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FRAMEWORK FOR THE DEVELOPMENT OF MATURITY BASED SELF-ASSESSMENTS FOR PROCESS IMPROVEMENT

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ABSTRACT
Increasing productivity and competitiveness are still major challenges for companies. One approach for performance improvement are maturity models. Their main principle is an objective performance evaluation and improvement that can be applied on different topics (e.g. innovation management, virtual prototyping & simulation). To simplify the application of the principle on new topics, this paper presents a framework that allows an efficient and standardised development of a maturity model that can be conducted as a self-assessment. The framework consists of a standardised architecture for the maturity model, a procedure model for its development and a software-tool. The application of the framework on the topic of Virtual Prototyping & Simulation resulted in the VPS-Benchmark, which serves as an example for a maturity based self-assessment throughout this paper. The paper concludes with an outlook on a future application of the framework in the course of the leading edge cluster it's OWL – Intelligent Technical Systems OstWestfalenLippe. Here a maturity based self-assessment will be provided to qualify the cluster partners for developing intelligent technical systems.

Keywords: organisation of product development, design process, process maturity models, performance self-assessment

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1 INTRODUCTION

Shorter product life cycles, increasing product variety and global competition are major challenges for the production industry. Therefore, companies have to increase productivity and competitiveness. Approaches for an increase in productivity are Simultaneous Engineering (Scheer et al., 2005), Integrated Product Development (Ehrlenspiel, 2002) or Lean Management (Womack and Jones, 2003). The mentioned approaches aim at effective and efficient processes. Maturity models also support the optimization of processes. The main principle of process optimization by means of maturity models are an objective performance evaluation, a concept for improvement and a subsequent monitoring of progress (de Bruin et al. 2005), (Becker et al., 2009).

When it comes to maturity models, then two perspectives can be differentiated: application and development of maturity models (Mettler, 2009). This is shown in figure 1.

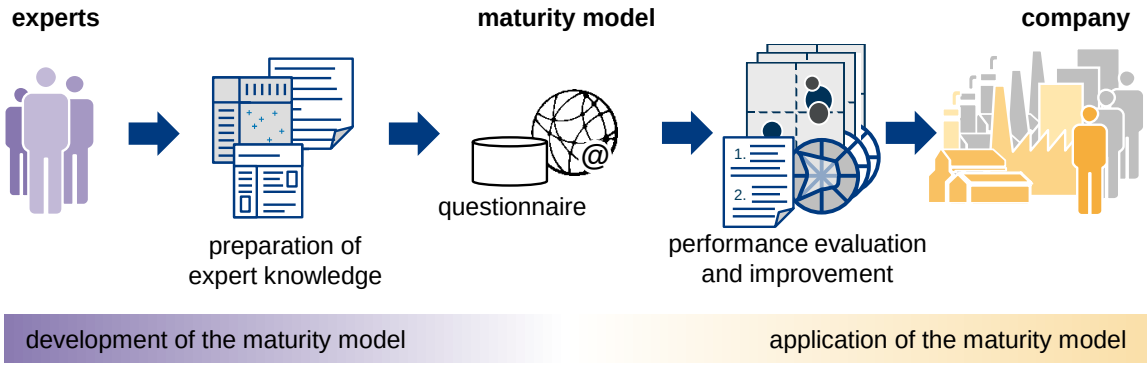

Figure 1. Development and application of maturity models

The **application of maturity models** in companies is carried out in assessments with the help of questionnaires, check lists and regulations for their application. Aim of the assessment is an objective performance evaluation that indicates the need for action. If these assessments are independently conducted by the company, it is called a self-assessment (Becker et al., 2009).

The **development of maturity models** is usually not done by the company itself, but rather through standardisation committees, business consultants or scientists. The principle of maturity models can be transferred to many different topics (e.g. innovation management, supply chain management), what makes them highly attractive as a business model as well as an instrument for sharing knowledge on a topic within a selected community. This led to a rapid growth in the development of maturity models and consequently to the question of how to improve this development. Recently, several approaches for improving the development of maturity models have been introduced. Examples are (Becker et al., 2009), (Christiansen, 2009), (Maier et al., 2012), who suggest procedure models for a more systematic development. This paper complements these approaches by introducing a framework that consists of an adapted procedure model, a standardised architecture for the maturity model and a software-tool. The framework allows an standardised and efficient development of a maturity model that can be conducted as a self-assessment.

This paper is organized as follows. In chapter 2, we point out the demand for a standardised framework for the development of maturity based self-assessments. Before we introduce the framework in chapter 4, we describe the VPS-Benchmark that serves as an example for a maturity based self-assessment. Later on, we introduce the framework with a special focus on the architecture of the maturity model and the systematic approach supporting the development. Finally, we give an outlook on another application of the framework within the leading edge cluster it's OWL.

2 DEVELOPMENT OF MATURITY MODELS

2.1 Basic terms of maturity model management

The growing number of available maturity models intensified the academic debate on maturity model management within the last years (Becker et al., 2009), (Christiansen, 2009), (Maier et al., 2012). For a better understanding, the following terms are defined: **Maturity levels** define performance levels for the properties of objects (i.e. the quality of data security in development departments). With the help of maturity levels, **maturity models** describe a simplified image of reality; they are reference models

(Mettler, 2009). Based on the assumption that the organisational development of a company follows a predictable pattern, maturity models can lead a company along a consistent path to higher performance (Röglinger et al., 2011), (van den Ven and Poole, 1995). This is what is meant by **maturity level management**. An example is the BESTVOR-maturity model; it serves as systematic improvement of mechatronic development processes in machine and plant engineering. Companies are supported to improve its processes from the maturity level "classic" over "mastered" to "advanced" (Rauchenberger, 2011). Other well-known maturity models are Capability Maturity Model Integration (CMMI) (Software Engineering Institute, 2006) or Process and Enterprise Maturity Model (PEMM) (Hammer, 2007). The growing number of available maturity models leads to the discussion of their development.

2.2 The need for a standardized development of maturity models

The development of a maturity model is a complex undertaking. Patterns have to be recognised, structured, and documented in order to lead a company along a logical path to higher performance (Röglinger et al., 2011). In order to reach this goal, the development has to follow a structured, iterative process, in which experts are involved. However, maturity models are often not developed on the basis of a systematic approach (Rosemann et al., 2006). In addition, maturity models are often inadequately documented and not reproducible. Therefore, quality and validity of the maturity models are not easily assessable (Becker et al., 2009). As this problem is known, there are several procedure models for a structured development that have already been outlined in literature. Examples are (de Bruin et al., 2005), (Becker et al., 2009), (Christiansen, 2009), (Mettler, 2009), (Maier et al., 2012).

All these procedure models already offer good assistance and lead from the *analysis* of the problem, over the *actual development* of the maturity model to *final evaluation* within the target group. However, the challenge of these procedure models is the actual development of the maturity model. In this phase, existing procedure models leave the architecture unanswered, which defines the fundamental structure of the maturity model.

The architecture essentially influences the development with regard to the content of the maturity model. Depending on the architecture, different elements have to be defined that specify the maturity model with regard to the corresponding topics, like innovation management or quality management. Consequently, the chosen architecture strongly affects the development procedure.

Additionally, the architecture influences the characteristics of the maturity model. Some examples for these characteristics are the assessment system and the effort for training. The comparison of CMMI and PEMM reveals this. Both have different architectures. Introducing CMMI in a company requires intensive training of staff and the involvement of different divisions (Software Engineering Institute, 2006). The introduction often requires months to years (Gausemeier et al., 2009). In contrast, PEMM is a very pragmatic approach that can be applied with minimal effort and without trained staff. The maturity levels can be determined within days (Hammer, 2007).

In order to achieve a standardised and more efficient development, it is thus necessary to define the architecture of the maturity model. In the following, we introduce a framework consisting of a standardised architecture and a thereupon aligned procedure model and software-tool. The whole framework is constructed in a way that the resulting maturity model is especially appropriate for the application in SMEs (for a detailed discussion see Gausemeier et al., 2012). The following aspects characterize the maturity model:

- **Self-assessment approach:** The maturity model can be conducted as self-assessment. The application is pragmatic and only takes a few days.
- **Comparability of results:** The model offers the option for comparing the own performance with those of other companies. Results are clear and reproducible.
- **Model-inherent recommendations for performance improvement:** Concrete recommendations on how to obtain a target state are given model-inherent. "Model-inherent" means that company-external experts do not add knowledge to the model during its application.

3 VPS-BENCHMARK – MATURITY BASED SELF ASSESSMENT FOR VIRTUAL PROTOTYPING & SIMULATION

Before we describe the framework in detail, we introduce the VPS-Benchmark – a maturity based self-assessment that was developed by applying the framework. The VPS-Benchmark builds up on a stand-

ardized architecture; its development followed a systematic approach, which was supported by a software-tool. It serves as an illustrative example for the frameworks outcome.
The VPS-Benchmark helps to analyze and optimise the use of virtual prototyping and simulation (VPS) in the product development process. The application of the model is tailored to the needs of small and medium-sized companies in mechanical engineering: it is quick, easy and requires no lengthy training. It can be performed in a few days. Figure 2 shows the structure and exemplary results of the VPS-Benchmark.

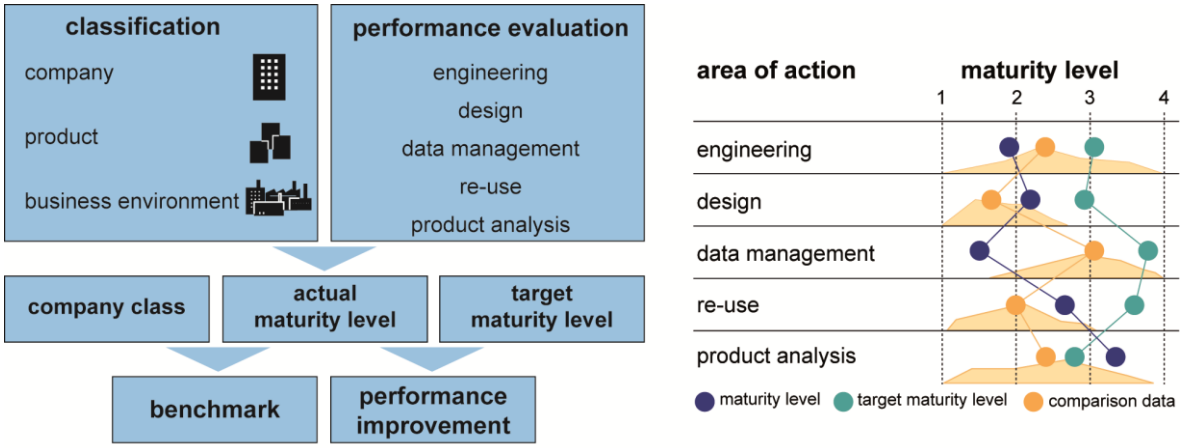

Figure 2. Structure of the VPS-Benchmark and visualisation of exemplary results

The VPS Benchmark is available as a self-assessment tool that guides the company through a structured online questionnaire containing up to 200 questions on the following areas of action: engineering management, design, data management, re-use and product analysis. On completion of the analysis, the results are immediately calculated and available to the company. A maturity level is determined for each of the areas of action. A graphic representation of the maturity levels shows the VPS-performance of the company in an easy-to-follow form. To improve performance, an individual target state is sought. This lays down a recommended optimal maturity level for each area of action, based on the classification of company characteristics (e.g. number of engineers), product characteristics (e.g. number of components) and business environment (e.g. competition). On the basis of current performance, the company will receive assistance in developing an individual strategy for performance improvement. Analyses that have already been conducted are stored in a database, allowing an anonymous benchmark with other companies of similar size from the same branch or industry.

4 FRAMEWORK FOR THE DEVELOPMENT OF MATURITY BASED SELF-ASSESSMENTS

In this chapter, we introduce the framework for the development of maturity based self-assessments. The framework allows the development of maturity models, like the VPS-Benchmark, in an efficient and standardised way. Next to an easy and quick performance assessment, the self-assessments propose a company-specific target state. Furthermore they give concrete recommendations for a performance improvement strategy that helps to obtain this target state. The framework consists of a standardised maturity model, a procedure model for its development and a corresponding software tool.

- **Standardised maturity model:** The maturity model is the core of the framework. It defines the necessary elements, contents, and calculation rules for the determination of the current performance level, the target state as well as useful recommendations for improvement. The architecture of the maturity model will be described in detail in section 4.1 and section 4.2.
- **Procedure model:** The procedure model defines the necessary activities for the development of the maturity based self-assessment. The procedure model will be described in detail in section 4.3.
- **Software tool:** The maturity model and the procedure model are supported by a software tool. This tool serves as development environment for the maturity model. It allows an extension of existing models as well as a completely new development. Additionally, the software tool supports the application of the self-assessment through the company. The software tool will not be presented in detail.

4.1 Architecture of the maturity model

The architecture of the maturity model is structured in 3 parts (figure 3): performance evaluation, definition of target state and performance improvement. In the following, we describe the elements of this architecture. Therefore, we use an intuitive example, the introduction of a PDM-system.

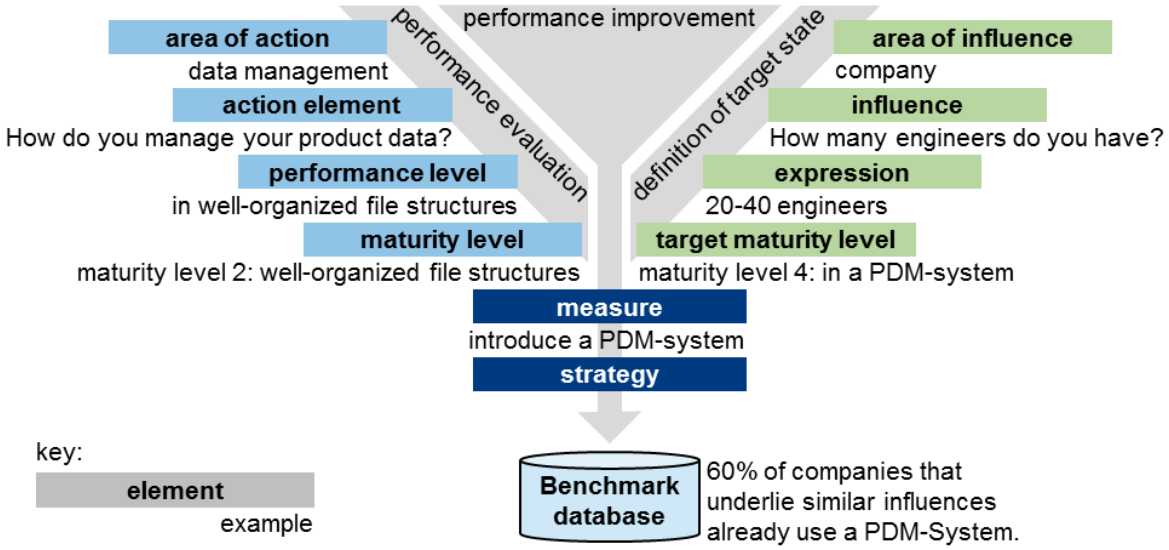

Figure 3. Architecture of the maturity model

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

- **Areas of action** categorise the topic 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 5 areas of action. An example for this is data management.
- **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 a PDM-system. Action elements are formulated as questions, such as: ”How do you manage your product data?“
- **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 well-organised file structures.
- All performance levels are associated with **maturity levels**. Maturity levels express the performance of an organisation in an objective and measureable manner. Consequently, a high maturity level means a highly 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.

- **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 the 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 receive the information that the company has 20-40 engineers.
- Out of the information given by the influences and its expressions, we can derive a recommendation for the target state, which is expressed as the **target maturity level**. In the example, the use of a PDM-system would be recommended to optimise the data management. The target maturity level is the equivalent to the maturity level in performance evaluation.

The bigger the difference between target maturity level and initial maturity level, the higher the need for action. The question, which arises, 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 the form of concrete measures. In case of the given example the measure would be introduce a PDM-system.
- As there can be a lot of resulting measures, a strategy for their implementation is needed. This performance improvement strategy must include a prioritisation 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: *60% of the companies that underlie similar influences already use a PDM-system*.

4.2 Setting the interrelations between the elements

The elements of the maturity model define the architecture of the model in an abstract way. The specification of these elements defines the content of the model. In the next step, the elements are interrelated with the help of different matrixes. Based on these interrelations, calculation rules and defined logics help to automatically interpret the answers which are given in the self-assessment. Figure 4 shows a schematic diagram of the interrelations between the elements and matrixes.

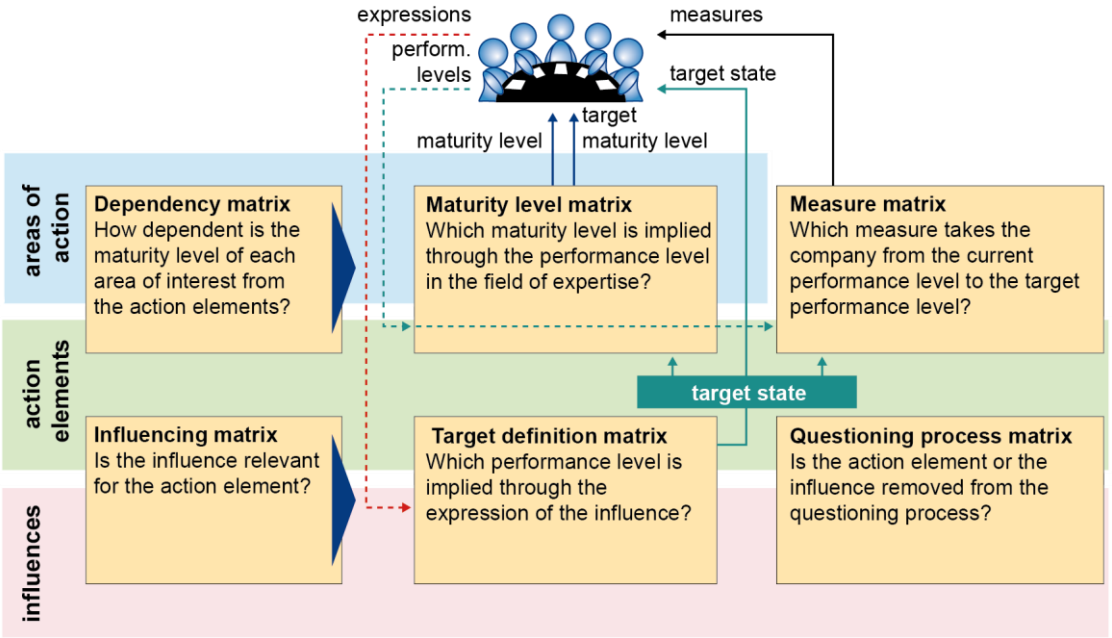

Figure 4. Schematic diagram of the interrelations of elements set by matrices

In the following, matrixes and the defined logics of the maturity model are described. Six matrixes connect the elements:

- The **Dependency matrix** describes how the action elements are influencing the areas of interest. This matrix reduces the complexity of the following maturity level matrix.
- Within the **Maturity level matrix** a maturity level for each performance level is defined. On the basis of this matrix, the maturity levels and the target maturity levels are calculated.
- The **Influencing matrix** describes the impact of the influences on the action elements. This matrix reduces the complexity of the target definition matrix.
- Within the **Target definition matrix** it is defined which performance level should be targeted according to the expression of the influence. On the basis of this matrix the target performance level for every action element can be determined.
- Within the **Measure matrix** the measures are defined that take the company from a defined performance level to a targeted performance level. With the help of this matrix the appropriate measures for performance improvement are selected and recommended.
- The **Questioning process matrix** controls the questioning process. As there are many dependencies between the questions, it is defined weather a question is asked or not.

By answering the questions of the action elements and influences, expressions and performance levels are set. This input initializes operations of the matrixes. On the basis of the chosen performance levels,

the maturity levels are determined in the maturity matrix. The target definition matrix allows the determination of the targeted performance levels on the basis of the influence expression. A comparison between the current maturity level and the target maturity level allows the derivation of concrete measures for improvement. The questioning process is controlled by the questioning process matrix

4.3 Procedure model for the development of self-assessments

Based on the standardised maturity model, the elements have to be specified with regard to the chosen topic. The software tool helps to initialize the maturity model as an executable self-assessment. This development process is structured as a procedure model, which is shown in figure 5. It follows the basic concept of existing procedure models (cf. section 2) and is adapted to the special needs of this framework. The procedure model is divided into 5 phases: preparation, definition of the elements for performance evaluation, for target definition and for performance improvement as well as introduction and maintenance. In the following, each phase is explained.

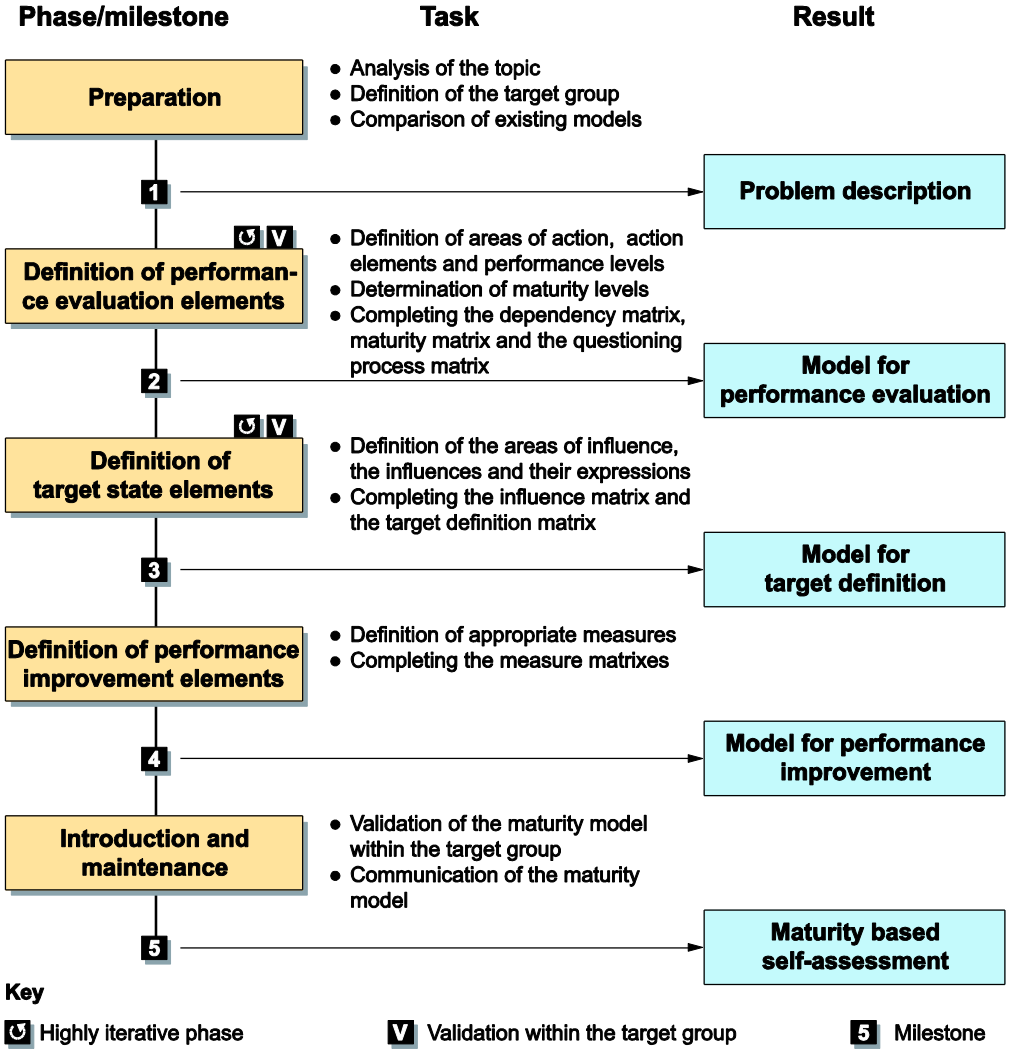

Figure 5. Procedure model for the development of the maturity based self-assessment

In the **preparation phase** (phase 1), the topic is analyzed and the need for action is further detailed. In the context of the VPS-Benchmark the topic is limited to Virtual Prototyping & Simulation. Subsequently, the general requirements of the maturity model are defined. Therefore, the target group is determined: Which company classes and which groups of people have to be reached? In the example of the VPS-Benchmark, the target group is limited to small and medium-sized companies of mechanical engineering. For the development of the model, a team is created, which ideally possesses experience in the application and also in the development of maturity models. Furthermore, basic knowledge in the addressed topic is needed. Specific knowledge should be consulted from external experts. In the case of the VPS-Benchmark, this was ensured through the cooperation between the Heinz Nixdorf Institute and the OWL-ViProSim – a competence centre for Virtual Prototyping & Simulation.

In the next phase, **definition of elements for performance evaluation** (phase 2)**,** the areas of action, the action elements and the performance levels are determined. The areas of action divide the topic into higher level tasks. For the VPS-Benchmark, these are for example data management and product analysis.
The next hierarchical level is the action elements. In the context of the standardised architecture within this framework they are formulated as questions. They always deal with a concrete aspect of the areas of action. An example for an action element is: *"What is your company's attitude towards the participation in research projects?"*
The next step is the definition of the performance levels. The performance levels represent possible states in levels from "poorly implemented" to "ideally implemented" including concrete status descriptions. Examples referring to the above mentioned action element are "*Research projects are unattractive for us"*, "*We actively work with the results from research projects, but do not actively participate"* and finally "*We actively participate in research projects"*. These examples illustrate what a concrete description of performance levels should look like. Phrases such as *"Research projects are less interesting for us", "Research projects are quite interesting for us"* and *"Research projects are very interesting for us"* should be avoided, as they are interpreted differently by each person.
For the identification of areas of action, action elements and performance levels various methods like literature research, creativity techniques, inventory model analysis, interviews or observations are available. To make sure that these elements represent reality in an adequate manner, they should be validated within the target group as early as possible. This leads to additional elements or changes in their formulations, which make this phase highly iterative.
As soon as all the elements are identified, the software tool can be used to complete the dependency matrix, maturity matrix and the questioning process matrix. After this phase, a maturity model for performance evaluation is available.
In phase 3, **definition of the elements for the target state**, the areas of influence, the influences and its expressions are determined. This can be done with the same methods as in phase 2. As soon as all the elements are described, the influence matrix and the target definition matrix are completed using the software tool. After this phase, the maturity model can recommend individual target states.
In phase 4, **definition of the elements for performance improvement**, measures are defined that lead a company from a certain performance level to a target performance level. As soon as all the measures are defined, the measure matrixes can be completed. After this phase, the model allows model-inherent recommendations for performance improvement.
In the last phase, **introduction and maintenance** (phase 5), the validation and the roll out of the model are planned. The maturity model is validated in the target group in order to evaluate how far the maturity model effects the originally aspired benefit and offers an improved solution for the original question (Becker et al. 2009). For this purpose, case studies are suitable in which the model is only applied to chosen companies. The results of the validation can provoke a revision of the maturity model. In the context of the VPS Benchmark, this was executed in a small circle together with partner companies of the OWL-ViProSim. After the successful validation, the maturity model is communicated to the target group in an appropriate way. Experience for the roll-out should already be gathered during the validation.

5 APPLICATION OF THE FRAMEWORK WITHIN THE LEADING EDGE CLUSTER IT'S OWL

The framework allows an efficient and standardised development of maturity based self-assessments, like the VPS-Benchmark. On the one hand, these self-assessments allow companies to evaluate and improve their own performance focused on a chosen topic. On the other hand, they are an appropriate tool to transfer knowledge to a selected community. This knowledge-transfer allows a target-oriented qualification of companies within a specialised topic. Therefore, we use the framework to develop a maturity based self-assessment for the leading edge cluster it's OWL. This self-assessment will be provided to help qualifying the cluster partners for developing intelligent technical systems (ITS).
The cluster "it´s OWL - Intelligent Technical Systems OstWestfalenLippe" promotes the innovation leap from mechatronics to systems with inherent partial intelligence. Among the participating 174 cluster partners, there is a heterogeneous group of 127 companies from mechanical engineering and the electrical and automotive supply industries. The common goal is to reach a top position in a global

competition on the field of ITS. Therefore, the cluster follows a strategy that is operationalised through multiple projects. Figure 6 shows a detail of the project structure.

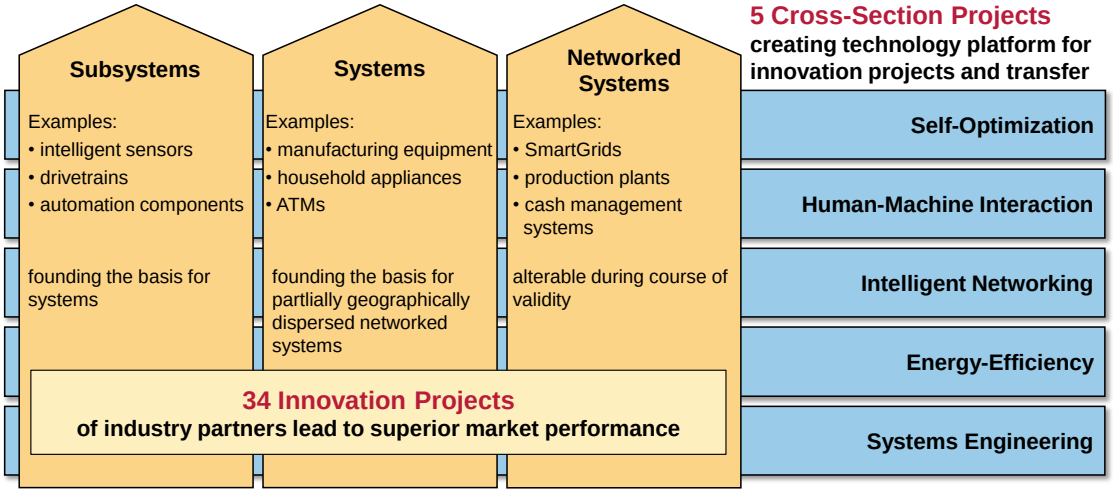

Figure 6. Detail of the project structure

At the centre of the strategy, there are 34 innovation projects leading to marketable achievements. In five cross-sectional projects universities and university-associated competence centres provide basic and industry-oriented research results. This includes results on technologies like self-optimization and human-machine interaction. Altogether these projects form a technology platform that builds the fundament for the development of ITS. However, the introduction of ITS-technologies in the product development process, requires new competences at the companies; the challenge is a systematic improvement of a variety of product development departments with regard to ITS.

One approach to face this challenge is the development of an ITS-oriented self-assessment. This self-assessment allows an evaluation of the product development departments of the cluster partners and recommends individual programs of measures for performance improvement. The measures aim at introducing the developed methods and technologies of the technology platform. Additionally, they suggest an improvement of methods, tools and processes within the company. A frequent application of the self-assessment helps monitoring the advancement of the whole cluster with regard to ITS.

The assessment has to be tailored to a heterogeneous target group. The product development departments reflect the different industrial backgrounds, products and company-sizes of the cluster partners. As an example, the development department of an automotive supplier has a different need for action than a medium-sized manufacturer of industrial washing equipment. Furthermore, the assessment has to consider the needs resulting from the application of ITS-technologies. All the mentioned requirements already give a good overview on the problem description, which is demanded by phase 1 of the procedure model in section 4.3. According to this procedure model, the next step is to define the elements for performance evaluation. Therefore, the topic of ITS is divided into five areas of action that correspond to the five cross-sectional projects. The areas of action are the basis for future work. Action elements and related performance levels as well as influences and its expressions have to be defined to specify the architecture of the maturity model in detail.

6 CONCLUSION AND OUTLOOK

Maturity models are a helpful instrument for performance evaluation and improvement that can be applied on different topics (e.g. innovation management, virtual prototyping & simulation or development of intelligent technical systems). We gave an overview on the development of maturity models and pointed out the requirements that have to be fulfilled by a framework for an efficient and standardised development of maturity based self-assessments. The framework requires a standardised architecture and a thereupon aligned procedure model and software-tool. We introduced the framework with a special focus on the architecture and the procedure model. To enhance understanding, the VPS-Benchmark was given as an example for a maturity based self-assessment. Future works concentrate on the application of the framework within the leading edge cluster it's OWL. Here, a maturity based self-assessment will be developed that focuses on a systematic improvement of product development processes with regard to the special requirements of intelligent technical systems.

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REFERENCES

Becker, J., Knackstedt, R., Pöppelbuß, J. (2009), ‘Entwicklung von Reifegradmodellen für das IT-Management – Vorgehensmodell und praktische Anwendung‘, Münster, Westfälische Wilhelms-Universität Münster, Institut für Wirtschaftsinformatik.

de Bruin, T., Rosemann, M., Freeze, R., Kulkarni, U. (2005), ‘Understanding the Main Phases of Developing a Maturity Assessment Model‘, in *Proceedings of the 16th Australasian Conference on Information Systems*, Sydney, Australia.

Christiansen, S.K. (2009), ‘Methode zur Klassifikation und Entwicklung reifegradbasierter Leistungsbewertungs- und Leistungssteigerungsmodelle‘, Dissertation, Fakultät für Maschinenbau, Universität Paderborn, HNI-Verlagsschriftenreihe, Band 264, Paderborn.

Ehrlenspiel, K. (2002), *Integrierte Produktentwicklung. Denkabläufe, Methodeneinsatz, Zusammenarbeit*, München, Carl Hanser Verlag.

Gausemeier, J., Bensiek, T., Kühn, A., Grafe, M. (2012), ‘Maturity Based Improvement of Product Development Processes in Small and Medium-Sized Enterprises‘, Dubrovnik, Croatia, *Proceedings of the Design 2012, 12th International Design Conference*.

Gausemeier, J., Plass, C., Wenzelmann, C. (2009), *Zunkunftsorientierte Unternehmensgestaltung – Strategien, Geschäftsprozesse und IT-Systeme für die Produktion von morgen*, München, Carl Hanser Verlag.

Hammer, M. (2007), ‘The Process Audit‘, Harvard Business Review.

Knoblinger, C., Oehmen, J., Rebentisch, E., Seering, W., Helten, K. (2011), ‘Requirements for product development Self-assessment tools‘, Kopenhagen, Denmark, *Proceedings of the International Conference on Engineering Design*.

Maier, A., Moultrie, J., Clarkson, P.J. (2012), ‘Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids‘, *IEEE Transactions On Engineering Management*, Vol. 59, No. 1.

Mettler, T. (2009), ‘A Design Science Research Perspective on Maturity Models in Information Systems‘, University of St. Gallen.

Rauchenberger, J., (2011), ‘Reifegradmodelle als Ordnungsrahmen zur systematischen Prozessverbesserung für mechatronische Entwicklungsprozesse‘, Dissertation, Aachen, Apprimus Verlag.

Röglinger, M., Pöppelbuß, J., Becker, J. (2011), ‘Maturity Models in Business Process management‘, *Business Process Management Journal*.

Rosemann, M., De Bruin, T., Power, B. (2006), ‘A Model to Measure Business Process Management Maturity and Improve Performance‘, inJeston, J., Nelis, J. (eds) (2006) *Business Process Management*, Butterworth-Heinemann, Boston.

Scheer, A.W., Boczanski, M., Muth, M., Sschmitz, W.G., Segel-Bacher, U. (2005), *‘Prozessorientiertes Product Lifecycle Management*‘, Berlin, Springer-Verlag.

Software Engineering Institute (SEI) (2006), CMMI® for Development, Version 1.2.

van den Ven, H, Poole, M. S. (1995), ‘Explaining Development and Change in Organizations‘, *Academy of Management Review*, vol. 20, no. 3, pp. 510-540.

Womack, J.P., Jones, D.T. (2003), ‘Lean Thinking: Banish waste and create wealth in your corporation‘, New York, Free Press.