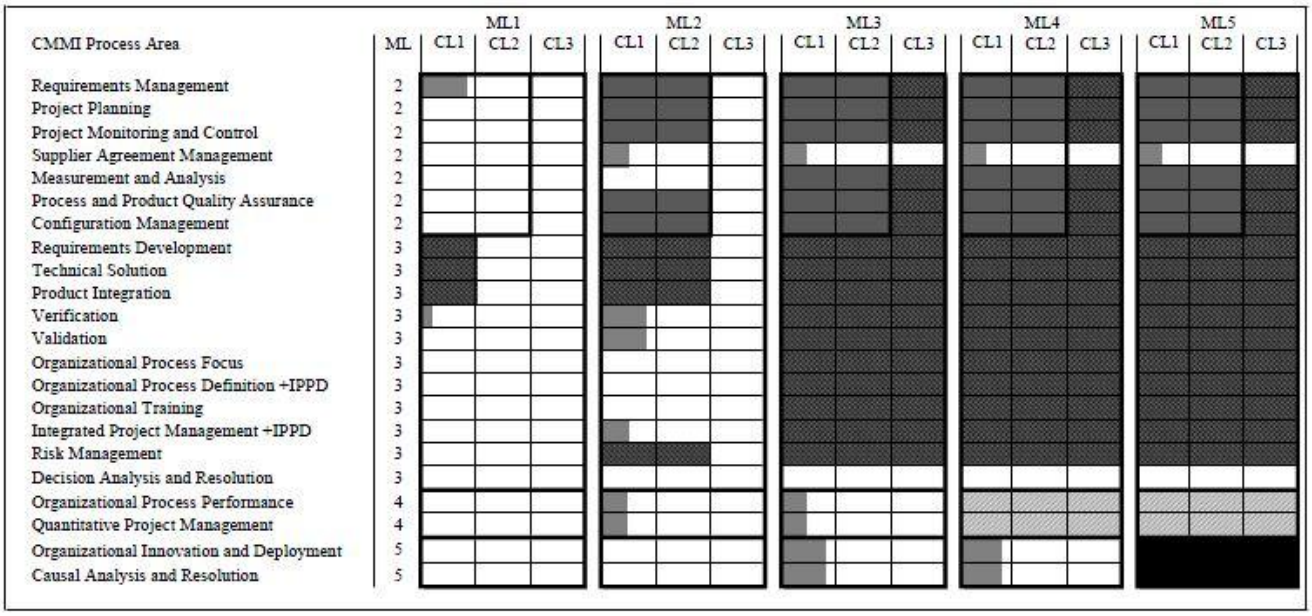

Fig.4 CMMI-DEV maturity levels coverage by ISO/IEC 15504 maturity levels

ISO/IEC 15504 maturity level 1 addresses only 1 of 7 process areas assigned to CMMI maturity level 2. So ISO/IEC 15504 level 1 organization could get level 1 according CMMI (as there are no special requirements for level 1). It should be noted that ISO/IEC 15504 ML1 assures capability level 1 for 3 engineering process areas but they are assigned to level 3 in CMMI-DEV.

ISO/IEC 15504 maturity level 2 does not assure CMMI maturity level higher than 1 because the Measurement and Analysis process area is not addressed at all. It could be noted that process areas Organizational Process Performance and Quantitative Project Management are already partially covered.

ISO/IEC 15504 maturity level 3 is treated as assuring CMMI maturity level 2 because according CMMI appraisal method [34] Supplier Agreement Management is the only process area that may be designated as not applicable. The mapping shows an evident gap in ISO/IEC 15504 process dimension: the Decision Analysis and Resolution process is not included. It should be noted that the new process model presented in ISO/IEC 12207:2008 already has a Decision Management Process. So, we assume that updated ISO/IEC 15504 will include this process and its maturity level 3 will guarantee CMMI ML3.

ISO/IEC 15504 maturity levels 4 and 5 assure only CMMI maturity level 2 because of the same reason. But adding of Decision Management Process will allow them to assure CMMI-DEV maturity levels 4 and 5 correspondingly.

V. Conclusions

This paper contributes to the software process assessment and improvement theory and practice by:

- establishing detailed ISO/IEC 15504 processes capability profiles for CMMI-DEV 1.2 maturity levels;
- establishing ISO/IEC 15504 maturity levels assured by CMMI-DEV 1.2 maturity levels;
- establishing CMMI-DEV 1.2 capability profiles for ISO/IEC 15504 maturity levels;
- establishing CMMI-DEV 1.2 maturity levels assured by ISO/IEC 15504 maturity levels;
- supporting the development of method for organization assessment results according one model translation into assessment results according other model.

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