A Process Reference Model for Reuse in Industrial Engineering: Enhancing the ISO/IEC 15504 Framework to Cope with Organizational Reuse Maturity

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Abstract

Improving reuse in industrial engineering for solution providers is more and more recognized as a key to economic success. Improving reuse increases the quality of the engineered systems, shortens engineering time, and decreases engineering costs regarding the development of customer-specific solutions. The GDES-Reuse project is therefore developing an integrated set of methods for assessing an organization's reuse practices, identifying its reuse potential and guiding the selection, planning and implementation of improvement actions.

The paper reports on the project's work on developing an ISO/IEC 15504 conformant process reference model for reuse in industrial engineering. Based on an overview and the background of the GDES-Reuse improvement methodology, the paper focuses on presenting the structure of the reference model and on describing the necessary enhancements to the ISO/IEC 15504 framework to enable the evaluation of organizational reuse maturity and the integration with a staged model of reuse maturity. A summary of the experiences and insights gained and of the current state of methodology development and future work together with considerations on the applicability of the project's results to the domain of software engineering round up the paper.

1. Introduction and Motivation

Industrial engineering is the discipline dealing with methods, processes and tools for the engineering of industrial solutions – ranging from power plants to airport logistic systems. Increasing reuse, vertical integration of involved disciplines, functional coverage of engineered modules relative to the overall solution, and horizontal integration of activities and artifacts across the engineering life cycle have been identified as key elements for increasing quality and productivity in industrial engineering (cf. [1]).

The GDES[1] series of projects carried out in cooperation *between Siemens AG Corporate Technology, Kepler University Linz* and the *Software Competence Center Hagenberg* aims at developing concepts and methods to exploit the respective improvement potentials of engineering organizations and to increase engineering maturity in general. Engineering organizations in this context mean the engineering divisions of industrial solution providers. The research cooperation started in 2001 and since then has focused on topics like integration of engineering processes and integration and synchronization of engineering data (cf. e.g. [2]). Since October 2004 the focus of the work is on developing a model based methodology for assessing and improving an organization's reuse practices and exploiting the respective reuse potential. The planned end of the work within this GDES-Reuse project is October 2006.

The following sub-sections describe the context of industrial engineering from a reuse perspective, provide the detailed goals of the methodology development work, describe the chosen development approach, and lay out the structure and relationships of the methodology components.

[1] Globally Distributed Engineering and Services

Finally, an overview on the remainder of the paper rounds up this introductory section.

1.1. Context of Industrial Engineering in Solution Business

Industrial engineering is generally used as a synonym for the acquisition, planning, development, realization and the start of operation of industrial plants and typically comprises the engineering of mechanical components, electrical engineering and the engineering of the control and communication system. Industrial Engineering further includes process or chemical engineering, i.e. the engineering of the technical processes necessary to operate the plant. Unlike the engineering of products or mass products industrial engineering typically focuses on developing solutions for highly individual customer requirements.

Industrial engineering today has to cope with increasing demands for more flexible, more reliable, more productive, and cost optimized planning and realization of industrial solutions. It is an omnipresent challenge to increase productivity and to decrease engineering costs and time, to improve quality and reliability, and to optimize internal engineering processes as well as external business relations. At the same time, industrial engineering has to deal with more demanding customer requirements, increased complexity of solutions and harder competition in a global market.

Reuse is one of the most basic techniques in industrial engineering. It is simply the idea to reuse previously developed engineering artifacts in the engineering of a new solution. Reuse in engineering is omnipresent and is not limited to solution components. Rather, it pervades all engineering phases and also applies to engineering artifacts like requirement specifications, use cases, architectures, test cases, test certificates, documentation, etc.

Although recognized as a fundamental and indispensable approach, reuse in industrial engineering is hardly systematized and often only applied in an ad hoc manner. Typically, a suitable artifact from a former project is selected, evaluated for its suitability and then adapted to meet the requirements of the current project – we call this approach “copy & modify”. Moreover, reuse often only occurs on the initiative of individuals and therefore depends on their skills and experience, i.e., there is no organization-wide awareness for the topic. Even in engineering organizations with existing well developed libraries of reusable components, reuse is often not established in a systematic way. Although it takes place in every day’s project work, the available reusable component libraries have not been analyzed and established in a systematic way in many cases.

As a consequence the reuse potential in industrial engineering organizations is hardly exploited and in most cases not even known. Therefore, the investigation of the reuse potential and introduction of effective improvement programs is a promising way to meet the challenges of industrial engineering.

1.2. Goals of Methodology Development

In order to help engineering organizations to tackle above challenges, the overall goal of the GDES-Reuse project has been set as the development of an integrated methodology for evaluating an organization’s reuse practices and identifying and exploiting the respective reuse potential. In more detail the objectives of the project are:

- development of an instrument for the evaluation of the current situation of an engineering organization with respect to reuse,
- development of a catalog of measures aligned with the instrument for evaluation of the current situation, that supports selection of measures for the improvement of engineering processes in order to introduce or optimize reuse,
- development of a method for the analysis of the benefits of improvement measures with respect to the overall goals functionality, quality, time, and costs,
- development of a method for implementation of improvement measures, including a method for cost estimation of such measures, and
- ensuring the adaptability of the methodology to specific organizational and business situations (tailoring).

The resulting deliverables should be packaged as a set of modular consulting services with an upper limit of approx. 25 working days for the total effort for methodology application in a typical engineering organization. It has to be noted that a process centered approach was not predetermined and the evaluation of reuse was principally targeting at practices as well as artifacts.

1.3. Development Approach

The core methodology development work was preceded by the evaluation of relevant process and product evaluation approaches and respective models and meta-models (e.g. [3][4][5][6][7][8][9][10]).

Based on the results of this evaluation a process-centered approach focusing on the identification of best practices for reuse in industrial engineering was identified to best meet the project’s goals. This was achieved particularly through supporting the seamless integration of the evaluation, the improvement measure selection, and the planning components of the methodology. As an adequate meta-model to be adapted or enhanced for organizing the respective reuse practices the ISO/IEC TR 15504 meta-model for process reference models and process assessment models as implicitly defined in [6] and [11] was chosen. This allows us to focus model development on core practices, i.e. practices of process capability level 1, while simultaneously maintaining the option to integrate the resulting methodology with existing process assessment and improvement approaches for managing solution business projects.

The identification of base reuse practices and the development of the respective models took place in an iterative and incremental way. For the field of industrial engineering this was achieved by analyzing a series of reuse approaches and paradigms known from the software engineering field (cf. section 2.3). The respective models of the methodology, i.e. reuse maturity model, process reference model, and process assessment model (c.f. section 1.4) were developed widely simultaneously with a focus on gathering core base practices within the assessment model at the beginning. Towards the end of model development a shift towards a process outcome or result-driven, i.e. towards a process reference model-driven, approach took place. Model development was also supported by early validation activities through application of the assessment model in and feedback from internal trials (cf. also sections 4 and 6). In particular in the early phases of model development the staged reuse maturity model served as a catalyst for the practices identifiable in various reuse approaches and paradigms.

1.4. Overview of the Methodology Components

Figure 1 shows the components of the GDES methodology for improvement of reuse in industrial engineering. The methodology is intended to be applicable to all kinds of organizations and market segments of industrial engineering. It is comprised of three sub-methodologies which are partly also applicable independently. The three sub-methodologies are:

- a methodology for the evaluation of the actual situation of an engineering organization with respect to reuse, consisting of an evaluation method (part 4), a reference model (part 5) and a maturity model (part 8) for reuse in industrial engineering and a conformant assessment model (part 6). These components together allow to assess to what extent the respective organization fulfills the identified reuse best practices,
- a methodology for potentials analysis, consisting of a method (part 2) and a model (part 3) for potentials analysis. Together with the maturity model for reuse (part 8) and through the consideration of external and environmental factors and organizational goals an optimal set of reuse practices for the respective organization can be identified, and
- a methodology respectively method for action planning (part 7) that is based on the results of the methodology for the appraisal of the current situation and the methodology for potentials analysis which identifies and prioritizes the necessary measures for introduction or improvement of reuse.

Finally, part 1 provides an introduction to the overall methodology and definitions and explanations of the concepts and terms used in the remainder of the methodology components as well as typical methodology application scenarios.

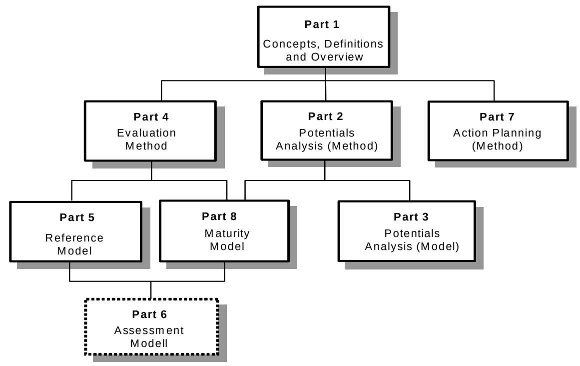

Figure 1: Components of the GDES Methodology for Improvement of Reuse in Industrial Engineering.

The reuse maturity model (part 8) provides the bridge between the evaluation methodology and the potentials analysis methodology by organizing the results and outcomes of the continuous reference model in a staged way, reflecting the 'natural' evolution of an organization with respect to reuse. The evaluation itself is carried out using the assessment model with its continuous organization of reuse best practices along engineering phases and processes, while the results can be represented either using the continuous reference model or the staged reuse maturity model.

The remainder of the paper is structured as follows: section 2 provides further background on developing industrial solutions, related work and the reuse approaches covered by the GDES methodology; section 3 describes the conceptual framework and meta-model behind the GDES model suite for reuse in industrial engineering and provides details on the structure and content of the reuse maturity model as well as the reuse process reference model; section 4 informs about the current state of methodology development and about future work; section 5 summarizes insights and experiences gained during model development; section 6 rounds up the paper with conclusions and considerations on the applicability of the project's results to the software engineering domain.

2. Background

In this chapter we try to characterize the development process for industrial solutions, the reuse models in software engineering and the reuse approaches covered by our approach.

2.1. Developing industrial solutions

Realizing industrial solutions is not about developing products but about carrying out projects in different size and complexity. These projects vary from rather simple and small projects (e.g., semi-automated assembly line) to large and highly complex projects – e.g. developing a nuclear power plant. The project runtime can therefore range from months to years.

Developing industrial solutions is typically carried out in different phases – similar to the phases typically found in software projects. The typical phases in industrial engineering are acquisition, requirements analysis, basic engineering, detail engineering, realization and operational test, start of operation, and operation and maintenance.

While software engineering deals with software only, industrial engineering has to enable the parallel development of different engineering crafts, like mechanical craft and electrical craft. During basic engineering the system is planned without considering the different crafts, i.e. the engineers try to derive a basic solution structure from the customer requirements that can hold as basis for further development.

During detail engineering – based on the basic structure – detailed planning activities are carried out for each engineering craft in parallel. This makes it necessary to integrate these engineering crafts before starting with the realization phase.

It has also to be understood that the involved engineering crafts have well established traditions, how the detail planning has to be carried out. In contrast to software engineering there also exist a number of legal and safety regulations that considerably restrict design choices.

2.2. Existing Models and Related Work

On a very general level [20] provides specific instructions for implementing reuse within the context of the IEEE Software Reuse Process Standard 1517 as well as the IEEE/EIA Standard 12207 - Standard for Information Technology — Software Life Cycle Processes. Nevertheless it does not give hints on how to evaluate reuse practices in organizations.

A specific process reference and assessment model for component-based software engineering was developed within the OOSPICE project (cf. [18][19]).

2.3. Covered Reuse Approaches

Reuse is well understood in the domain of software engineering (see e.g. [14], [15] and [16]). In the software domain the distinction between bottom-up reuse concepts and top-down approaches is well understood and established. Component-oriented reuse is the major bottom-up approach for reuse. The main idea is to build a system bottom-up, reusing existing components, where a component is a self contained element that may be parameterized to fulfill the specific needs in a reuse context.

Even more interesting for industrial engineering are top-down approaches, as they imply that the reusing organization has a general understanding for the overall structure of an engineering solution. We characterize the most important top-down approaches, omitting details and variations of selected approaches.

The simplest top-down reuse approach is to copy an existing solution and to modify it according to the project requirements. This approach is very basic and is applied in organizations with poorly developed reuse programs.

Reusing prefabricates and applying platforms promises higher benefits. Prefabricates incorporate the knowledge how to realize a system or part of a system. A typical prefabricate in the software engineering domain is an application framework, in the engineering domain a CPU-board (without processor, memory chips etc.) is an example for a prefabricate. A platform serves as basis for realizing a family of solutions on top of this platform. Siemens PCS7 [13] is one example for a platform for realizing control systems in the industrial engineering domain.

The system-family approach – which is also a top-down approach – (also known as software product lines [12]) promises even higher benefits, as this approach facilitates the development of solutions for a family of systems. The basic idea is to capture the requirements of a domain with all known variations in a feature model. In a project, where a solution has to be built, the needed features are selected and in the optimal case, all relevant and necessary artifacts (e.g. documentation, architectures, components, semi-finished products, test specifications) are provided and have to be customized, only.

3. The GDES Best Practice Model Suite for Reuse in Industrial Engineering

Our evaluation methodology is focused around three distinct, but interplaying and related models: the process reference model for reuse in industrial engineering, the reuse maturity model for industrial engineering, and the assessment model for reuse in industrial engineering (cf. also 1.4).

The conceptual framework and meta-model behind this model suite and details on the structure and content of the models are provided in the following sub-sections.

3.1. Conceptual Framework and Meta-Model

All three models, the process reference model (PRM), the reuse maturity model (RMM), and the process assessment model (PAM) for reuse in industrial engineering, capture reuse best practices at different levels of abstraction and organize and represent these from different points of view (cf. also *Figure 2*):

- The PRM as well as the RMM contain the same set of *reuse results* in the sense of ISO/IEC 15504 process outcomes. While the PRM organizes these *reuse results* by *phases* of the engineering life cycle which are themselves grouped into *categories of phases*, the RMM organizes these *reuse results* into *stages of organizational reuse maturity*.
- The PAM on the other hand picks up the set of *reuse results* as defined in the PRM and RMM together with the organization of these reuse results into *phases* from the PRM and breaks down these reuse results into *reuse base practices* and *input and output artifacts* as indicators for the respective *reuse results* during evaluation.

Consequently, reuse results grouped into the same phase of the PRM jointly define the result of the successful implementation of the reuse aspects within the respective engineering phase, while the reuse results grouped into a stage of the RMM jointly define the result of the successful implementation of that reuse maturity stage. Reuse results thus represent the core conceptual element of the GDES methodology providing the bridge between the continuous PRM and the staged RMM and in consequence between the evaluation methodology and the methodology for potentials analysis.

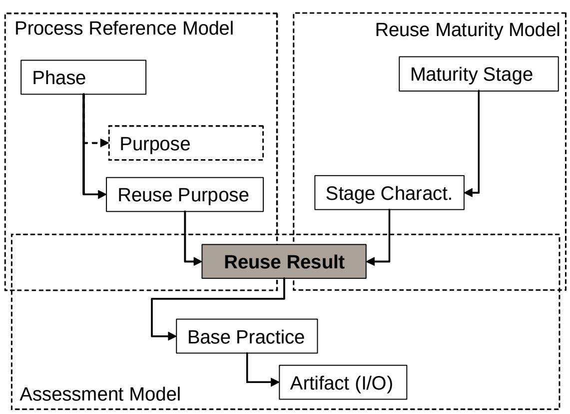

Figure 2: Process Reference and Reuse Maturity Model Meta-Model.

A phase of the PRM is further defined by its *reuse purpose*, while a *characterization* is provided for each stage of the RMM. As the phases of the PRM are also used in the PAM and the evaluation method they additionally contain a definition of the general *purpose* of the phase within the engineering life cycle - not only the reuse purpose - to enable on the identification of the phases in and their mapping onto a real-world engineering organization. Additionally this general purpose of the phase facilitates integration of the GDES methodology with existing methods for process assessment and improvement.

From a meta-model point of view the PRM as defined in the GDES methodology is fully compliant to the requirements of ISO/IEC 15504 for process reference models. It can be interpreted as a partial model of the overall engineering life cycle containing and describing only the processes or parts of processes relevant for successful reuse.

Due to the compliance of the PRM to the requirements of ISO/IEC 15504 the measurement framework for process capability as defined in ISO/IEC 15504 (capability levels, process attributes, rating scale) can be easily applied to the phases of the PAM and directly translated to the phases of the PRM. More detailed, according the GDES methodology this measurement framework is applied at the level of reuse results and respective aggregation mechanisms are foreseen for aggregation towards the phases of the PRM on the one side and for aggregation towards the maturity stages of the RMM on the other side.

As a ‘side effect’ of the chosen model architecture and of the application of the ISO/IEC 15504 process capability rating scale at the level of reuse results, a specifically required process capability level can be defined from the perspective of the RMM and from a methodology tailoring perspective for each reuse result. Thus, an efficient means for expressing the complex relationships between process capability and reuse maturity is provided which is fully integrated into the evaluation methodology.

From a content point of view, reuse results are generally broken down into multiple reuse base practices, on the one hand facilitating evaluation of reuse results according to the ISO/IEC 15504 measurement framework, on the other hand serving as a first means of aggregation of appraisal results for use within the more strategically oriented potentials analysis.

The stages and stage characteristics of the RMM and the categories and phases of the PRM as currently defined in the respective models are described in the following subsections.

3.2. The Reuse Maturity Model for Industrial Engineering

The reuse maturity model for industrial engineering as developed within the GDES-Reuse project defines the results necessary for successful reuse in industrial engineering. Based on [17], it organizes these results in order to provide general guidance for the introduction and improvement of reuse within an engineering organisation into distinct organisational reuse maturity stages that build one upon the other.

The model currently foresees four maturity stages that are characterized in *Table 1*. Maturity stage one does not have specific results assigned.

Table 1: Characteristics of Reuse Maturity Stages.

1 – Chaotic: Reuse is done ad-hoc only and not systematically. If needed, artifacts from previous projects are used as starting point for new ones. Reuse takes place unplanned, uncoordinated, undocumented, informal, occasional, and local and randomly on a small scale. Form and degree heavily depends on persons. Its contribution to achieving business goals is limited.
2 - Systematical: Reuse is pursued systematically. The technical and organisational measures for structured reuse are in place. Solutions are designed modular and the reuse of artifacts is supported by in-house development, purchasing as well as documentation of the use of artifacts. Reuse of artifacts is based on conformance with industry specific standards as well as definition and compliance with internal standards or interfaces.
3 - Domain-oriented: The domain specific benefits of reuse are exploited. The business is analysed and reusable artifacts are defined based on the analysis of recurring requirements. Reusable artifacts are thus customized to the business domain. Reuse is supported by organisation and processes. An organisation wide infrastructure for reuse is in place and planning, coordination and controlling of a reuse oriented engineering process is established. Domain specific reference architectures are typical at this stage.
4 – Strategic: The whole organisation is strategically oriented towards reuse. Reuse is performed systematically and integrated across all phases of the engineering life cycle. This is reflected in the business strategy as well as in the orientation of all business functions towards reuse, including marketing, sales, acquisition, etc. The portion of reused artifacts is high, as well as the contribution of reuse to achieving business goals.

3.3. Process Reference Model for Reuse in Industrial Engineering

The process reference model for reuse in industrial engineering defines the results necessary for successful reuse in industrial engineering and organizes these results according to the typical phases of the engineering life cycle which are themselves grouped into categories. The overall objective is to support the representation of evaluation results and to make evaluation results comparable across organizational boundaries. Table 2 provides an overview of the categories and phases of the process reference model.

The category *Contracting* (CON) combines those phases of the engineering life cycle that are related to the organization’s interface to its clients. The covered phases range from customer acquisition, via requirements analysis and bid preparation, to customer acceptance.

The core engineering phases for planning and realization of a solution are split into two categories: *Engineering with Reuse* and (EWR) and *Engineering for Reuse* (EFR).

The *Engineering for Reuse* category groups the phases of the engineering life cycle that contain activities for increasing the reusability of artifacts and for providing reusable artifacts. The respective activities are usually carried out across projects, in the context of a specific domain, or at an organizational level.

The *Engineering with Reuse* category groups the phases of the engineering life cycle that deal with the project-oriented planning and realization of customer specific solutions. These phases particularly aim at increasing reuse and therefore productivity by means of using already existing artifacts.

The category *Organizational Support of Reuse* (OSR) finally groups all activities that support the phases of the other categories in organizational, administrative or other way.

Table 2: Structure of the Reference Model

Contracting (CON)
CON.1 Acquisition/Initiation CON.2 Customer Requirements Analysis CON.3 Bid Preparation CON.4 Customer Acceptance
Engineering for Reuse (EFR)
EFR.1 Domain Analysis EFR.2 Domain Design EFR.3 Domain Implementation - EFR.3.1 Domain Implementation - Discipline - EFR.3.2 Domain Implementation - Integration
Engineering with Reuse (EWR)
EWR.1 System Requirements Analysis EWR.2 Basic Engineering EWR.3 Detail Engineering - EWR.3.1 Detail Engineering - Discipline - EWR.3.2 Detail Engineering - Integration EWR.4 Realisation and Operational Test EWR.5 Start of Operation EWR.6 Maintenance and Servicing
Organizational Support of Reuse (OSR)
OSR.1 Reuse Program Management OSR.2 Improvement of Reuse OSR.3 Measurement of Reuse OSR.4 Asset Management OSR.5 Quality Assurance OSR.6 Change Management OSR.7 Problem Resolution

The activities related to detail engineering or domain implementation within a discipline are packaged in the generic phases *EWR.3.1 Detail Engineering – Discipline* and *EFR.3.1 Domain Implementation - Discipline* respectively. In the case of applying the model in a context of the interaction of multiple disciplines (e.g. mechanics, electrics, etc.) the respective phases are instantiated multiple times within the evaluation model according to the number of disciplines investigated.

4. Current State of Model and Methodology Development and Future Work

Currently, the concept for the overall methodology as well as drafts of all sub-methodologies for evaluation, potentials analysis and action planning are developed. The focus of work is now on refining and validating the methodology and the involved models.

The process reference and the assessment model can be regarded as rather stable, while some aspects related to stages of the maturity model are still under investigation and discussion. The evaluation method itself has so far been applied in three internal trials (cf. section 6). The respective feedback has been incorporated into the model suite which is now ready for external real-world trials. The trials did not uncover methodological or systematic problems, but contributed to adding and re-assigning base practices and to sharpen formulations.

Future work on the methodology – beside the planned shift of work towards refinement of the potentials analysis and the measurement planning methodologies – will focus on the investigation on how to integrate key aspects related to horizontal and vertical integration (cf. section 1, paragraph 2) into the reference model. This work might raise the need to further extend the currently reuse-oriented partial model towards a more complete lifecycle model – tailored to the needs of industrial engineering.

Further key challenges in future work can be identified in the detailed – also empirical – investigation of the relationship between process capability (on or above capability level 2) and organisational reuse maturity and in research on the systematisation of the evolution of key engineering artifacts as a further means for guidance in the potentials analysis.

The concept of process reference models and process assessment models in the context of the industrial engineering domain also provides the possibility to develop a well structured and interconnected set of assessment models specialising into specific reuse approaches or into the specifics of single disciplines involved in industrial engineering.

5. Experiences and Insights from Model Development

The almost non-existence of a process reference model for industrial engineering agreed across the various involved engineering disciplines and the weak establishment of a process improvement community within industrial engineering turned out as major hurdles in the early phases of development work. They inhibited to focus on the development of a partial reference model for evaluation and assessment of reuse and made further investigation and abstraction and generalization of existing engineering life cycle models necessary. Nevertheless, from today's point of view these hurdles constitute a challenge for further work and chance for take-up of the project's results.

A key challenge of the ongoing development work is the relationship of process capability and reuse maturity not from a conceptual or meta-model, but from a content or instantiation point of view. While the assignment of base reuse practices (more exactly: reuse results), i.e. process capability level 1 practices, to maturity stages is quite intuitive and can be widely derived from the definition of the stages of the maturity model, the assignment of process capability level requirements higher than level 1 to these reuse results and their mapping onto the stages of the maturity model remains a widely unsolved issue. It is currently seen as a means of tailoring of the appraisal methodology and a field of further - also empirical - investigation.

In this context and from a potentials analysis point of view the reuse improvement path of an organization is rather guided by reuse maturity stages than process capability levels. The evolution through reuse maturity stages leads to the 'activation' of reuse results (as 'parts' of engineering phases) associated to specific reuse approaches in a coordinated way, while process capability provides the means for the fine-tuning of these parts. Thus, improvement of reuse can be interpreted to take place through the two dimensions of process capability and reuse maturity that are not orthogonal. The rather granular reuse reference model (in the sense of modeling depth) combined with the maturity model and the potentials analysis and measurement planning methods can be seen as a means to implement process change in the sense of process capability level 5.

6. Summary and Conclusions

The paper reported on the extension and adaptation of the ISO/IEC 15504 framework for integration with a staged model for organizational reuse maturity and the development work on the respective models in the course of the development of a reuse improvement methodology for the domain of industrial engineering. The focus of the paper was on describing the necessary enhancements to the ISO/IEC 15504 framework to enable the evaluation of organizational reuse maturity and on presenting the high level structure of the developed reference model and maturity model.

The work described has successfully progressed through the stages of meta-model selection, meta-model enhancement, and model development. By now a series of three initial trials has been performed within Siemens AG. These trials were executed in experimental settings with the assessed organisational units. The trials focused on validating the evaluation method, the assessment model, the reference model and the maturity model with respect to applicability and usability of the method and its supporting material, completeness of the respective models, consistency of the practices and results defined within these models, adequacy of these practices and results for the domain of industrial engineering, and accuracy of the assignment of results and practices to reuse maturity levels. The results from these initial trials exhibited a satisfactory maturity of the developed models and clearly demonstrate the feasibility and soundness of the overall approach (e.g., 'sanity check' of assessment results vs. other known or perceived reuse indicators). A process capability based evaluation approach can be efficiently used to evaluate reuse maturity. With the feedback from these initial trials incorporated, the evaluation method and the respective models are regarded ready for first industrial trials in real engineering settings.

From a scientific point of view the value of the work is primarily located in the integration and systematisation (through the reuse maturity model) of best practices from a series of reuse approaches in a single model and in the integration of a 'staged' reuse maturity model with a 'continuous' process model.

The project's results are particularly regarded applicable or re-transformable to the domain of software engineering, as the various reuse paradigms and approaches developed in the field of software engineering represented a starting point for model development. Moreover, the engineering of control and communication systems, as one of the core industrial engineering disciplines, typically includes software engineering as a major sub-discipline.

The focus of the work described is on providing a best practice framework for the strategic design of engineering processes in the sense of which paradigm or development approach or combination of those to use. The approach chosen to help resolving this problem is similar or compliant to established process assessment and improvement approaches like CMMI or SPICE, but much deeper and focused with respect to modelling depth, and thus rather a complement to those models than a substitution of those.

7. References

[1] U. Löwen, R. Bertsch, B. Böhm, S. Prummer, and T. Tetzner: Systematisierung des Engineerings von Industrieanlagen (in German), *atp - Automatisierungstechnische Praxis*, Oldenbourg Industrieverlag, 04/2005, pp. 54-61.

[2] B. Dorninger, H. Prähofer, S. Prummer, J. Altmann, and R. Kraus: Technologische Synchronisation von Engineering Daten (in German), Proc. Automation Days 2003 - Software Automation Technology, Nürnberg, Germany, September 17-19, 2003, pp 301-314.

[3] R. Chillarege, I. S. Bhandari, J. K. Chaar, M. J. Halliday, D. S. Moebus, B. K. Ray, M-Y. Wong: Orthogonal Defect Classification – A Concept for In-Process Measurements, IEEE Transactions on Software Engineering, Vol. 18, No. 11, November 1992, pp. 943-955.

[4] P. Clements, R. Kazman, M. Klein: Evaluating Software Architectures – Methods and Case Studies, Addison-Wesley, 2002.

[5] ISO/IEC 14598: Information Technology – Software Product Evaluation, ISO/IEC, 1999.

[6] ISO/IEC TR 15504: 1998, Information Technology – Software process assessment, International Standards Organization, 1998.

[7] DIN ISO 9126: Informationstechnik – Beurteilen von Softwareprodukten, Qualitätsmerkmale und Leitfaden zu deren Verwendung (in German), 1991.

[8] M. C. Paulk, B. Curtis, M. B. Chrissis., C. V. Weber: Capability Maturity Model for Software, Version 1.1, Software Engineering Institute, Carnegie Mellon University, Technical Report CMU/SEI-93-TR-24, Pittsburgh, February 1993.

[9] Quality Measures Taxonomy, Software Engineering Institute, http://www.sei.cmu.edu/str/taxonomies/qm_tax.html (Nov. 2004)

[10] CMMI-SE/SW/IPPD/SS, Version 1.1, Software Engineering Institute, http://www.sei.cmu.edu/cmmi/models (Dec. 2004).

[11] ISO/IEC 15504: 2003, Information Technology – Process Assessment, International Standards Organization, 2003.

[12] P. Clements, L. N. Northrop: Software Product Lines: Practices and Patterns, Addison Wesley Professional Series: The SEI Series in Software Engineering, 2002.

[13] H. Berger, Automatic with SIMATIC, Publicis Corporate Publishing, 2003.

[14] I. Jacobson, M. Griss, P. Jonsson: Software Reuse: Architecture, Process and Organization for Business Success, Addison-Wesley Professional, 1997.

[15] J. Sametinger: Software Engineering with Reusable Components, Springer, 2001.

[16] H. Mili, A. Mili, S. Yacoub, E. Addy: Reuse-Based Software Engineering: Techniques, Organizations, and Controls, Wiley-Interscience, 2001.

[17] G. Pomberger, M. Rezagholi, C. Stobbe: Evaluation und Verbesserung wiederverwendungs-orientierter Software-Entwicklung, in: L.J. Heinrich, I. Häntschel (Eds.): Handbuch für Evaluation und Evaluierungsforschung in der Wirtschaftsinformatik - Handbuch für Praxis, Lehre und Forschung (in German), Oldenbourg Verlag, München/Wien, 2000.

[18] F. Stallinger, A. Dorling, T. Rout, B. Henderson-Sellers, B. Lefever: Software Process Improvement for Component-based Software Engineering: an Introduction to the OOSPICE project, Procs. Euromicro 2002, IEEE Computer Society Press, Los Alamitos, CA, USA, pp. 318-323.

[19] F. Stallinger, B. Henderson-Sellers, J. Torgersson: The OOSPICE Assessment Component: Customizing Software Process Assessment to CBD, in: F. Barbier (ed.): Business Component-Based Software Engineering, Kluwer Academic Publishers, 2002, pp. 119-134.

[20] C. McClure: Software Reuse: A Standards-Based Guide, Wiley-IEEE Computer Society Press, 1st edition, 2001.