Towards Higher Configuration Management Maturity

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Abstract. Configuration Management (CM) as a discipline assuring the consistency between product information with the reality all along the product lifecycle has recently been more appreciated by most industries. Although the extensive benefits of this discipline such as direct impact on increasing return on investment, lowering lifecycle costs and leadtime, are realized by most organizations, there is no specific maturity model in the field for evaluating different aspects of organizations' CM activities. Therefore, a Configuration Management Maturity Assessment framework is developed in this paper using state-of-the-art, standards and other maturity models. In order to evaluate the overall CM maturity of various industry sectors using the developed maturity model, the maturity appraisal material in the frame of a web-survey has been sent to a wide range of CM related employees in different industrial sectors. The extensive results coming out of this analysis has shown the overall competency level of various industries as well as potentials for improvement.

Keywords: Product Lifecycle Management, Configuration Management, Maturity model, Continuous Improvement, Self-assessment

1 Introduction

Configuration management (CM) is a managerial discipline that aims at providing consistency and accuracy of product knowledge throughout its lifecycle and for the same purpose it is being used in different extents in most of the organizations. The primary objective of CM is to ensure that in all the phases of the product lifecycle, changes to product components such as requirements, design and "as-made" information for both software and hardware aspects are assessed and approved before being implemented and recorded and traced after implementation [1]. In a shorter form, CM ensures that products and facilities, including all the systems, equipment and components, are accurately described all the time [2].

It is noted by many researchers that implementing effective configuration management processes not only improves the safety in organizations, but also has direct positive impacts on return on investment, product lifecycle costs, on-time deliveries and product quality [1, 3-4]. Although the benefits of effective CM discipline in place are prominent to all professional organizations, there have not been many works to elucidate a clear roadmap to evaluate their maturity in the field, prioritize their improvement activities and implement missing elements step-by-step. Therefore, it is highly beneficial for organizations to have a framework by which they can evaluate their CM activities in order to uncover their gaps and focus on future

improvements in a more efficient manner. This lack escalates in higher levels when organizations intend to compare their know-hows in the field with best practices in their industrial sectors.
The rest of this paper is organized in the following order. Next section gives a brief description about the nature of maturity models. Section 3 illustrates the key features of CM in standards and maturity models. Accordingly, in Section 4 the concept of CM maturity model is presented. Section 5 describes the research methodology followed for the overall industry assessment. Section 6 provides the results of the survey followed in section 7 by conclusion and overview of future work.

2 Maturity Models

Due to the high importance of continuous improvement in organizations for obtaining more competitive advantages, there are always needs for supportive tools to assess the "as-is" situation, prioritize improvement measures and control the progress of such improvements. Maturity models are the essential tools to address these issues [5, 6].
A maturity model consists of a sequence of maturity levels ranging from the very basic level to the completely mature level for each important criterion within the discipline being measured. [7,8] The main elements of maturity models according to [9], are (1) a number of maturity levels, (2) a descriptor for each level, (3) the characteristics of organizations in each maturity level, (4) a number of important dimensions of the discipline being assessed, (5) important activities under each dimension and (6) the description of the way each activity might be performed in each maturity level.
So far Configuration Management has mostly been considered as part of other subject areas and therefore has not been covered comprehensively and with sufficient level of details in maturity models [10]. Thus, the aim of this paper is to extract the primary dimensions of Configuration Management and develop a CM Maturity Model with sufficient level of detail.
For this purpose, the maturity model design framework proposed by De Bruin *et al.* [5] is chosen for developing the Configuration Management Maturity Model (Figure 1). Based on these principles, first the most important dimensions of CM and the critical activities under each dimension shall be extracted and formalized by using state-of-the-art analysis and comprehensive review of current maturity models and standards in the field. The collected information then was verified by using expert in the field feedback through a case study at CERN [11]. Subsequently, suitable maturity levels were developed based on the Idea of maturity and organizational alignment [12]. Finally the appraisal material in the frame of a web survey was developed and used.

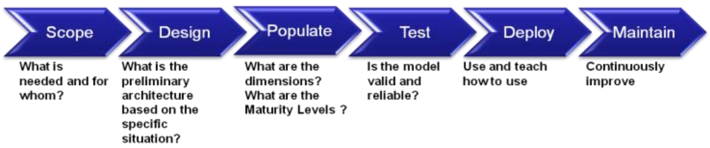

Figure 1. Development phases of a maturity model [5]

3 CM in maturity models and standards

Configuration Management has so far been mostly considered as part of other disciplines. Therefore, its coverage in other maturity models has to a high extent been limited to application of change management processes. The available Maturity Models in the field of business processes are mostly focusing on the organizational development in general and although some of them include requirements for CM, the requirements vary from model to model depending on the processes they are focused on. [10]

CMMI (Capability Maturity Model Integrated) [13], developed by Software Engineering Institute (SEI) at Carnegie Mellon University, as one of the most comprehensive maturity models, covers and evaluates organizations Configuration Management processes as one of the sixteen core functions in an organization. Here, Configuration Management is a support process that shall be followed along with some other processes for the organization to reach the second level of maturity out of five. As an example of a necessity for complementary requirements from other aspect than sole processes to this maturity model, Gupta & RAO [14] acknowledge the role of IT tools for reaching higher maturity levels in Configuration Management practices and try to find matches between the CM process areas described in the CMMI standard and IT tools for supporting those process areas.

In its proposed self assessment framework, IAEA (International Atomic Energy Agency) [2], more deeply focuses on CM discipline and defines main criteria for assessing the Configuration Management discipline in safety-critical environments based on experience and best practices gathered from different nuclear power plants. These criteria include program management, design requirements, information and change control, assessment and training.

BOOTSTRAP, a European assessment process was developed in the 1990s for assessing the capability of the European Software industry [15]. Bootstrap served as a basis for SPICE (now ISO 15504 [16]) as an overall framework for developing maturity assessment models and was later extended to include guidelines from the ISO 9000 [17]. Similar to SEI Software assessment model [18] it utilizes both Capability and Maturity levels. Configuration Management, as a support process, is a necessity for process areas to reach capability level 2. For this purpose, a CM strategy shall be developed and all process and project items shall be identified and baselined. Modifications to those items shall be controlled, recorded and reported. Finally storage, handling and delivery of the item shall be recorded.

The Project Management Maturity Model [19] developed by the US Project Management Institute (PMI) based on the Project Management Body of Knowledge (PMBOK® Guide [20]). Here, CM is part of the Project Integration Management knowledge area which mainly focuses on the integration of the different project deliverables and documents and thus it is being assessed as an individual function. In order for reaching higher levels of maturity, organizations shall practice change monitoring and control to the scope, schedule and cost and also communicate the information about changes to all stakeholders. [19]

In the American standard EIA-731.1 or Systems Engineering Capability Model, CM involves Identification, Change control, Status accounting and auditing of the product and its elements. The CM definitions here are taken from the National Consensus Standard for Configuration management, EIA- STD-649-A. [21]

ISO/IEC 12207 [22] emphasizes on the importance of defining a CM strategy and policy which shall include the authorities for decision making and change control as well as methodology and process storage to be used for the CM system. In this standard, the organizations are suggested to ensure the changes to baselines are properly identified, evaluated, approved, incorporated and verified. For further information this standard refers to more specific CM standard, ISO 10007. ISO 10007:2003 standard [23] is developed to give a better understanding of the CM subject to organizations and promote the use of CM as well as assist the organizations in applying this discipline. According to this standard, the CM process is comprised of the main five stages of planning, identification, change control, status accounting and audit. This standard provides a more detailed description of what is expected in a Configuration Management Plan. This shows the importance of having a CM strategy and policy together with a clear set of defined roadmaps and methodologies, as well as clearly defined responsibilities and authorities to be used in each process stage.

US military standard EIA-649-B [24] which replaces the old MIL-STD-973 covers Configuration Management principles and practices more comprehensively than the others. The importance of using a clear set of terminology for Configuration Management is acknowledged and followed in this standard. However, the main functions of CM are similar to the main five functions introduced in ISO 10007.

EIA-649-B proposes that implementing policies, assigning functional responsibilities, CM-related training, considering CM-tools and their necessary functionalities, establishing KPIs for CM, assuring supplier’s involvement in CM activities and integrating organization wide CM processes shall be included for CM planning & Management.

Currently, the U.S. Department of Defence (DoD) is in the process of releasing a new standard for Configuration Management (MIL-STD-3046 [25]). The draft version issued for feedback collection purposes shows more or less the same level of comprehensiveness as EIA-649-B with more focus on standardization of processes. This purpose is achieved by providing standard and simplified process steps and forms for CM functions.

4 Configuration Management Maturity Model

According to the various functions and categories discussed in the previous section, the authors propose the following five primary dimensions of CM discipline and the sub-dimensions in each area for maturity assessment purposes in organizations (for further details also see [11]).(Figure 3)

Strategy & Performance	Processes	Information Technology	Organization & Value-stream	Knowledge & Support
CM strategic objective and policy	Clear processes for different org. units, projects and lifecycle phases	High level of visualization and user-friendliness corresponding all stakeholders needs	Suitable CM organization structure with respect to Org. complexity and CM needs	Standard CM terminology and knowledge support accessible by stakeholders
Deployment of CM strategy in different organization levels	Standard processes: ✓ Configuration Identification ✓ Baselining ✓ Product structure management ✓ Change evaluation, control & implementation ✓ Status Accounting ✓ Configuration Audits	Integration of CM tool with other IT systems	Defined roles and responsibilities for CM personnel	Regular CM-related training activities (processes, IT, etc)
Communication of the deployed strategy to stakeholders	Process ownership, maintenance and update based on feedbacks	Supporting the CM functionalities such as Naming, Numbering, Versioning, Workflow management, Change traceability	Cross-functional collaboration among different stakeholders for CM purposes	Accessibility and promotion of latest standards, lessons learned, best practices and internal & external benchmarks in CM field
KPIs for performance measurements	Stakeholders access to processes	Solid IT tool all over the organization for all lifecycle phases	Consideration of suppliers and subcontractors in CM activities	Support and empowerment of CM discipline by top management
Regular measurement and update of KPIs	Process customizability for different scenarios	Authorization capabilities for different CM activities	Involvement of key stakeholders in major configuration changes	Communication of CM benefits to stakeholders by top management

Figure 3. Configuration Management primary dimensions and sub-dimensions

As one of the support disciplines in systems engineering and product lifecycle management, the extent up to which it permeate into the organization's structure and activities could represent the level of organization's maturity in this discipline. Therefore, the concept of Maturity and Organizational Alignment utilized by [12] is used for categorizing different maturity levels of organizations with respect to their CM activities. Figure 4 represents the authors' proposition for CM four maturity levels.

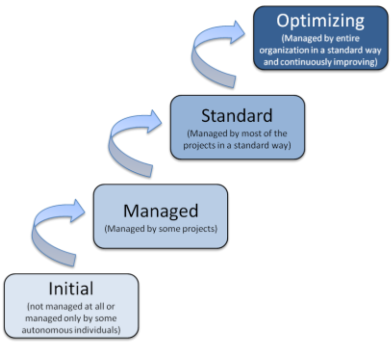

Figure 4. Configuration Management Maturity Levels

Considering the CM maturity dimensions and sub-categories discussed in previous section, the detailed description for organizations fulfilling the requirements for each maturity level is brought below. [11]

Initial - In this level, there is no specific level of Configuration Management dimensions and sub-dimensions in place and people just rely on their own grasp of every situation.

Managed - At this level, the generic need for a formal CM discipline is still missing; however some specific methods are in place in some projects or groups.

Standard - At this level, due to the understood need for CM discipline, clear methods are in place as standard way of doing things in most/all projects and groups. However, such methods are not being reviewed and updated based on the benchmark results.
Optimizing - The Configuration Management activities and processes are regularly updated. The organization has processes for collecting feedback to improve its CM-related activities continuously.

5 Research Methodology

In order for the appraisal material to be distributed rapidly and easily to all target cases and at the same time collect as detail information as possible, online survey methodology was selected [26]. Through a partnership with CM experts from a leading consultant company in CM area, the survey went through 11 iterations for the content and 20 iterations for the visuals. For raising the quality and quantity of the answers, the survey was made available in both English and German languages. Altogether there were 53 questions in the survey which were mostly multiple-choice questions with the choices matching the maturity areas described in section 4. This was chosen to give a logical measure for the respondents for rating the maturity of their organization in the respective subject. After completion, the survey was tested by three CM professionals who were not involved in the process. The content was approved to be sufficiently covering various CM aspects and a few editorial comments were made and implemented. Afterwards, the survey link was distributed to about 150 professionals and CM-related employees from different industrial sectors. Simultaneously the link was posted on well-known online CM communities to collect data from international experts and practitioners. The survey material could be sent for further use upon contacting the authors.

6 Results

Altogether 61 complete answers were recorded of which 4 were excluded due to having lower response time than average. The analysis result of the remaining responses is clustered in the following sections.

6.1 Demographic and General

Important characteristics such as organization sizes and nature, respondents' involvement extent in CM activities, distribution of industrial sectors and level of CM application in various lifecycle phases among participants are shown in Figure 5.

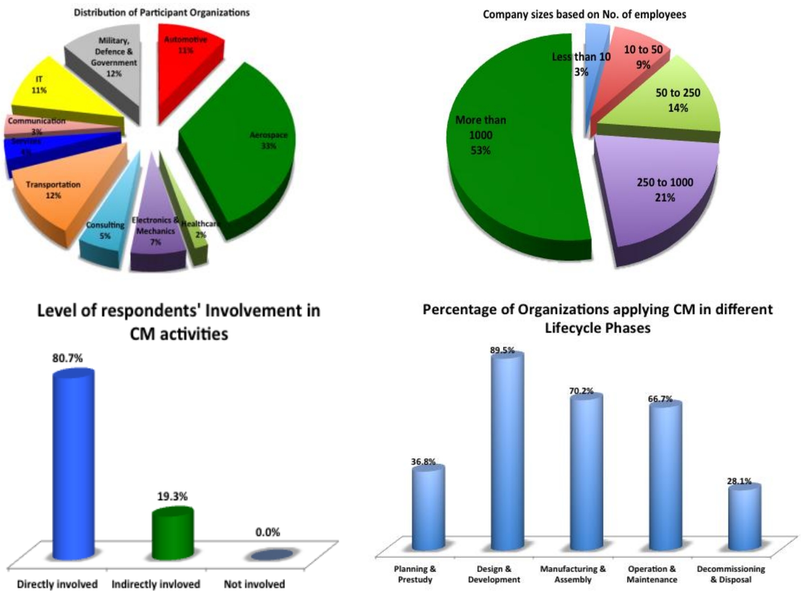

Figure 5. Various characteristics of the survey participants and their organizations

6.2 Criteria-based maturity results

The overall maturity of each dimension is calculated based on a simple weighted average formula shown below.

$$M = \frac{\sum_{k=1}^{j}\left(\sum_{i=1}^{4} i * xi\right)}{j} \qquad (1)$$

Where M is the maturity in the dimension e.g. Strategy & Performance, i is the maturity level from 1 corresponding to the level initial to 4 corresponding to the level optimizing. xi is the percentage of answers in the i_{th} choice and j is the number of questions in the dimension.

For the whole Strategy & Performance dimension overall maturity observed from all responses is 2.25 which is just a bit more than managed level. This shows the need for a more advanced focus on measuring strategic performance in organizations.

In the Process dimension, the outcome maturity from the detailed questions in CM Process showed a maturity level of 2.29. This level still leaves much room for improvement of the CM processes to higher levels of Standard and Optimizing.

In the Information Technology dimension, the interesting results show that only 33 percent of the organizations use single IT systems while 16 percent don't even use an information system support for CM and about 51 percent use different CM IT systems for different projects or groups of the organization. Some organizations have introduced more than 6 different tools in this respect. More specifically for

Engineering Change Management process, the support of IT systems is in a low level of managed only and considering the impact of this function needs immediate care and focus. With the overall Maturity of 2.15 in IT dimension, obviously more standardization among different groups and project teams as well as more consistency among the tools being chosen for the whole lifecycle could lead to much better results.
In Organization and Value-stream dimension, more than 60% of the respondents believe their choice of CM organization structure to a high extent does not correspond to the organization complexity and needs. As it was expected before, the maturity of organizations with respect to consideration of subcontractors' CM tasks during contract negotiations is very low (1.8) where more than 70 percent of the companies do not have an standard and consistent procedure for this matter. The overall maturity in this dimension is 2.17 with the strength of organizations being the involvement of key stakeholders in major changes.
The last dimension Knowledge & Support shows an overall maturity of 1.9 where the use of internal and external benchmarks has a maturity of as low as 1.67 which could show the lack of continuous improvement in this discipline's practices. Another interesting aspect could be the low maturity (1.81) for communication of CM benefits by management which could show the lack of support, promotion and motivation. The overall maturity of target organizations in CM discipline could be observed in Figure 7a.

6.3 Industry-Specific Maturity

In this section the maturity results of specific industries which had the most respondents are discussed and illustrated in Figure 7. In the Aerospace industry with the majority of respondents, the overall maturity level is 2.61 which compared to 1.65 in Transportation with lowest maturity is rather high. The results show that in most industries especially transportation, focusing on Information Technology, Knowledge & Support and Strategy modules could result in higher efficiency.

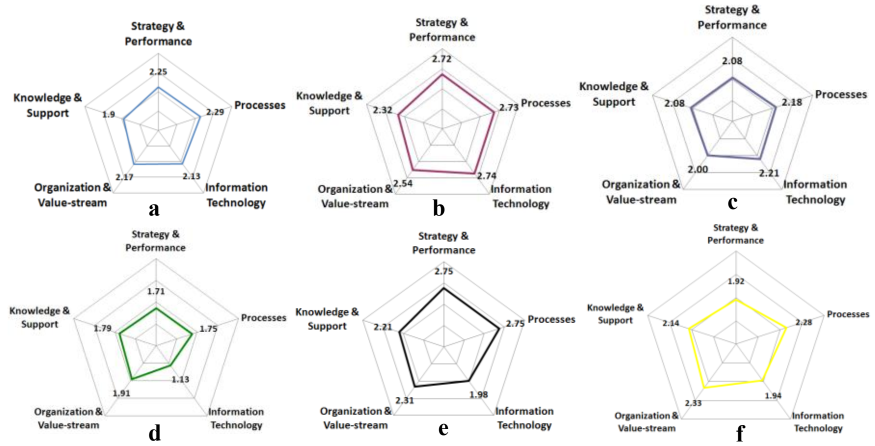

Figure 7. CM maturity in **a)** all industries **b)** Aerospace **c)** Automotive **d)** Transportation **e)** Military & Government **f)** IT

7 Conclusion and future work

In this paper the key influential factors for the success of Configuration Management activities have been extracted and categorized. Configuration Management maturity model was developed and was used to identify the level of maturity and gaps in various industrial organizations. The results demonstrated a rather high potential for improvement in different aspects associated with this discipline. Considering the direct and indirect effect of CM discipline on product leadtime, cost, quality, safety, etc, filling the gap could be of high importance and benefit for all organizations.
Nature of the CM maturity model, developed in this paper, is so far descriptive in the sense that it is limited to evaluation of CM maturity level in the target organizations and identification of gaps in different areas. However, in order for the organizations to have an ideal model, next step would be to develop the model further for having prescriptive abilities and leading the organizations for filling the identified gaps in an optimized way. Also using weights for various sub-dimensions according to their importance could obviously lead to more practical results but the importance of each subject could vary in different industries. The choice of web survey was made for its suitability to industry-wide studies and its simplicity in simultaneous data collection from different organizations and in analysis of the quantitative data. However, the level of detail that could be covered in this method is as deep as the level that understanding of the questions would not be difficult. In order to have a specific case study for one organization, a more comprehensive appraisal material shall be developed for other methods such as focus group meetings and semi-structured interviews.

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