INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012
Dubrovnik - Croatia, May 21 - 24, 2012.

DESIGN 2012

MATURITY BASED IMPROVEMENT OF PRODUCT DEVELOPMENT PROCESSES IN SMALL AND MEDIUM-SIZED ENTERPRISES

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Keywords: performance evaluation and improvement, process maturity models, product development process, virtual prototyping

1. Introduction

Effective and efficient processes characterize successful companies in mechanical engineering and related industrial sectors. Particularly, the product development process is of special interest, as it determines the features of the future product and about 80% of product costs. The way this process is organized and managed has a crucial impact on the effectiveness of designers and design teams.
Methods and tools of Virtual Prototyping and Simulation (VPS) become more and more accepted in these processes. Virtual prototyping means creating and analyzing computer models of products in development. This reduces the number of physical prototypes, improves communication in development processes and helps to avoid design errors. That way, companies save time and money [Gausemeier et al. 2009].
In the past, lots of domain-specific methods and tools for VPS (e.g. CAD and FEM) emerged. The transition from a traditional product development, based on physical prototypes, to VPS-driven development is expensive and often characterized by costly failures. The integration of these tools into the processes and the PDM/PLM infrastructure of the company is a success factor in the development of complex technical systems. However, especially small and medium sized enterprises (SMEs) often run isolated applications that are insufficiently integrated into the development process and the PDM/PLM infrastructure. They only exploit fractions of the potential benefits of VPS.
Reasons are the missing experience in VPS-technologies and the lack of knowledge about their potential benefits. Additionally, the introduction of VPS requires extensive planning and thus financial and human resources that are often missing. While large companies maintain own planning departments, SMEs have little time to perform process improvements in addition to the dominant day-to-day business.
In order to improve their product development processes, SMEs need support for planning and optimization of their VPS-usage. Key points of process improvement are both, an objective evaluation of current performance as well as a coherent conception for improvement. Process maturity models target at these points. Specific requirements arise out of the application of maturity models in SMEs:

- **Pragmatic performance evaluation with low effort:** Time to investigate possible approaches and the extensive bureaucracy are barriers to use assessment tools for performance improvement [Knoblinger et al. 2011]. SMEs have neither the time nor the money to get into complex models for performance evaluation and improvement. Thus, an easy learnable and practicable model is necessary. External experts should be at least to some extent unnecessary. Additionally, time for application should be as short as possible and not exceed a few days.

- **Consideration of performance improvement:** Due to the lack of knowledge about potential benefits of VPS, SMEs need concrete recommendations for performance improvement. Thus, the approach has to support the interpretation of the performance evaluation.
- **Definition of a company-specific target state:** Especially for SMEs, it can be uneconomical to achieve the highest performance level. Considering a SME with only a few engineers, the cost-benefit-ratio of implementing and maintaining a PDM-system is questionable. Ignoring other possible influences, managing data within well-organized file structures would be adequate. The example demonstrates that recommendations have to aim at an individual target state.

This paper begins with a brief overview on existing approaches for performance evaluation and improvement. We point out the demand for a new approach specialized on the requirements of SMEs. The new approach will then be introduced. Goal of the approach is a quick and easy evaluation and improvement of the strategies, methods and tool-support in the product development process. After describing the framework of the model, we focus on the definition of the target state ensuring that SMEs only seek for economically reasonable performance levels. Finally, we give an overview on the prototypical implementation of the maturity model. We show that the introduced approach is easily adaptable and thus universally applicable in other areas of interest, such as Innovation Management and Supply Chain Management.

2. Performance evaluation and improvement using maturity models

According to current estimates, more than 200 different maturity models are available [Harmon 2009]. Therefore, structuring the state of the art of performance evaluation and improvement is necessary.

Selecting an optimal model depends on two main factors. First, the model has to fit the area of interest. Existing models cover a wide spectrum of different applications. CMMI-DEV (Capability Maturity Model Integration for Development) e.g. focuses on product development, ITIL (IT Infrastructure Library) on IT management and SPICE (Software Process Improvement and Capability Evaluation) on software development [Harmon 2009], [Chrissis 2003], [van Loon 2004]. Also for the area of interest VPS there are already existing models, such as "ENGINEERING produktiv!"[1].

Second, the methodology of the maturity model must match the user’s requirements. The methodology has impact on features such as the consideration of performance improvement, the assessment system and the effort for training [Christiansen et al. 2010]. Comparing CMMI-DEV and PEMM (Process and Enterprise Maturity Model) demonstrates that these features differ heavily between the available models.

Introducing CMMI-DEV in a company requires intensive training of staff and involvement of different divisions [Software Engineering Institute 2006]. A complete implementation of CMMI-DEV often requires months (depending on company size) [Gausemeier et al. 2009]. In contrast, PEMM is a very pragmatic approach that can be applied with minimal effort and without trained staff. In a self-assessment, the maturity levels can be determined within days [Hammer 2007].

Due to the variety of these models, selecting an appropriate maturity model is difficult. Therefore, the Heinz Nixdorf Institute developed a classification of models for performance evaluation and improvement. The classification gives a first indication, which methodical approach could fit the individual requirements described in section 1. Five main classes of models for performance evaluation and improvement were identified. Figure 1 shows the five classes and the associated models. [Christiansen et al. 2010] give a detailed instruction to the classification system.

In the following, we describe the classes in detail [Christiansen et al. 2010]. Furthermore, we discuss how they meet the requirements defined in section 1.

- **Class 1 - Rigid Regulations:** Characterizing for this class is the specification of a defined set of rules. Usually, they recommend a stepwise performance improvement. However, there is no methodology defined that indicates, which performance level would be reasonable for the company. These models suit companies that require standardized maturity levels as a quality characteristic or a possibility for comparison to other companies. Due to the high

[1] Internet portal of the initiative ENGINEERING produktiv!: http://www.engineering-produktiv.de

standardization, usually cost-intensive audits by independent institutions are necessary. Introducing and applying these models is therefore associated with high effort.

- **Class 2 - Methodological tools:** In this class, only the methodological framework of the model is defined. The models are fully adaptable to the specific needs of its users. There are procedures for the development of user-specific contents and for the definition of a target state. Because of the individual assessment, an inter-company comparability is not possible. These maturity models are used, if a highly individualized model is required that is feasible in a short time (1-2 months).
- **Class 3 - Flexible Regulations:** This class is particularly suitable, if there is a need to adapt the model largely on the specific requirements of the user. The adaption or extension is not arbitrary but supported by methods. In contrast to class 2, these methods enable an inter-company comparability. The effort for adaption and application is high and only useful for specialized companies.
- **Class 4 - Striking state representations:** This class focuses on a pragmatic performance evaluation. The models typically provide no guidance for performance improvement. Most of these models are highly focused on the particular area of interest. A performance evaluation can be carried out with little effort. Diagrams often visualize the current state of the company. An inter-company comparability is possible. These models allow for a quick (a few days) impression about the current performance of a specific area of the company.
- **Class 5 - Pragmatic cause-effect analysis**: This class is based on company-specific cause-effect chains that are indicated by key figures. These key figures are used for performance evaluation and monitoring. Generally, there are no predefined measures to manage these key figures in order to achieve a performance improvement. Models of this class usually require a well-established process management within the company, because they generally build on existing performance measurement systems.

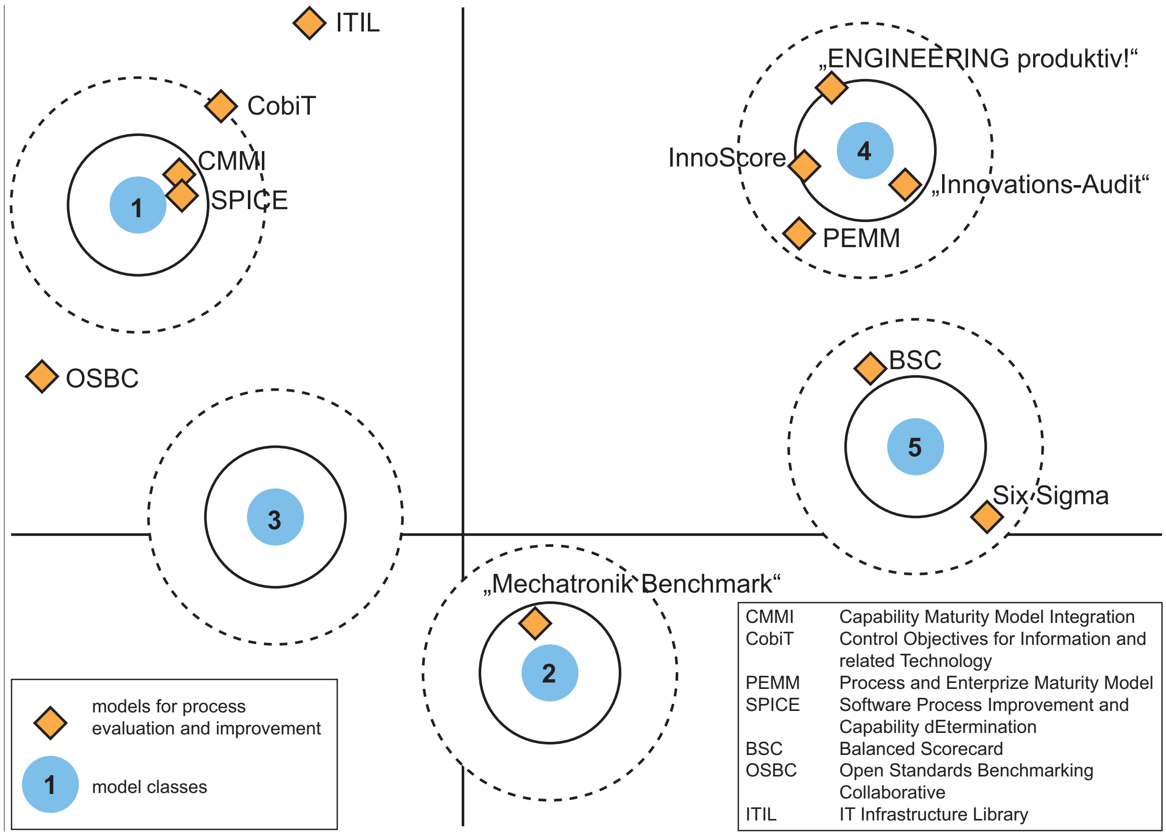

Figure 1. Classification of models for performance evaluation and improvement according to Christiansen [Christiansen et al. 2010]

Figure 1 shows that the models Six Sigma and Balanced Scorecard belong to class 5, while CMMI and SPICE fit to class 1. The distance between two models is a measure of their similarity. Due to the proximity of CMMI and SPICE, it can be concluded that these two models are similar. Despite the affiliation of Six Sigma and Balanced Scorecard to a common class, the models are rather different, since they are relatively far apart.

The existing models of the classes 1 and 5 (CMMI, SPICE, Six Sigma) are primarily used in large companies. They are very complex and the implementation requires a team of specialists being thoroughly familiar with the model. For many SMEs already the structure and nomenclature appear very theoretical and therefore daunting. For use in SMEs and particularly for such a specialized topic as VPS the models are not suitable. The classes 2 and 3 offer a high degree of flexibility for customization. Usually, this customization is not interesting for SMEs as they search for easy learnable and practicable models.

At best, the models of class 4 meet the requirements for a maturity based performance evaluation and improvement in SMEs. They are interesting due to the low effort resulting from the pragmatic application. The disadvantage of these models is the missing consideration of performance improvement. Deriving concrete measures to improve performance requires expert knowledge about the particular topic. As the SMEs often lack this knowledge, they are reliant on specialists supporting the development of a performance improvement strategy. Therefore, an approach is needed that gives concrete measures for performance improvement. As already mentioned in section 1, the highest level of performance must not be the most economical one for a SME. Thus, the approach also has to support the definition of a company-specific target state.

3. A maturity model for process improvement in SMEs

In the following, we introduce the VPS-Benchmark – a maturity model for performance evaluation and improvement focusing on VPS. Goal of the the model is a quick and easy evaluation and identification of potential process improvements. Additionally, the strategic planning of VPS-usage is supported. The target group are SMEs in mechanical engineering and related industrial sectors.

After explaining the basic concept of the maturity model, we describe its elements and procedure (section 3.1). Furthermore, we detail the definition of the target state (section 3.2).

The basic concept of the model is described in Figure 2. We differentiate between the development and the application of the maturity model. Both are interconnected by an interactive questionnaire, which will be available on an internet portal[2].

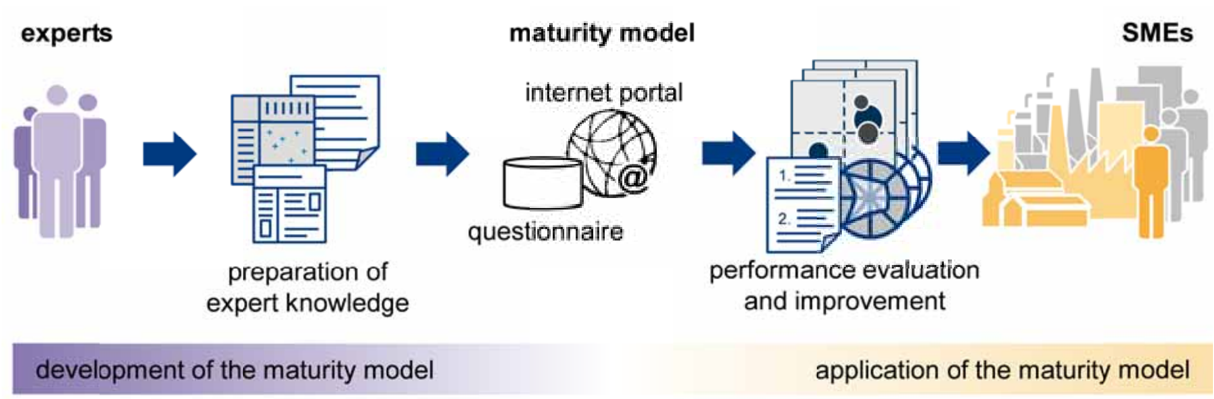

Figure 2. Basic concept of the maturity model

The *development of the maturity model* is based on expert knowledge that is prepared and converted for the interactive questionnaire. Various elements and their interrelations represent the knowledge, as it will be detailed in section 3.1. The knowledge is gathered in expert-workshops. In the context of VPS, we differentiate between three types of experts:

[2] The internet portal www.viprosim.de promotes the usage of VPS especially in SMEs.

- **Vendors** are specialists for dedicated VPS-tools, such as CAD-, PDM- or CAE-systems. They know best about the functional range of their tool and its potential benefits.
- **Consultants** can compare various product development processes and the advantageous application of VPS. They are specialists for optimal process integration.
- **Commendable SMEs** provide best practices. They know best about their particular requirements.

The SME *applies the maturity model* by answering the questionnaire. The questionnaire should be completed in a team including representatives from engineering, sales, marketing, production and documentation. First, the SME answers questions to various topics of VPS. Herewith, the current state expressed as maturity level is evaluated. Afterwards, questions about the company, its products and its business environment are asked. This information determines a company-class and a company-specific target state. The company-class and the maturity level enable a cross-company benchmark. Furthermore, the comparison between maturity level and target state allows deriving concrete measures for performance improvement. These measures are presented to the SME in measure-profiles under consideration of cost-benefit-ratios.

3.1 Elements and procedure of the maturity model

The procedure of the VPS-Benchmark is structured in 3 parts (Figure 3): performance evaluation, definition of target state and performance improvement. In the following, we describe the framework of the maturity model. Therefore, we use the intuitive example of CAD-tools.

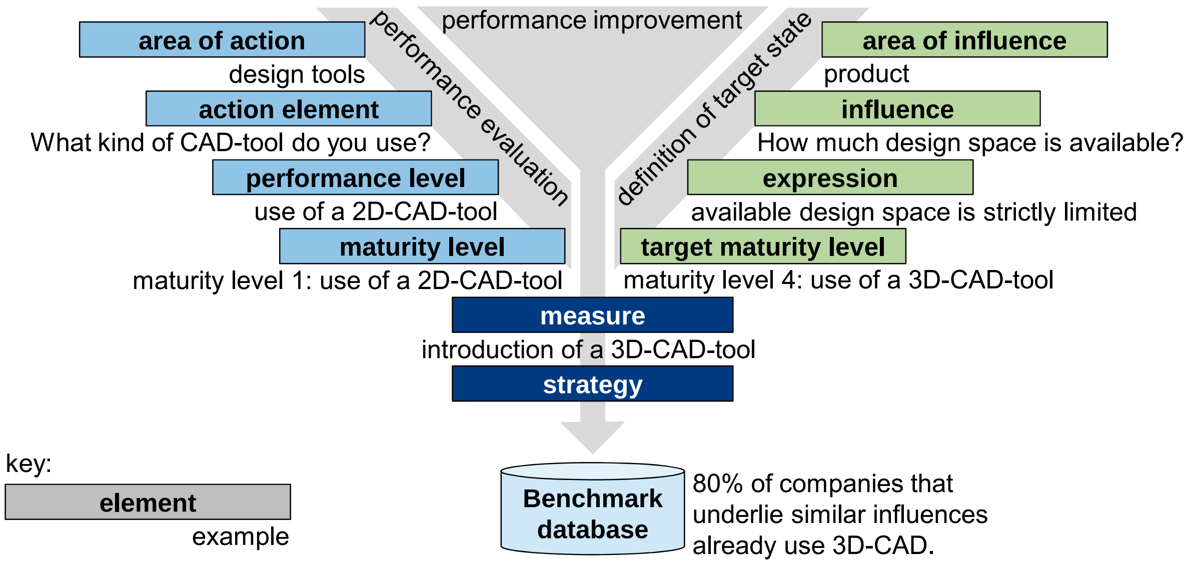

Figure 3. Framework of the maturity model

The left wing, the **performance evaluation**, consists of 4 elements. These elements are closely related to the basic structure of typical maturity models as described in [Gausemeier et al. 2009].

- **Areas of action** categorize the area of interest according to superior criteria, such as organization and technology. They ensure that all relevant facets are considered without having a one-sided perspective. In the context of VPS we consider six areas of action. An example is *design tools*.
- **Action elements** are performance indicators for the particular area of action. For each area of action, there are 20 to 50 action elements. An example is the application of CAD-tools. Action elements are formulated as questions, such as: *„What kind of CAD-tool do you use?“*
- **Performance levels** are the predetermined answers to the questions of the action elements. They indicate in which stage of development the action element is established. A low performance level would be the *use of 2D-CAD-tools*.

- All performance levels are associated with **maturity levels**. Maturity levels express the performance of an organization in an objective and measureable manner. Consequently, a high maturity level means a high-developed action element and thus a good performance in the particular area of action.

Beyond the current maturity level, the **definition of the target state** is required for deriving a strategy for performance improvement. A company-specific target state is defined in the right wing of the framework.

- **Areas of influence** are the equivalent to the areas of action in performance evaluation. They ensure that all relevant aspects are considered, which have an impact on the definition of the target state. Areas of influence in the context of VPS are the *company,* its *products* and its *business environment*.
- **Influences** and its **expressions** indicate in which stage of development the action element should be established. Similar to the action elements and performance levels they are formulated as questions with predetermined answers. In the example, we win the information that the *available space for design is strictly limited*.
- Out of the information given by the influences and its expressions, we can derive a recommendation for the target state expressed as **target maturity level**. In the example, the *use of a 3D-CAD-tool* would be recommended to optimize the usage of available design space. The target maturity level is the equivalent to the maturity level in performance evaluation. The interrelations between influences, expressions and maturity levels are detailed in section 3.2.

The bigger the difference between target maturity level and initial maturity level, the higher the need for action. The question arising is how to achieve the desired target state. This question is answered by the third part, the **performance improvement**.

- The comparison between target maturity level and initial maturity level provides recommendations for improvement in form of concrete **measures**. In case of the given example the measure would be the *introduction of a 3D-CAD-tool*.
- As there can be a lot of resulting measures, a **strategy** for their implementation is needed. This performance improvement strategy must include a prioritization of measures in terms of a cost-benefit-evaluation.

All results are collected in a so called **benchmark-database**. This database allows a benchmark between companies that underlie similar influences. Having enough data sets, the conclusion could be: *80% of the companies that underlie similar influences already use 3D-CAD*.

3.2 Definition of the target state

In the following, we detail the definition of the target state. As already mentioned, the definition of a target state ensures that SMEs only seek for economically advantageous performance levels. We again emphasize this with an example.

Two times per year, an SME is challenged by the integration of a dryer into his system. As the drying process is of crucial importance for product quality, the company decides to buy a suitable CFD[3]-tool and to simulate the process in-house. It quickly recognizes that the effort for practice is very high. In addition, the simulation results deviate from reality, because the boundary parameters are not defined properly. Simulating the second dryer a few months later, it can barely remember the operation of the CFD-tool. It decides to quit working with the tool. The investment in software and many staff hours are lost. Besides the economic loss, also the trust in VPS suffers, since the SME now decides that CFD is too complex and unnecessary. In this case, the SME would have been more successful, if it would have started on a lower performance level. It should have engaged an external service provider for simulation.

In this example, we can identify two factors that have had an influence on making the right decision: the frequency of the upcoming need for simulation as well as the importance of the process itself. A

[3] Computational Fluid Dynamics (CFD) means the computer-aided simulation of fluid mechanics [Wendt et al. 2009]

variety of influences affects the product development process. Such factors determine the desirable performance level per action element.

The VPS-Benchmark analyzes these influences to recommend an individually reasonable target state. Therefore, the influences have to be associated with the action elements and evaluated according to their relevance on the performance level. Figure 4 describes this procedure.

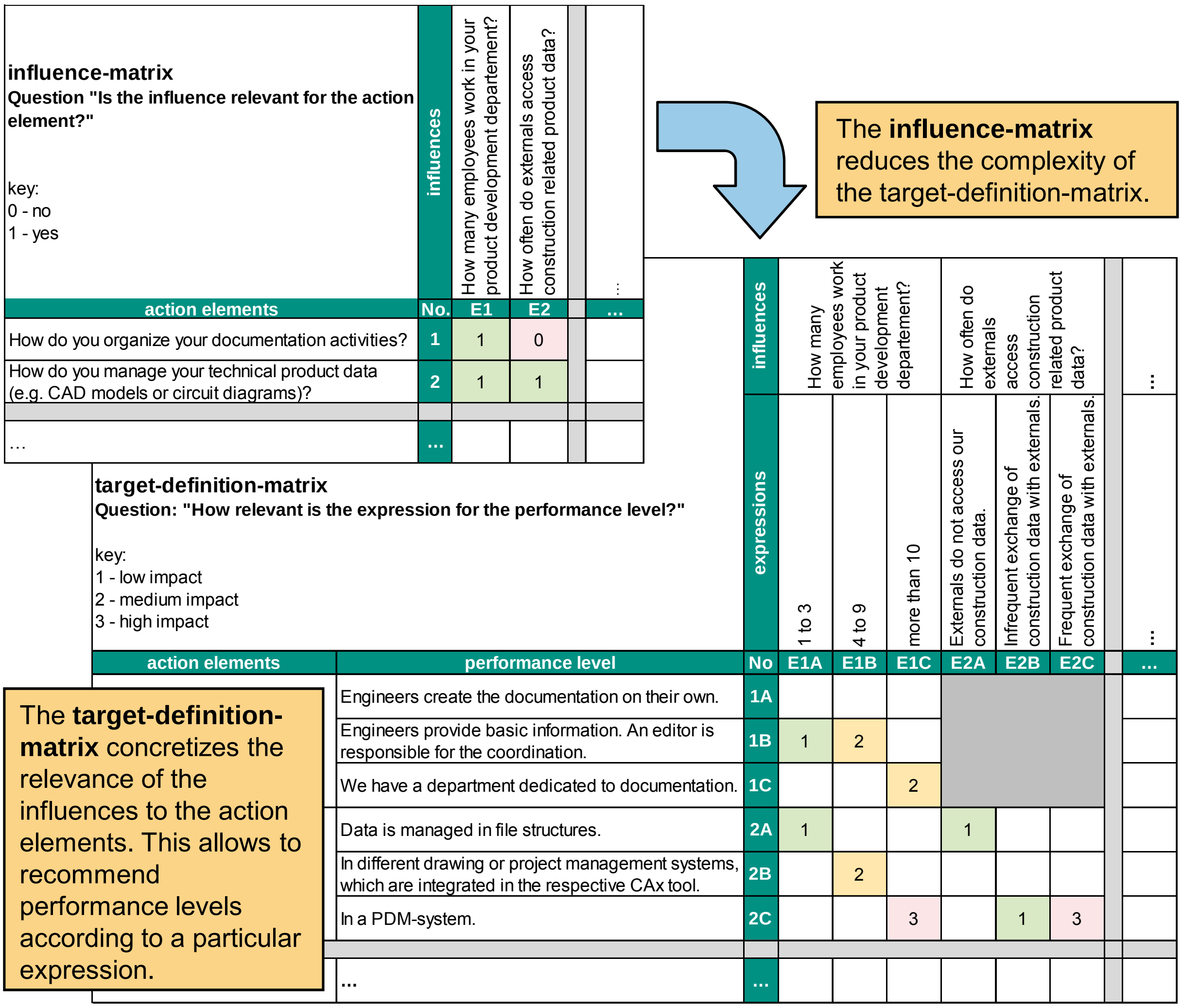

Figure 4. Influence- and target-definition-matrix linking action elements and influences

In the **influence-matrix,** influences are shown off against action elements. An influence can be relevant for different action elements as well as each action element can be affected by different influences. In a first step, it is decided whether the influence is relevant for an action element or not. This reduces the following target-definition-matrix.

In the **target-definition-matrix,** the expressions and performance levels are added. For each expression, its relevance for the performance level is rated. This rating now allows recommending a performance level according to a particular expression. During the application of the maturity model, the SME chooses its appropriate expressions. Based on the target-definition-matrix we can now recommend the desirable performance level for the SME.

In the following, examples illustrate the definition of the target state. First, we take a closer look on the influence-matrix. The *number of engineers* (No. E1) certainly has an influence on the *organization of documentation activities* (No. 1) and is rated with "1". In contrast, the *access of externals on construction related product data* (E2) has no impact and is thus rated with "0". For the *management of technical product data* (No. 2) both, the *number of engineers* (No. E1) as well as the *access of externals* (No. E2) are relevant.

In a second step, the expressions are evaluated according to their relevance on the particular performance level. This link is determined in the target-definition-matrix. In cases No. E1A and No. E1B it is advisable to appoint a *responsible editor for the documentation activities* (1B). From a *certain number of engineers* (E1C) it is reasonable to relocate the *documentation in a separate department* (1C). As already mentioned above, the *access of externals on the company's database* (E2) has no influence on the action element No. 1. Thus, a further consideration in the target-definition-matrix is not necessary. The field is grayed out.

In example No. 2, we have to consider two influences. In this case, the ratings of each performance level are summed up according to the chosen expressions. If the user has *five engineers* (E1B) and an *infrequent access of externals on the company's database* (E2B), the recommendation would be performance level 2B, as it is rated with 0:2:1 (2A: 2B: 2C). In this case, it is sufficient to *manage the data in an integrated system* (2B). The data exchange could be done via email or disk. In contrast, if there is a *frequent data exchange with external parties* (E2C), the performance level 2C wins with 0:2:3 (2A: 2B: 2C). It is then recommended to *manage product data with a PDM-system* (2C). PDM-systems typically provide opportunities to easily integrate externals. If the company has *more than 10 engineers* (E1C) and again a *frequent access by externals* (E2C), also the performance level 2C would be recommended with 0:0:5 (2A: 2B: 2C).

As it can be seen, the relations between the elements of the maturity model are complex. Handling this complexity requires software support. Section 4 describes the prototypical implementation of this software.

4. Prototypical implementation of a self-assessment tool

In the following, we introduce the software-environment of the VPS-benchmark. We describe the software's architectural concept and specify its functionality.

Since the state of the art of VPS is dynamically developing, the areas of action, its elements as well as the influences have to be customizable and extensible. Therefore, software has been developed that supports the development and the application of the maturity model. We differentiate between the *administration tool* and the *user tool*.

The software's architecture is based upon the model-view-controller-concept (MVC) [Sommerville 2010]. The MVC stringently separates three components: the data-model, the controller and views. The main advantage of this concept is that it enables easy modifications on one component without changing the other. The MVC has been used for the administration tool and the user tool as it can be seen in Figure 5. The interconnection of both tools bases upon the instantiated data-model of the administration tool.

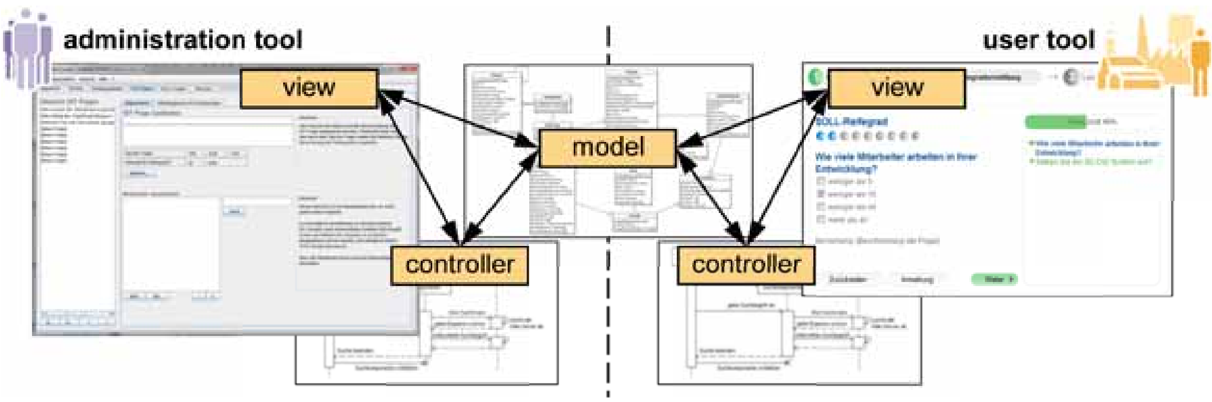

Figure 5. Model-view-controller-concept of the administration and user tool

The administration tool serves as a development environment for defining maturity models. This allows to extend the existing model as well as to implement completely new areas of interest with the same methodology. Conceivable are benchmarks to topics, such as Innovation Management or Supply Chain Management. While the content of the maturity model is variable, controlling and evaluation procedures (controller) as well as the view remain the same.

In the administration tool, tabs guide the user through the development of the maturity model. Thus, the elements required for the maturity model can be created quickly and structured. After all elements have been created, linked and evaluated a version of the data-model can be generated for online use in the user tool.
As the user tool is browser-based, no software installation is necessary. The user can directly start with maturity-based performance evaluation and improvement. The questionnaire guides the user; previous answers determine the sequence of questions. After answering all questions, the results are presented by diagrams, measure profiles and a cost-benefit-portfolio.

5. Conclusion and outlook

The paper started with a brief overview on existing approaches for performance evaluation and improvement. We pointed out that specific requirements arise out of the need for maturity models in SMEs. SMEs have neither the time nor the money to get into complex models for performance improvement, such as CMMI (Capability Maturity Model Integration). We introduced an approach for maturity based process improvement that is suitable for SMEs and focused on VPS.
The approach achieves all the specific requirements that arise out of the need for maturity models in SMEs. The interactive questionnaire supports the performance evaluation and is easy applicable. Due to the fact that the questionnaire is internet based no special software is required. Additionally, only a short time for application is necessary. The questionnaire can be completed in not more than two days. Through the prepared expert knowledge no external consultants are necessary. Based on the analysis of influences we define an economical company-specific target state. We are able to recommend concrete measures for performance improvement.
For future works, the prototypical implementation enables the validation of the maturity model. Therefore, we will evaluate the product development processes of several SMEs in mechanical engineering. For each SME we will compare the results of the VPS-Benchmark with the recommendations of consultants.

Acknowledgement

This contribution was developed in the course of the project "Virtual Prototyping and Simulation Benchmark: tools for analysing and optimizing the use of virtual prototyping and simulation in the product development process" funded by the Ziel-2 programme "Hightech.NRW" of North Rhine-Westphalia.

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