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STASYS PELDŽIUS

SOFTWARE PROCESS ASSESSMENT USING MULTIPLE PROCESS ASSESSMENT MODELS

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VILNIAUS UNIVERSITETAS

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Introduction

Field of the research and relevance of the problem

Many software companies face such problems as projects being behind schedule, exceeding the budget, customer dissatisfaction with product quality [1]–[4]. The situation has changed in recent decades; however, the Report of the Standish Group (2013) shows that the number of successful projects is still less than one-half (39%) [5]. The share of successful projects has been constantly growing because of attempts to solve the problems of failure. At first, these problems were approached by technological means, but later it has been realised that most of the problems arise due to immature software process of the company [6].

Process assessment models are the result of customers' needs for objective criteria when selecting the most appropriate supplier. From the very beginning of the models' development, their appropriateness for process improvement has been of not lesser importance. The greater process maturity/capability, the less defects in company projects, the lower labour costs, the more precise forecast of project deadlines and the budget [7]–[11].

The most popular process assessment models worldwide are the International Standard ISO/IEC 15504 and CMMI, which has become a *de facto* standard [12]. Companies seeking wider official recognition choose between these two models. It should be noted that the choice of the model usually depends not only on the characteristics of the model itself, but also on external circumstances. For instance, a company seeking to work with US customers will certainly choose CMMI. Lithuanian companies most often choose CMMI [13], [14] because it is free and there is a large amount of additional information on its application, whereas the use of ISO/IEC 15504 is promoted in state-funded projects [15], [16] as it is an international process assessment standard.

Companies face the problem that different customers require process assessment according to different models. Therefore, it is important for companies to have an instrument that would transform company's assessment results according to one process assessment model to another model without actual reassessment each time. For instance, a company having capability assessment results according to ISO/IEC 15504 could automatically obtain its capability profiles according to the CMMI-DEV model or later (earlier) version of ISO/IEC 15504.

Object of the research

The object of the research is software process assessment and improvement using several process assessment models.

Objectives and tasks of the research

The objective of the research is to develop a software process assessment method which would allow an organisation to transform assessment results of organisation's software process capability according to a chosen assessment model into assessment results according to other process assessment models. The following tasks were solved to achieve the objective.

1. Perform case study: to develop mappings among the most popular software process assessment models.
2. Develop a method which would allow an organisation to receive software assessment results according to several process assessment models performing only single process assessment. The method should cover:
   - the methodology of including new process assessment models;
   - automated transformation of the assessment results.
3. Validate the proposed method.

Research methods

The content analysis method has been used in the dissertation for mapping of the models. Transitional process assessment model has been developed following the requirements of the International Standard ISO/IEC 15504-2. Case study transforming the assessment results of particular software development process has been used for validation of transitional process assessment model (abbr. TPAM).

Results and scientific innovation of the work

1. Established correspondence between ISO/IEC 15504-5:2006, ISO/IEC 15504-7:2008 and CMMI-DEV V1.3 models.
2. The method for transitional process assessment model development and the transformation of assessment results was proposed.
3. Transitional process assessment model, including the assessment models ISO/IEC 15504-5:2006, ISO/IEC 15504-7:2008, ISO/IEC 15504-5:2012 and CMMI-DEV V1.3, was developed.
4. Automated transformation prototype was developed, it allows storing the assessment results and transforming them into other process assessment models.
5. CMMI-DEV V1.3 and ISO/IEC 15504-5:2006 capability profiles ensured by DSDM were obtained, they provide the companies advance information about

the capability level could be ensured by implementing DSDM.

Practical application of the results

The transitional process assessment model proposed in the dissertation allows the companies in the automotive, defence, space, medical, and other industries to have assessment results according to different process assessment models by performing only single process assessment.

The presented method for TPAM development could be used developing transitional process assessment models in other domains. For example, service companies could implement a transitional model covering CMMI-SVC and ISO/IEC 15504-8 assessment models, and companies working in other areas could implement a transitional model covering Enterprise SPICE and FAA-iCMM assessment models.

The tool developed under the principles presented in the dissertation and approved in the prototype would allow the companies to receive automatically capability profiles according to several assessment models and to analyse their possible changes when improving selected processes.

Defended statements

1. Software process assessment results according to particular process assessment model could be transformed to assessment results according to other process assessment models.
2. The proposed method for the transitional software process assessment model development is suitable for developing the transitional software process assessment model covering CMMI and ISO/IEC 15504 models.
3. The method for developing the transitional software process assessment model could be applied for developing transitional process assessment models in other domains.

1. Process Assessment Models

The maturity of company's software process is directly related to the success of implemented projects and, therefore, intense development in this field of software engineering has started. Back in 1987, W. Humprey, Professor at Carnegie Melon University, proposed the idea of software process assessment and implemented it later on [17]. Process assessment is used to analyse software companies and to determine the quality of their software process. Having assessed the process, actions to improve the state of the process may be taken [18].

All software process assessment models define the best practices of software development. However, although the field of all software process assessment models is the same – software development, – the scope and framework of the models is different. Therefore, organisations face the problem of choosing the process assessment model and its representation so that the model would best meet the objectives of the organisation [19]. The desire of the organisations to benefit from the advantages of different assessment models complicates the decision even further. Therefore, a need for studies arises, which would determine the compliance of different assessment models. Most studies are carried out with CMMI staged model and ISO/IEC 15504 continuous model. However, after ISO/IEC 15504 staged model was issued in 2008, which counterbalanced CMMI staged representation, research of the former was also started [20]. In Lithuania, research in this field is also being carried out: in 2005, a project Development of Mature Software Process Implementation Methodology and Tools (PKP Branda) [13], [14], [21]–[23].

Companies desire a possibility to combine two most popular models, CMMI and ISO/IEC 15504, and, therefore, it is attempted to compare them, but there is no mapping of official process assessment results according to one model to another model [24]–[28].

The first attempts to combine CMMI and ISO/IEC 15504 assessment models were made over a decade ago. At first, the analysis was carried out whether they were compatible at all [29]. Then the analysis of their compliance was started [30]. The essential studies were carried out by T. Rout, who presented the mapping of CMMI V.1.1 maturity levels to ISO/IEC 15504-2:1998 capability profiles [31]. This compliance of models was then adjusted: the first capability level was expressed by NPLF assessment and the mapping of capability levels 4 and 5 was made more specific [32]. The first mapping of model capability dimensions was proposed by T. Rout and A. Tuffley [33]. There are also other works analysing the compliance of CMMI and ISO/IEC 15504 and attempts to develop multimodels, which would involve several models at a time [34].

The factors that determine the wish of the companies to combine several models [35]:

- The companies launching activities in industries which use particular models must have a variety of certificates. For instance, a European company seeking to work in automotive industry must be assessed according to Automotive SPICE, and if it decides to participate in public procurement, it may need the ISO 9001 certificate. A company that already holds CMMI-DEV certificate necessary to work with NASA in USA will need a SPICE for SPACE certificate to work with ESA in Europe [36].
- Business needs. A company itself decides to use new models expecting they would help to boost the business, e.g. to reduce net cost of services/products, to

increase customer satisfaction, etc.

- Merger. There may be cases where organisations to be merged are using different models and, therefore, they must be able to combine them so that the whole organisation operated under the same regulations and procedures.
- Seeking for more possibilities to enhance the process capability of the organisation. A company which focuses on the enhancement of capability in a specific field seeks to benefit from advantages of different models, thus ensuring maximum benefit from synergy.

2. Bidirectional mapping of Process Assessment Models

After assessment models became popular, a natural necessity to compare them arose. Companies may find it important to know the level of maturity they would receive according to CMMI-DEV, if they have a certain maturity level according to ISO/IEC 15504, and vice versa; the comparison of continuous representation assessment results is also important. When mapping the maturity level or capability profile of a company according to a different model, the received results indicate the minimum maturity level or capability profile a company could receive, if the process was assessed according to a different assessment model. Mapping of company assessment results according to another model is called transformation; however, before performing the transformation, full mapping of the models must be carried out.

In order to compare the models, first, their structure has to be analysed and it has to be determined, whether the models are compatible and whether mapping may be carried out. According to the assessment results defined in ISO/IEC 15504-2, process attributes are evaluated on a scale: NPLF as presented in Table 1. CMMI practices are assessed on an equivalent scale.

Table 1. Rating scale

Rating values	Achievement
N –Not achieved	0 to 15 %
P –Partially achieved	> 15 % to 50 %
L –Largely achieved	> 50 % to 85 %
F –Fully achieved	> 85 % to 100 %

2.1. Framework analysis of Process Assessment Models

CMMI and ISO/IEC 15504 model frameworks and assessment procedures have many differences; however, they are not critical. The principal assessment subject is the practices, because they implement the objectives of the processes. It is them that are assessed in company assessment and therefore, the practices will be compared in model mapping: ISO/IEC 15504 basic practices and CMMI specific practices as well as general practices of both.

Maturity level 1 of ISO/IEC 15504 does not have an equivalent among CMMI maturity levels. Maturity and capability levels are related as depicted in Table 2, based on the comparison of general practices of CMMI and ISO/IEC 15504.

Table 2. Maturity and capability levels of CMMI and ISO/IEC 15504

Maturity levels		Capability levels	
CMMI	ISO/IEC 15504-7	CMMI	ISO/IEC 15504-5
1. Initial	0. Immature	0. Incomplete	0. Incomplete
	1. Basic	1. Performed	1. Performed
2. Managed	2. Managed	2. Managed	2. Managed
3. Defined	3. Effective	3. Defined	3. Established
4. Quantitatively Managed	4. Predictable		4. Predictable
5. Optimizing	5. Optimized		5. Optimizing

In order to transform the assessment result between the models, the first, second and third capability levels have first to be mapped and coverage between them has to be checked. The most important task in this area was the comparison of how CMMI capability levels are mapped to ISO/IEC 15504 capability levels [33]. In this article, and older version CMMI V1.2 was used; however the changes in the general objectives and practices in the new version are minimum [37]: the essential difference is the exclusion of capability levels 4 and 5 [38]. The mapping presented in the [33] article was carried out between CMMI general practices and ISO/IEC 15504 process attributes achievements. This mapping has to be updated according to ISO/IEC 15504 general practices, because they are more detailed and better correspond to CMMI general practices.

After mapping capability dimensions, process dimensions have to be mapped. First, CMMI mapping according to ISO/IEC 15504 was carried out and then vice versa. Mapping is done as follows: a named process is selected in each maturity level in succession (from first to last) and the equivalents of the selected process practices are sought for among all practices of another model. If compliance is found, it is evaluated in percent, i.e. what is the percentage of the coverage of the named process over the practice found in another model. A practice may cover several practices in another model as well as a practice of another model may be covered by several practices. After full mapping, some practices in the new model will have from 0 to several assessments in percent. Having summed up the coverages, the coverage of practice from 0 % to 100 % is received. Then the process capability or maturity level is calculated according to the assessment rules of that model.

2.2. CMMI-DEV mapping to ISO/IEC 15504

After mapping CMMI-DEV V1.3 capability level to ISO/IEC 15504-5:2006 capability profile, the received result is such that the actual capability profile of the company would not be less than the one received after mapping.

ISO/IEC 15504 processes are not mapped to *ENG.2 System requirements analysis*, *ENG.3 System architectural design*, *ENG.9 System integration*, and *ENG.10 System testing*, since these processes are intended exclusively for the companies that develop not only software, but systems as well, meanwhile CMMI maturity levels are assessed in software companies.

Received ISO/IEC 15504 capability profiles are minimum profiles that the organisation would receive when assessing the process according to ISO/IEC 15504 continuous model. ISO/IEC 15504 covers a wider software development domain, because capability level five of CMMI does not cover 8 ISO/IEC 15504 processes at all and other five processes do not reach the first capability level.

After mapping CMMI-DEV V1.3 maturity levels to ISO/IEC 15504-7:2007 maturity levels, the received ISO/IEC 15504-7 maturity level is such that the actually assesses maturity level of the company would not be less than the one received after mapping. CMMI-DEV V1.3 maturity level 3 ensures maturity level 1 of ISO/IEC 15504-7:2008. Higher CMMI-DEV maturity levels do not ensure a higher maturity level of ISO/IEC 15504-7:2008, because ISO/IEC 15504-7:2008 has a larger scope and CMMI maturity levels do not cover a large part of the processes included in level 2 and higher maturity levels of ISO/IEC 15504-7:2008.

2.3. ISO/IEC 15504 mapping to CMMI-DEV

After CMMI mapping to ISO/IEC 15504, reverse mapping was also carried out, because one-way mapping does not show the practices of nominal processes that are completely absent from the other model. After CMMI mapping to ISO/IEC 15504, it could not be seen what in CMMI was not mapped to ISO/IEC 15504 and therefore, reverse mapping must be carried out. The mapping may be done to CMMI-DEV stage model, because the number of process areas in stage and continuous models is the same.

ISO/IEC 15504 third maturity level ensures the second maturity level of CMMI because all mandatory process areas reach the capability level 3. For ISO/IEC 15504 third maturity level to ensure CMMI third maturity level the mapping of *DAR* process area is lacking. This process area is covered by PRO.3 process from the new version (2012) of ISO/IEC 15504-5. It is likely that this process will be included in the updated ISO/IEC 15504 stage model and then the organisation having the maturity level 3 in ISO/IEC 15504 could expect to have the maturity level 3 in CMMI as well.

Respectively maturity levels 4 and 5 cover the process areas in maturity levels 4 and 5 of CMMI. The same two process areas as in maturity level 3 remain not covered. Therefore, assuming that decision management is included in the new ISO/IEC 15504 stage model, ISO/IEC 15504 maturity level 4 would be equivalent to CMMI maturity level 4 and the same with maturity level 5.

Having carried out bidirectional mapping between the models, their discrepancies were identified. ISO/IEC 15504 is a more detailed model with a broader scope in comparison to CMMI-DEV. ISO/IEC 15504 essentially covers the whole CMMI-DEV model. CMMI-DEV does not completely cover the Resource and Infrastructure Process Group, partially covers some processes from Support Process Group, and organisational and knowledge management is completely absent from it.

3. Transitional Process Assessment Model

The aim of the transitional process assessment model is to get several assessment results after performing a single assessment of the processes in the organisation, thereby resolving the problem of performing several assessments. This section presents the construction of TPAM. TPAM compliance with other evaluation models is depicted in Figure 1. An organisation having the results according to any model can transform them to all other models included in TPAM.

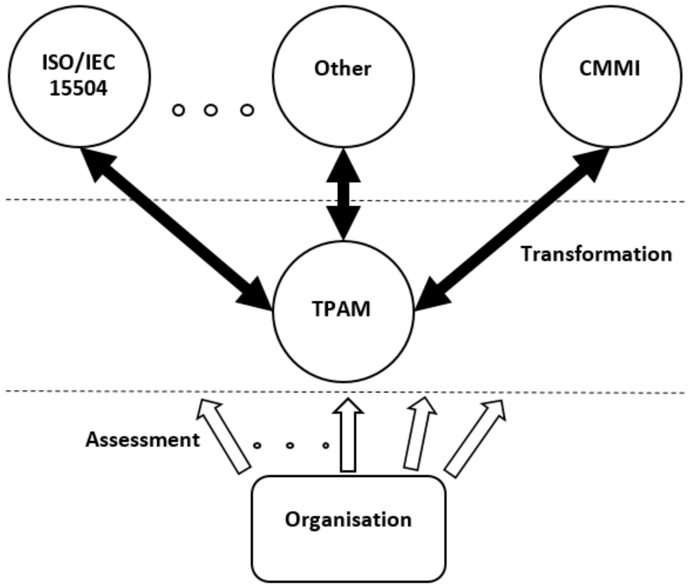

Figure 1. Transforming of the organisation assessment results between the models

TPAM enables the companies to transform the results of software process assessment according to ISO/IEC 15504 to an assessment according to CMMI and vice versa. It can be immediately evaluated by TPAM and then, after the transformation, results according to CMMI and ISO/IEC 15504 or other evaluation models can be received. This section also describes the methodology of including new models in TPAM, thus expanding TPAM to successfully carry out the assessments according to another software process assessment model or an updated version of the existing model. If the assessment is carried out officially in accordance with existing assessment models, assessment certificates are available, indicating that the assessed organisation's processes reach the appropriate levels of capability or maturity. After an assessment by TPAM, the organisation does not receive a certificate, but the obtained results can be transformed to assessments by CMMI or ISO/IEC 15504 and then used to improve the process or efficiently prepare for a formal assessment.

The inclusion of many models forces TPAM practices to split approaching the atomic practices. Such ideal TPAM can be defined as a universal set $U = \{a_1, a_2, a_3, \dots, a_n\} = \{a: a - atomic\}$, $\forall\, TPAM \in \mathrm{P}(U), \forall\, PAM \in \mathrm{P}(U)$, where $\mathrm{P}(U)$ is the power set of universal set and each TPAM and PAM practice is an element of $\mathrm{P}(U)$. The coverage of the PAM practice by the TPAM practice is calculated using cardinality of a set (1):

$$P = \{p_1, p_2, \dots, p_n\}, |P| = n, \tag{1}$$
$$TP = \{t_1, t_2, \dots, t_m\}, |TP| = m,$$
$$then\, TP\, covers\, {}^{m}/_{n}\, part\, of\, P\,,$$
$$that\, is\, called\, as\, TP\, practice\, weight.$$

This section presents six requirements that must be met by TPAM:

1. Terminology of TSPM.
2. Harmonised description of the TPAM.
3. Empirical and Descriptive model.
4. Methodology for PAM inclusion.
5. Assessment results interpretation.
6. Assessment results transformation.

The following sections describe the implementation of the requirements in the implementation of TPAM. If the requirements are met, TPAM can perform the transformation of the assessment results according to a variety of PAM.

3.1. Terminology of TSPM

It is not clear what terminology should be used to present, describe or otherwise use the identical properties of the assessment models, since there is no unified terminology established. For example, the same concept that the ISO/IEC 15504 refers to as a process in CMMI is referred to as process area.

If unified terminology is used, it is clear what objects have equivalents in other PAMs. Moreover, in order to add new PAMs to TPAM, it is necessary to know how to combine the objects of the new PAM with this terminology.

To meet this requirement, all terms that have equivalents in both CMMI and ISO/IEC 15504 models have to be given the same names (Table 3). These terms are used to describe the assessment of processes as well as to implement TPAM.

TPAM is a continuous process assessment model and therefore, it is necessary to define the dimension of capability. Capability dimension consists of generic properties, and each generic property is implemented by generic practices. TPAM capability levels match the ISO/IEC 15504.

The term "practice capability" is not present in other assessment models. This concept is necessary to save the percent assessment of generic practices of included models in the TPAM, which are received by all nominal processes that have reached a certain level of capability.

Table 3. TPAM terminology

TPAM	ISO/IEC 15504	CMMI
Organisational Process	-	Process
Named Process	Process	Process Area
Purpose	Process Purpose	Purpose Statement
Outcome	Process Outcome	Specific Goal
Practice	Base Practice	Specific Practice
Generic Property	Process Attribute	Generic Goal
Generic Practice	Generic Practice	Generic Practice
Practice Capability	-	-
Practice Weight	-	-
Capability Level	Capability Level	Capability Level

3.2. Harmonised description of the TPAM

It is necessary to uniformly describe the TPAM using the defined terminology as well as other evaluation models so that all definitions have the same structure. Preferably, a unified structure should be depicted visually. The unified description of the models highlights the framework similarities between the models and therefore, it is easier to include a new model in TPAM.

The SPEM metamodel is most appropriate to describe PAM. SPEM has its own terminology and therefore, it is necessary to match the terms in TPAM and SPEM and then the description of the models in accordance to the SPEM metamodel. Matching terms are presented in Table 4. SPEM metamodel has a visual display tool – EPF, which is used to describe TPAM and its constituent models.

Table 4. Relations between TPAM and SPEM terms

TPAM	SPEM	SPEM icon
Named Process	Category	
Outcome	Outcome	
Practice	Practice	
Generic Property	Task	
Generic Practice	Step	n/a
Practice Capability	Used for process assessment, not for representation	
Practice Weight		
Capability Level		

3.3. Empirical and Descriptive model

TPAM must be based on the best practices of the represented domain. When creating TPAM practices, two rules must be followed. First, TPAM practices must define the described and analysed software process, and second, they must be formulated so that they answered the question “what to do?” All TPAM practices must have sources, i.e. all of them must originate from included models and not be added as extras. If the included model contains practices that are not compliant with these rules, they must be recreated.

3.4. Methodology for PAM inclusion

In order to perform the process assessment once and to receive the results according to several assessment models, these models have to be included in TPAM. To this end, the methodology for including a new model into TPAM has to be created. CMMI-DEV and ISO/IEC 15504 models are included in TPAM using the methodology. The inclusion of each new PAM is the process of six successive steps. If any of the steps cannot be performed, PAM cannot be included in TPAM.

The first step is the verification of compatibility, which involves two parts: 1) the domains of TPAM and the new model must coincide; 2) there must be a possibility to map the terminology of both models and this way, verify that the framework of the included PAM is compatible with TPAM and other included models and transforming of assessment results between them are possible.

The second step is making the copy of TPAM to ensure the mapping of already included PAMs to the older TPAM.

The third step is the selection of PAM processes to be included. Generally, all processes of the new model are included in TPAM, but it is not mandatory. Any set of PAM processes may be selected. The requirement of the second step is compliant with paragraph 6.3.2.1 of ISO/IEC 15504-2 requirements, which defines the implementation of PAM from PRM: PAM must be related to at least one process from the selected PRM or PRMs.

The fourth step is determining the compliance of PAM practices. The practices of selected PAM processes are included one after another. Since TPAM and the included PAM are of the same domain or the domain of PAM is seen from the point of view of software, it is likely that the majority of practices of the new model will already be included in TPAM from previous models. The rule of full coverage must always be met: each TPAM practice must be covered 100 % in each model or not covered at all in the particular model. This rule formally expressed as follows (2):

$$\begin{gathered} \forall PAM \in TPAM: \\ TPAM = \bigcup_{k=1}^{m} TP_k, PAM = \bigcup_{l=1}^{n} P_l \\ P_i \cap P_j = \emptyset, when\ i \neq j \\ \forall\ P_i = \bigcup_{t=1}^{n} TP_t. \\ TP_i \cap TP_j = \emptyset, when\ i \neq j \\ \forall\ TP_i\ \exists\ PAM\ ir\ P_j: \\ TP_i \subseteq P_j. \\ where\ P_n - PAM\ practice, TP_n - TPAM\ practice. \end{gathered} \tag{2}$$

Between any PAM and TPAM can be defined function as follows (3):

$$f: TPAM \to PAM, kur\ f\ - \text{Surjective}, but\ not\ \text{injection}. \tag{3}$$

When including new models into TPAM, all practices of the new model are verified by one or several of the four variants and it is determined how it is mapped to TPAM.

Variant 1. In the first variant of selection of practices, the included practice is not covered by any TPAM practice. Such practice automatically becomes a new TPAM practice with mapping to the respective practice of PAM. This variant formally expressed as follows (4):

$$\nexists TP, that\ TP \cap P \neq \emptyset. \tag{4}$$

Variant 2. The included model and TPAM have the same practices – variant 2. In this case, the new practice is not included in TPAM, but a note is made that the practice of the included model is 100 % covered by the respective practice of TPAM. This variant formally expressed as follows (5):

$$\exists TP, that\ TP = P\ . \tag{5}$$

Variant 3. Variant 3 is when PAM practices are much more detailed and their scope is smaller than the respective practices of TPAM. Therefore, instead of the existing TPAM practice, new, more detailed, practices are created, which cover the former TPAM practice by 100 %. This variant formally expressed as follows (6):

$$\exists TP, that \bigcup P_i = TP. \quad (6)$$

Variant 4. The last variant of inclusion of new model practices deals with the cases, when the new practice partially covers one or several TPAM practices. In such case, both TPAM practice and PAM practice must be split. %. This variant formally expressed as follows (7):

$$\exists TP, that\ P \cap TP \neq \emptyset\ ir\ P \neq TP. \quad (7)$$

The fifth step is mapping the generic properties. The model being included in TPAM must have equivalents for generic properties and practices. If the included PAM has a different capability dimension, the differences between the generic practices must be included in TPAM. This is performed according to the principles of the third step applied to specific or basic practices.

Last step is mapping the previous version of TPAM to the new version of TPAM, thus ensuring that the assessment results according to previously included PAMs could be transformed to the newly included PAM and vice versa.

3.5. Assessment results interpretation

The capability of a company is assessed by qualified assessors whose assessment result is a capability profile or a maturity level. An important aspect is the level of detail of the assessment, which determines the precision of transformed results.

Received assessment results may be of different form and level of detail, but they must be reduced to percent evaluations of all practices – this is the first variant of level of detail.

The second variant of the level of detail of a capability profile is the assessment of named processes and generic practices positioned on NPLF scale.

Having obtained the assessment of all practices on NPLF scale, percent evaluation of named processes practices must be received. NPLF may be converted to percent based on the crosshairs on the scale presented in Table 1.

The third variant of capability profile level of detail means that the assessments of each named process under the generic properties according to generic properties of a capability dimension (CMMI – Generic Goal, ISO/IEC 15504 – Process Attribute), yet nothing is known about the achievements of individual practices. With such assessments, NPLF assessment of the practices must be obtained according to the rules of that assessment model. When NPLF assessment is available, the previously described variant to receive the practice assessment in percent must be followed.

The fourth capability profile level of detail is just the capability levels of specific named processes. According to the rules of assessment of the models, the assessment of generic properties is received from the capability levels, and then the above method is applied to receive percent assessment of practices from them.

3.6. Assessment results transformation

Having received the assessment results of a certain model, they are transformed to the version of TPAM they were mapped to. After transforming the assessment results to TPAM, each TPAM practice cannot have higher coverage than 100 %. All TPAM practices that cover a respective PAM practice must satisfy the equation (8), where p_i is practice coverage percentage:

$$\sum_{i=1}^{n} p_i = 100\% \tag{8}$$

The sum of coverage of practices must be equal to 100 %, because they all completely cover one PAM practice. Having received a capability profile, where PAM practice is assessed px, the extent of assessment of each related practice must be calculated; such practices are covered respectively by $p_1,\ p_2,\ ..,p_n$, i.e. to find the weights $w_1,\ w_2,\ ..,w_n$. The following equation (9) is received:

$$\sum_{i=1}^{n} w_i p_i = px \tag{9}$$

the solution of which is an infinite number $w_1,\ w_2,\ ..,w_n$ of set variants.

First, the received PAM results must be transformed to TPAM. The simplest variant is just to transfer the percent evaluation of the model practice to respective practices of TPAM, which are covered by that practice. In this case, $w_1,\ w_2,\ ..,w_n$ are equal to px. Equation (10) is not vulnerable, because after replacing w_i by px, equation (9) is received based on equation (8):

$$\sum_{i=1}^{n} px * p_i = px \sum_{i=1}^{n} p_i = px * 1 = px \tag{10}$$

This variant is also applied for the transforming of results from lower TPAM versions to higher versions. All $TPAM_N$ practices related to respective $TPAM_{N-1}$ practices will receive the same assessment.

Another profile assessment transfer to TPAM is by evaluation of the weight of the practices. The essence of this method is to divide the assessment among related TPAM practices not equally, but depending on the part of coverage. This version divides the assessment so that the most covered practice would receive the highest assessment. The practices are ranked from lowest to highest weight. Then the coefficient is introduced (11):

$$e = p_1 * (1 - px) * px \quad (11)$$

Then for all w_i, where i is up to $n/2$, formula (12) is applied:

$$w_i = px - e/p_i \quad (12)$$

and for all w_i, where i is more than $n/2 + 1$, formula (13) is applied:

$$w_i = px + e/p_i \quad (13)$$

and if n is an odd number, then $w_{n/2+1}$ receives the same assessment as the practice of the assessed model (14):

$$w_{n/2+1} = px \quad (14)$$

This variant divides the coverage around the middle and the margins are farther away from the average. If the assessment transfer version is selected, TPAM capability profile is obtained. Then TPAM assessment results must be transformed to another assessment model.

The result is a TPAM capability profile received after transformation or by direct assessment by TPAM. TPAM practices that were not assessed are considered to have 0% coverage. TPAM capability profile transformation algorithm is as follows: known TPAM practices evaluated in percent $a_1, a_2, .., a_n$, which completely cover PAM x practice by weights $C_{1,} C_2, .., C_n$, where $C_1 + C_2 + .. + C_n = 1$, then practice x assessment, when transforming the results from TPAM is received as follows (15):

$$x = \sum_{j=1}^{n} a_j * C_j \quad (15)$$

Generic practices are covered the same way, but not only the weights of generic practices are checked, but also the weight of the practice, the capability of which has to be calculated. Each TPAM practice has attributed coverage in percent of all generic practices. We note that PAM generic practice is bp, and it is covered by TPAM general practices weights $b_1, b_2, .., b_n$, which are $b_1 + b_2 + .. + b_n = 100\%$ and they are covered in each TPAM practice a_i respectively $v_{i_1}, v_{i_2}, .., v_{i_n}$, then x generic practice value of practice pb is calculated as follows (16):

$$bp = \sum_{i=1}^{m} a_i * \sum_{j=1}^{n} b_j v_{i_j} \quad (16)$$

When applying the above rules, the capability profile of the desired model is received.

If available PAM assessment results are transformed to an older version of TPAM, the transformations are performed from the older TPAM version to the newer TPAM version, until the current TPAM version is reached. The transformations are the same as from PAM to TPAM. Transformations from newer TPAM versions to older ones are performed when the available assessment results were received according to PAM included later than the previously included PAM, the assessment results of which are requested. This is done by the same principle as the transforming from TPAM to PAM.

3.7. Automated transformation

TPAM is described by SPEM metamodel, which is realized by EPF tool. TPAM may be analysed in a browser: named processes, their objectives and practices. However, in order to perform the transformation of assessment results, a tool that allows entering available assessment results is necessary. After entering the available assessment results, the assessment model and its version must be selected to transform the results to. The transformation is carried out automatically by recalculating the assessments according to the selected transformation variants. In order to perform the transformations automatically, the model, the results of which have been received, and the model, the results of which are required must be included in the tool. This tool is suitable for TPAM of any domain. The designed automated transformation tool is available online[1].

4. Models inclusion into TPAM

Currently the following models are included into TPAM: ISO/IEC 15504-5:2006, ISO/IEC 15504-7:2008 (two named processes from maturity levels 4 and 5 are added), CMMI-DEV V1.3, and ISO/IEC 15504-5:2012.

When starting the inclusion of the models, first, the decision must be made, which model should be included first and would become the core of TPAM, because all practices of this model will automatically become TPAM practices, all later models will be mapped to these practices and when including new practices, their wording will have to be adjusted to this model. ISO/IEC 15504-5:2006 was selected as the first model. After including ISO/IEC 15504 continuous model, ISO/IEC 15504-7:2012 stage model was also included.

The methodology of inclusion of new PAM was applied to include the third model: CMMI-DEV V1.3. According to the defined methodology, all CMMI-DEV

[1] http://www.mif.vu.lt/~stasys/TPAM/TPAM_tool.xlsx

process areas were included into TPAM. All new TPAM practices were included or updated in the previous named processes. Only one new named process appeared – *DAR*, because ISO/IEC 15504 does not have explicitly described practices of this process. All CMMI-DEV is completely mapped to TPAM practices: many TPAM practices were split to meet the full coverage rule. Only several CMMI-DEV practices were not mapped to previous TPAM practices and were included as new ones.

It is essential to include the most recent ISO/IEC 15504-5 version into TPAM. This will facilitate the migration from the version of 2006 to the version of 2012 for the organisations. After including ISO/IEC 15504-5:2012 DEV to TPAM, it was noticed that although the new version has many structural changes, the scope of the domains of the processes was not broadened, but became more detailed. The inclusion of models into TPAM is available online[2].

5. Validation of TPAM

Once the transitional process assessment model has been created, its validity must be tested. To this end, a fictional organisation must be created and assessed. In order to maintain objectivity and an independent verification of the results, let us suppose that this organisation works according to a particular software development process. In this case, one does not need to assess the fictional organisation itself, but rather its capability profile, which can be secured by the software development process. The fictional organisation is assessed according to the PAM and then according to the TPAM. Later, the results of the TPAM assessment are transformed according to the PAM for a comparison of the assessment results, which should, essentially, be the same.

The DSDM [39] was chosen to validate the TPAM because it covers 60% of the process areas in the CMMI-DEV model Because it is important to produce the most accurate CMMI capability profile possible, it is mapped to a continuous CMMI framework. An assessment of the DSDM ensured CMMI-DEV capability profile was also completed and the results were presented in the [40] article. These results can be relied upon to test the validity of the TPAM because mapping was conducted before the construction of the TPAM. Aside from this, the assessment was conducted with independent assessors.

The DSDM assessment demonstrated that the organisation, operating according to the DSDM, can reach the second maturity level according to CMMI-DEV V1.3, even though the *Supplier Agreement Management* process area is not

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[2] http://www.mif.vu.lt/~stasys/TPAM/TPAM_inclusion.xlsx

covered (however, the latter is not compulsory).

When assessing the DSDM directly according to the TPAM model, the TPAM assessment method was used. All TPAM processes were assessed. The following processes received evaluations of zero for their practices: *SUP.5 Audit, SUP.6 Product evaluation, SUP.7 Documentation, SPL.1 Supplier tendering, all Acquisition Process Group, MAN.1 Organisational alignment, MAN.2 Organisational management, PIM.2 Process assessment, RIN.3 Knowledge management, REU.3 Domain engineering, QNT.2 Quantitative Process Improvement.*

Having the DSDM secured capability profile according to the TPAM, and using the compliance of CMMI to the practices of the TPAM, the TPAM capability profile must be transformed into a CMMI capability profile. The resulting CMMI capability profile is presented Figure 2. Additional three columns were added: the first represents the percentage of coverage for all specific practices of the respective process areas, the second column displays the execution of specific practices when conducting an assessment directly according to CMMI, and the third column presents the difference.

CMMI-DEV process areas	CL1	CL2	CL3	From TPAM to CMMI, %	By CMMI, %	Difference, %
Configuration Management				85,71	85,71	0
Measurement and Analysis				95,75	100	-4,25
Project Monitoring and Control				85	85	0
Project Planning				95,71	100	-4,29
Process and Product Quality Assurance				95	100	-5
Requirements Management				100	100	0
Supplier Agreement Management				0	0	0
Decision Analysis and Resolution				8,33	8,33	0
Integrated Project Management				91,5	100	-8,5
Organizational Process Definition				68,29	71,43	-3,14
Organizational Process Focus				0	0	0
Organizational Training				20,19	21,43	-1,24
Product Integration				**82,22**	**88,89**	**-6,67**
Requirements Development				98,5	100	-1,5
Risk Management				100	100	0
Technical Solution				98,75	100	-1,25
Validation				100	100	0
Verification				50	50	0
Organizational Process Performance				0	0	0
Quantitative Project Management				55,71	57,14	-1,43
Causal Analysis and Resolution				0	0	0
Organizational Performance Management				0	0	0

Figure 2. Coverage of CMMI process areas

Coverage of the named process is calculated according to the following formula (17):

$$VP = \frac{1}{n}\sum_{i=1}^{n} P_i \qquad (17)$$

VP – coverage of the named process in percent;
P_i – assessment of the i-th practice of the named process in percent;
n – the number of practices within a named process.

The only difference in the capability profiles once the percentages were converted to the NPLF scale was that, according to a CMMI assessment, the *PI* process area reached the second capability level, and according to the TPAM assessment with the results transformed to CMMI, this process area only reached the first capability level because the difference in assessment percentages was less than 7 percent and evaluations were close to the margin, which is why they exceeded it without exceeding the coverage. Discrepancies in the assessments of all the other process areas occurred due to the same reasons: TPAM assesses in more detail than the CMMI model, thus it is only natural that the existence of more practices leads to more of them not being fully covered.

Comparing the two CMMI capability profiles, one produced directly and another produced through a TPAM, the conclusion can be made that the TPAM can be used to transform assessment results within a certain margin of error. A real company could immediately assess its process according to the TPAM, transform the results into CMMI and ISO/IEC 15504 and expect to produce quite an accurate description of its capability profile.

Conclusions

1. The TPAM can be used to automatically transform assessment results between different PAMs. More accurate results can be received when an organisation assesses its processes according to TPAM, and assessment results produced according to other models are received by conducting transformations.
2. The TPAM is suitable for assessing processes as it provides an organisation's process capability profile as produced by various PAMs. The assessment results obtained by transformation are suitable for process improvement: they provide capability profiles that allow users to assess which named processes are of unsatisfactory capability and are not suitable for the target capability profile. The assessment results obtained by transformation cannot be officially certified; however, official assessment would produce a similar capability profile.
3. The method for developing the TPAM could be applied developing TPAMs in various domains. A transitional service process assessment model can be developed to cover CMMI-SVC [41] and ISO/IEC 15504-8 [42] assessment models with the possibility to conduct transformations from one to the other.

It is also possible to implement a TPAM that would not be attached to a specific domain and that would include Enterprise SPICE [43] and FAA-ICMM [44] assessment models. Implementing a transitional process assessment model that would include TestSPICE [45] and TMMi [46] assessment models is also possible.

Publications on the thesis topic

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Reziumė

Tyrimų sritis ir problemos aktualumas

Dauguma programinę įrangą kuriančių įmonių susiduria su problemomis: projektai vėluoja, viršijamas biudžetas, klientai nepatenkinti produktų kokybe. Pastaraisiais dešimtmečiais padėtis pagerėjo, nors, pagal Standish Group 2013 metų ataskaitą, sėkmingų projektų vis dar yra mažiau nei pusė (39%). Sėkmingų projektų dalis nuolatos auga, nes buvo ieškomos nesėkmių priežastys. Pirmiausia šias problemas buvo bandoma spręsti technologinėmis priemonėmis, bet buvo suprasta, kad daugelis problemų kyla dėl nebrandaus programų kūrimo proceso, pagal kurį įmonė įgyvendina projektus.

Programų kūrimo procesų vertinimo modelių atsiradimą inicijavo užsakovų poreikiai turėti objektyvius kriterijus, renkantis tinkamiausią projekto vykdytoją. Jau nuo pat modelių kūrimo pradžios ne mažiau svarbus buvo vertinimo modelių tinkamumas proceso gerinimui. Kuo proceso branda/gebėjimas didesnis, tuo įmonės projektuose mažiau aptinkama defektų, ženkliai mažėja darbo sąnaudos, tiksliau prognozuojami projekto terminai ir biudžetas.

Populiariausi pasaulyje programų kūrimo procesų vertinimo modeliai yra tarptautinis standartas ISO/IEC 15504 ir CMMI, kuris yra tapęs standartu *de facto*. Įmonės, norėdamos būti oficialiai pripažintos platesnėje aplinkoje, renkasi vieną iš šių dviejų modelių. Pažymėtina, kad modelio pasirinkimą dažniausiai nulemia ne paties modelio savybės, bet išorinės aplinkybės, pavyzdžiui, jei įmonė siekia dirbti su JAV užsakovais, ji neabejotinai renkasi CMMI. Lietuvos įmonės dažniausiai pasirenka CMMI, kadangi jis yra nemokamas ir yra daug papildomos informacijos apie jo taikymą, o valstybės remiamuose projektuose skatinama naudoti ISO/IEC 15504, kadangi jis yra tarptautinis procesų vertinimo standartas.

Įmonės susiduria su problema, kad skirtingi užsakovai reikalauja skirtingų procesų vertinimo modelių. Todėl įmonėms yra aktualu turėti instrumentą, kuris atvaizduotų jos vertinimo rezultatus iš vieno procesų vertinimo modelio į kitą, neatliekant kaskart realaus įmonės procesų vertinimo. Pavyzdžiui, įmonė, turinti savo procesų gebėjimo vertinimą pagal ISO/IEC 15504 modelį, galėtų automatiškai gauti tų pačių procesų gebėjimą pagal CMMI-DEV modelį, ar naujesnę (senesnę) ISO/IEC 15504 versiją.

Tyrimų objektas

Šios disertacijos tyrimų objektas yra programų kūrimo procesų vertinimas ir gerinimas, naudojant keletą procesų vertinimo modelių.

Darbo tikslas ir uždaviniai

Darbo tikslas – sukurti metodą organizacijos programų kūrimo procesų gebėjimo vertinimo rezultatų pagal pasirinktąjį procesų vertinimo modelį atvaizdavimui į vertinimo rezultatus pagal kitus procesų vertinimo modelius.

Tikslui pasiekti buvo sprendžiami šie uždaviniai:

1. Ištirti atskirus programų kūrimo procesų vertinimo rezultatų atvaizdavimo atvejus: sukurti atvaizdavimus tarp labiausiai paplitusių programų kūrimo procesų vertinimo modelių.
2. Pasiūlyti metodą programų kūrimo procesų vertinimo rezultatų pagal kelis procesų vertinimo modelius gavimui, atlikus vieną procesų vertinimą. Šis

metodas turi apimti:
- naujų procesų vertinimo modelių įtraukimo metodiką;
- vertinimo rezultatų automatizuotą atvaizdavimą.
3. Atlikti pasiūlyto metodo korektiškumo vertinimą.

Tyrimų metodika

Disertacijoje modelių atvaizdavimai buvo sudaryti, taikant turinio analizės metodą. Tarpinis modelis sukonstruotas pagal tarptautinio standarto ISO/IEC 15504-2 reikalavimus. Tarpinio modelio korektiškumas vertintas atliekant atskiro atvejo tyrimą su konkretaus sistemų kūrimo proceso vertinimo rezultatų atvaizdavimu.

Darbo rezultatai ir mokslinis naujumas

1. Sudaryti tarpusavio ryšiai tarp ISO/IEC 15504-5:2006, ISO/IEC 15504-7:2008 ir CMMI-DEV V1.3 modelių.
2. Sukurtas tarpinio programų kūrimo procesų vertinimo modelio kūrimo ir vertinimo rezultatų atvaizdavimo metodas.
3. Sukurtas tarpinis programų kūrimo procesų vertinimo modelis, apimantis ISO/IEC 15504-5:2006, ISO/IEC 15504-7:2008, ISO/IEC 15504-5:2012 bei CMMI-DEV V1.3 procesų vertinimo modelius.
4. Sukurtas automatizuoto atvaizdavimo bandomasis maketas, kuris gali kaupti vertinimo rezultatus ir juos atvaizduoti į kitus procesų vertinimo modelius.
5. Sudaryti DSDM užtikrinami CMMI-DEV V1.3 ir ISO/IEC 15504-5:2006 gebėjimo profiliai, pagal kuriuos įmonės gali iš anksto sužinoti, ką gali užtikrinti DSDM taikymas.

Praktinė darbo rezultatų reikšmė

Disertacijoje pateiktas tarpinis programų kūrimo procesų vertinimo modelis yra instrumentas įmonėms, siekiančioms kurti programų sistemas automobilių, krašto apsaugos, kosmoso, medicinos ir kitose pramonės šakose, gauti vertinimo rezultatus pagal įvairius procesų vertinimo modelius, atliekant vieną procesų vertinimą.

Pagal pasiūlytą tarpinio programų kūrimo procesų vertinimo modelio kūrimo metodą galima kurti tarpinius modelius ir kitų sričių procesams vertinti. Pavyzdžiui, galima konstruoti tarpinį modelį paslaugas teikiančioms organizacijoms, apimantį CMMI-SVC ir ISO/IEC 15504-8 vertinimo modelius, arba tarpinį modelį bet kokia veikla užsiimančioms organizacijoms, apimantį Enterprise SPICE ir FAA-iCMM vertinimo modelius.

Pagal disertacijoje pasiūlytus ir bandomajame makete išbandytus principus sukurtu įrankiu įmonės galėtų automatizuotai gauti gebėjimo profilius pagal kelis procesų vertinimo modelius, taip pat analizuoti, kaip pasikeistų gebėjimo profiliai, pagerinus pasirinktus vardinius procesus.

Ginami teiginiai

1. Organizacijos programų kūrimo procesų vertinimo pagal vieną procesų vertinimo modelį rezultatai gali būti atvaizduoti į vertinimo rezultatus pagal kitus modelius.
2. Taikant tarpinio programų kūrimo procesų vertinimo modelio kūrimo metodą, galima sukurti tarpinį programų kūrimo procesų vertinimo modelį, kuris apimtų CMMI ir ISO/IEC 15504 modelius.
3. Tarpinio programų kūrimo procesų vertinimo modelio kūrimo metodą galima pritaikyti kitų dalykinių sričių tarpinių procesų vertinimo modelių kūrimui.

Išvados

1. Naudojant tarpinį programų kūrimo procesų vertinimo modelį, galima automatizuotai atvaizduoti vertinimo rezultatus tarp skirtingų procesų vertinimo modelių. Tikslesni vertinimo rezultatai gaunami, kai organizacija vertina programų kūrimo procesus pagal tarpinį modelį, o vertinimo rezultatus pagal kitus modelius gauna atlikus atvaizdavimus.
2. Tarpinis programų kūrimo procesų vertinimo modelis yra tinkamas procesų vertinimui, nes suteikia organizacijos proceso gebėjimo profilį pagal įvairius procesų vertinimo modelius. Atvaizduotieji vertinimo rezultatai tinkami proceso gerinimui, nes yra gaunami gebėjimo profiliai, kur galima įvertinti, kurie vardiniai procesai yra netenkinamo gebėjimo, arba neatitinka tikslinio gebėjimo profilio. Atvaizduotų vertinimo rezultatų negalima oficialiai sertifikuoti, tačiau oficialus vertinimas duotų panašų rezultatą.
3. Tarpinio programų kūrimo procesų vertinimo modelio kūrimo metodą galima pritaikyti kitų dalykinių sričių tarpinių procesų vertinimo modelių kūrimui. Galima konstruoti tarpinį paslaugų procesų vertinimo modelį, kuris apimtų CMMI-SVC [108] ir ISO/IEC 15504-8 [152] vertinimo modelius ir būtų galima atlikti atvaizdavimus tarp jų, taip pat galima konstruoti tarpinį procesų vertinimo modelį, kuris nebūtų susietas su konkrečia dalykine sritimi ir apimtų Enterprise SPICE [115] ir FAA-ICMM [153] vertinimo modelius. Taip pat galima konstruoti ir tarpinį testavimo procesų vertinimo modelį, kuris apimtų TestSPICE [111] ir TMMi [106] vertinimo modelius.