



MASTER THESIS

**SYSTEMS ENGINEERING
MATURITY OF DUTCH
CONSTRUCTION COMPANIES
(AND THEIR BARRIERS)**

J. Reuvers – s1235230

FACULTY OF ENGINEERING TECHNOLOGY
CIVIL ENGINEERING AND MANAGEMENT

EXAMINATION COMMITTEE

dr.ir. R.S. de Graaf
dr J.T. Voordijk

3-3-2019

UNIVERSITY OF TWENTE.

Systems Engineering maturity of Dutch construction companies (and their barriers)

Jesper Reuvers

Faculty of Engineering Technology, University of Twente – Drienerlolaan 5, 7522NB Enschede, the Netherlands

3 March 2019

Key words: Systems Engineering, maturity models, processes, construction company, maturity assessment, design processes.

1 INTRODUCTION

The scope of contractors, within engineering projects, is growing and becoming more complex (Locatelli, Mancini, & Romano, 2014). It is changing from making the final design and construction, towards responsibility of the entire life cycle of the project. For these projects, success is not only based on the so called ‘iron-triangle; Cost, Time and Quality (Locatelli et al., 2014). According the iron-triangle, a project is a success if it is delivered within time and budget, and in respect of the customer’s specifications. The iron triangle focusses on the outcome of a project in time and budget, not specifically on the process towards the outcome. With the growing scope of the contractor in mind, this iron-triangle no longer suffices for the success of a project. The growing scope of the contractors ensure that the work packages of the contractor are also growing and more boundaries with stakeholders are addressed.

To keep control on the project, more knowledge of the processes within the project and their performance is needed. Systems Engineering is a discipline that is developed to deliver successful projects (and systems) in complex environments (INCOSE, 2015), by specifying and addressing the relevant processes within a construction project. In the last couple of years, Systems Engineering (SE) is getting more attention within the civil and construction industry. Especially the companies in the civil and infrastructure sector are more and more introducing SE within the design and implementation phase.

In the Netherlands, the use of SE by the contractor is required to accomplish projects for the government within the infrastructure sector. Main clients in the civil industry: ProRail and Rijkswaterstaat, are introducing guidelines for implementing Systems

Engineering in the civil and infrastructure sector (ProRail et al., 2013). Rijkswaterstaat and ProRail are managing most of the large infrastructure projects. The use of Systems Engineering can bring many benefits, for example: finish projects within the set time, upholding budgeting, and more. Systems Engineering is an effective way to manage complex projects and to keep track of changes within the project (INCOSE, 2015).

Within the housing sector the concept of Systems Engineering is still quite unknown (Pioneering, 2012). Systems Engineering demands a different perception of project management from what most building companies are used to, because the focus is more on the processes towards the outcome than the outcome itself (Pioneering, 2012). More and more building companies are interested in the use of Systems Engineering, therefore the research on Systems Engineering is getting more attention.

Also, construction companies in the housing sector are getting more confronted with an integrated demand of the clients. Instead of a preliminary design, which needs to be further detailed to an execution design, companies are confronted with requirements, which the design needs to meet (Graaf, 2014). Thereby, the work and the scope of the contractor starts earlier in the design process. In the future, the market will change more, and the building companies will be involved within the project earlier than they are used to. This means more processes are involved and more design steps needs to be performed by the contractor, which results in more responsibilities for the contractor. Building companies are therefore changing their organisational structure into a more process-oriented organisation.

Construction companies in the housing sector see similarities with the challenges of the infrastructure sector in the past twenty years. In the past twenty years, construction companies in the civil and infrastructure sector, are changed more towards a process-based organisation. In the civil and infrastructure sector, SE improved the processes of the construction companies to make the projects successful and to get more control on the processes within the projects. Therefore, construction companies in the housing sector are interested which of the implementations of SE in the civil and infrastructure sector are showing similarities with the construction companies in the housing sector.

Construction companies in the housing sector are interested which of the SE processes from the civil and infrastructure sector can also improve the construction companies in the housing sector to move towards a more process-based organisation. How can these construction companies change and improve their organisational structure by looking at the lessons learned from the civil and infrastructure sector.

In this research, the construction company in the housing sector is interested in to what extent the organisation of the company is designed to implement and use Systems Engineering within their organisation. To analyse the processes within the organisation and to what extent Systems Engineering is used in design process, a SE maturity assessment can be assessed within the organisation. A maturity assessment can be regarded as a specific competency model that points out different degrees of maturity for a designed set of processes (Jochem, Sinha, Geers, & Heinze, 2011).

A maturity assessment can be executed with help of a maturity model. A maturity model is a tool to get an overview of the readiness of organisational units

under their responsibilities to face deployment of, for example, SE processes and identify what and where the weaknesses of their organizations endangering the future deployment of SE processes are (Cornu, Chapurlat, Quiot, & Irigoien, 2012). A maturity model is represented as a matrix with one dimension describing the assessment criteria, in this case the SE processes, and the other the maturity levels. In a deployment contexts, like in this research, maturity models are relevant since they are easy to use, open-ended and enable making an initial assessment to track progress achieved while making managers and design stakeholders aware of their organisations maturity and the possibilities for improvement (Cornu et al., 2012). In the civil engineering sector, several companies and organisations have done research on the maturity and implementation of SE within their organisations (Graaf, Voordijk, & Heuvel, 2016; Graaf, Vromen, & Boes, 2017).

The goal of this research is to conduct a SE maturity assessment and conduct this assessment at a middle-sized construction company in the housing sector. In the SE literature, the focus lies mostly on large and complex infrastructure projects; studies on smaller projects are missing (Graaf et al., 2017). SE in de housing sector is a topic that is not often addressed, even though in this sector a lot of improvement can be made.

The goal of the research can be translated in the following research question: What are the SE maturity levels within the organisation of the construction companies and how can these maturity levels be explained and improved?

In this study, first a SE maturity assessment is designed based in existing maturity models in the literature. Second this assessment executed within the construction company to explore the current SE maturity of the company. Therefore, a single-case

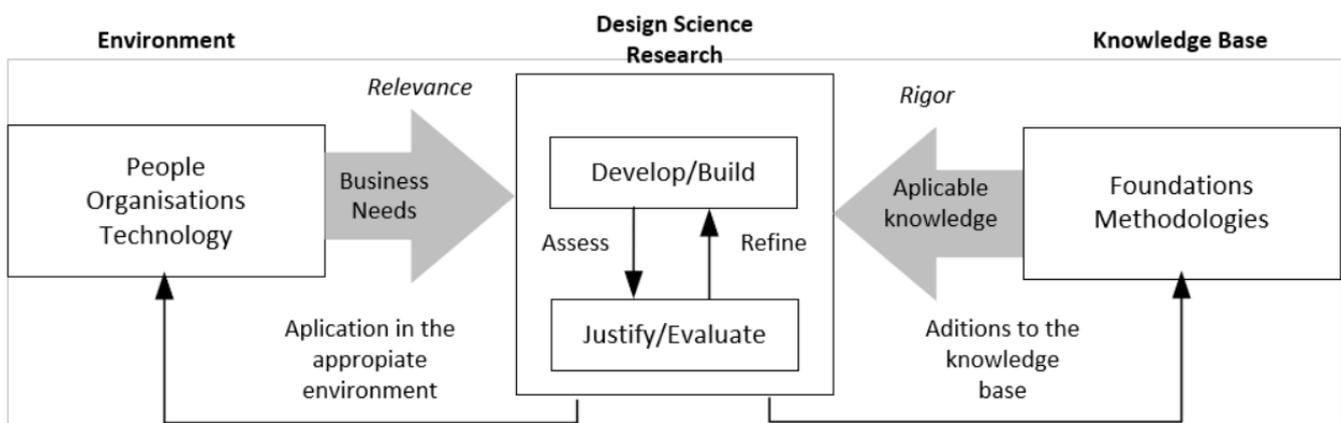


Figure 1 Design science research by Hevner, March, Park, and Ram (2004)

study is conducted at a middle-size construction company within the housing sector in the Netherlands. This construction company is interested in their SE maturity, because they face the challenges that are described within these introduction.

The research in this paper is designed using the design science research cycles as developed by Hevner, March, Park, and Ram (2004). The design is given in figure 1.

In section 1, the relevance of this research is addressed. This is the “business needs” or the relevance of the study in the Design science research model (Hevner et al., 2004). The Rigor, or the “applicable knowledge” is described in the first part of section 2. In the second part of section 2 the maturity assessment is built. Section 3 describes the execution or “assessing” of the maturity assessment. In section 4, the results of the research are described. In this section, and in section 5, the evaluation and refine part of the design science research is discussed. In section 6 the conclusion of the research is stated. Finally, limitations are addressed in section 7, which can be compared with the feedback loops of the Design science research that go back to the environment and the knowledge base.

2 THEORETICAL FRAMEWORK

First, a description of Systems Engineering is presented. In section 2.2 the maturity assessments which are described in the literature are discussed. Thereafter, in section 2.3, the maturity assessment used in this study is explained in more detail. Also, the SE processes are compared and aligned on the project phases of a construction company to address the most important processes. Finally, in section 2.4 the maturity levels are described.

2.1 *Systems Engineering*

In literature, several definitions of Systems Engineering are presented. The two most used definitions are from the US department of Defense (2001) and INCOSE (2015). De US department of Defence (2001) uses the following definition “In summary, systems engineering is an interdisciplinary engineering management process that evolves and verifies an integrated, life cycle balanced set of system solutions that satisfy customer needs” (US department of Defense, 2001, p. 3).

The definition of the International Council on Systems Engineering (INCOSE, 2015), uses a combined definition of the following descriptions:

Systems Engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from parts. It involves looking at a problem in its entirety, considering all the facets and all the variables and relating the social to the technical aspect.

Systems Engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system.

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems.

Key concepts that are mentioned in these definitions are interdisciplinary, iterative, social, technical and complete (INCOSE, 2015).

The definition of INCOSE (2015) is often used in the scientific research on Systems Engineering (Cornu et al., 2012; Elliott, O'Neil, Roberts, Schmid, & Shannon, 2012; Graaf et al., 2016; Graaf et al., 2017; S. A. Sheard, Lykins, & Armstrong, 2000). This definition will also be used in this study.

2.2 *(Systems Engineering) Maturity Models*

To measure the SE maturity of an organisation, a maturity model needs to be implemented. Most of the maturity assessments are not particularly focused on Systems Engineering but are designed for assessing systems and software processes within an organisation. Most of the maturity models and process standards have been developed at the end of the 20th century (Chang, Perng, & Juang, 2008). Sheard (2001) created a framework of all these models and standards and addressed the connections between these process standards and maturity models. Because of the size and complexity it is called the framework quagmire (Sheard, 2001). One of the Systems Engineering Maturity Models is the ‘Systems Engineering Capability Assessment Model (SECAM), developed by INCOSE (1996).

At the same time the Enterprise Process Improvement Collaboration (EPIC) developed the Systems Engineering Capability Model (SE-CMM) (Bate, 1995). A couple years after the publishing of these models, INCOSE and EPIC came to the conclusion to work together for the next maturity model (S. A. Sheard & Lake, 1998). This model was published in 1997 as the Systems Engineering Capability Model (SECM – EIA/IS 731). This model is further developed as the Capability Maturity Model

Integration (CMMI) which is at this moment still the most known Capability model for assessing the maturity of an organisation (Minnich, 2002; Peldzius & Ragaisis, 2011).

Besides the maturity models, the maturity of the organisation can also be assessed with process standards from the International Organisation for Standardisation (ISO). For Systems Engineering the ISO developed the ISO 15288 – systems and software engineering – Systems life cycle processes, which defines a set of processes within Systems Engineering (ISO/IEC-IEEE, 2015). The ISO 15288 itself cannot be used as a maturity assessment, because it is a set of description of processes without a maturity scale. Therefore, the assessment model ISO 15504 (SPICE) is needed. The ISO 15504 part 6 gives an example of process assessment on the ISO 15288 processes (ISO/IEC, 2008). With the assessment model, maturity levels can be assessed to the processes described in the ISO 15288.

At this moment, the ISO 15288 with ISO 15504 and the CMMI are the most used Systems Engineering assessments (Cornu et al., 2012; Ehsan, Perwaiz, Arif, Mirza, & Ishaque, 2010; Peldzius & Ragaisis, 2011).

In this study, the ISO 15288 in combination with the ISO 15504 is chosen for assessing the maturity of

Systems Engineering within the organisation. There are several reasons: (1) the ISO 15288 is the Systems Engineering standard in the construction industry of the Netherlands. The clients demand from the companies that they use Systems Engineering based on the ISO 15288 processes. Also (2) the largest Systems Engineering organisation worldwide, INCOSE, mentioned the processes from the ISO 15288 as a basis for their Systems Engineering handbook (INCOSE, 2015). The (3) processes in the ISO 15288 can be tailored more on project-based companies, like building companies. While the CMMI maturity assessment has more focus on the entire organisation.

2.3 Explaining the SE maturity assessment

In this section, the maturity assessment used in this research will be described in more detail. Also, the processes of the ISO 15288 will be addressed on the relevant project phases. Further on, a distinction between SE design processes and SE processes will be made.

2.3.1 Relationship of the ISO 15288 and the ISO 15504

The ISO 15288 is an international standard that describes a framework of processes that describes activities within the life cycle phases of a system or a project. These activities are designed and defined in

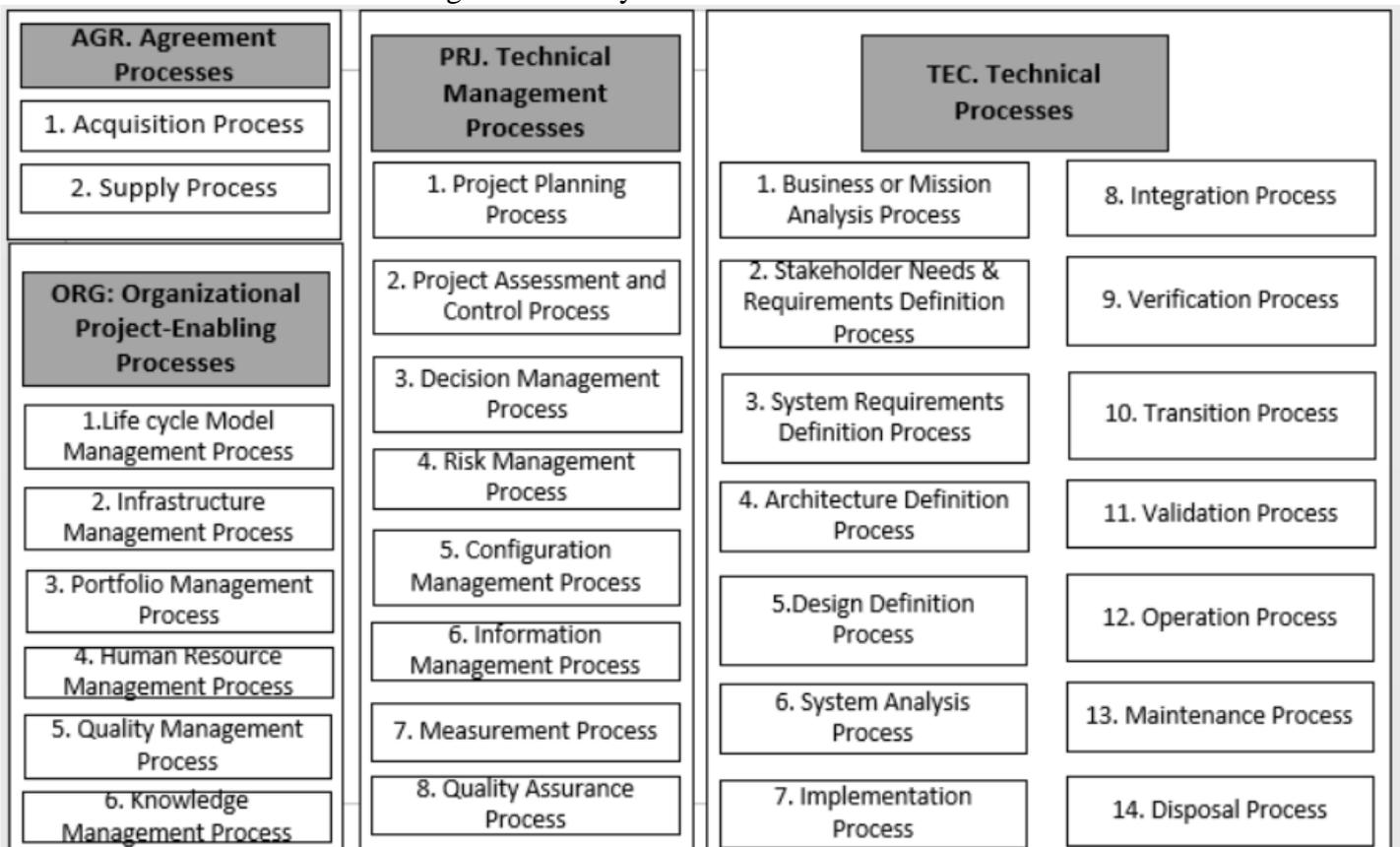


Figure 2 ISO 15288 processes divided in four categories

such a way that results can be reached within every life cycle of the project (ISO/IEC-IEEE, 2015). This ISO-standard is usable on systems that exist of hardware, software, data, people, processes, procedures, facilities and materials (ISO/IEC-IEEE, 2015). This means that the standard can be implemented in almost all organisations and thus also in building companies. It is commonly known as the standard below SE (INCOSE, 2015).

The ISO-15288 describes 30 processes, which are divided in four categories: agreement processes, organisational project-enabling processes, technical management processes and technical processes. In figure 2, the ISO 15288 processes are mentioned per category. The ISO 15288 describes, for every process, the desired outcomes and the possible activities that can be implemented to reach these outcomes. Important to mention, is that the ISO 15288 does not describe these processes as obligatory (ISO/IEC-IEEE, 2015). The organisation is advised to customize the processes within the organisation, so that the processes that are important for the organisation will be implemented. When an organisation implements these processes as they are prescribed in the ISO 15288, visible results are said to be reached in the performance of Systems Engineering.

As mentioned, the ISO 15288 only describes the process outcomes and activities. To assess the maturity of these processes, the ISO 15504: Information Technology – Process assessment is used (ISO/IEC, 2008). This assessment translates the performance of the processes within the organisation to the corresponding maturity level, which are described in section 2.4. The maturity levels in the

ISO 15504 are defined through process attributes. These process attributes describe the various maturity levels. In the assessment, respondents give scores to what extent process attributes are implemented in the project or organisation. Based on these scores, the maturity levels are addressed.

2.3.3 Addressing the important SE processes of the ISO 15288

The focus of this research is the maturity of the Systems Engineering processes. It is important to get an overview of how ISO 15288 processes and Systems Engineering processes, are situated in the building process of the construction companies.

The ISO 15288 processes can all be defined as SE processes, however there can be made a distinction between SE core/actual design processes in the design phase, and processes which support the design phase. By making a distinction between the SE processes and supporting processes, a more detailed overview can be made of the maturity within the organization. The ISO 15288 distinguishes four process categories, as can be seen in figure 2. Not all categories and processes are equally relevant for the design process of a building company. To distinguish the most important processes, the SE model of the US Department of Defence is used. In 2001 the US Department of Defence made a model with the Systems Engineering design processes. This design process is nowadays still widely used for, among others: the SE handbook by INCOSE (2015) and the guideline Systems Engineering by ProRail et al. (2013). Also, several researchers used the design by the US Department of Defence to assess the use of Systems Engineering within organizations in the building sector (Graaf et al., 2016, Graaf et al., 2017).

The SE design process based on US department of

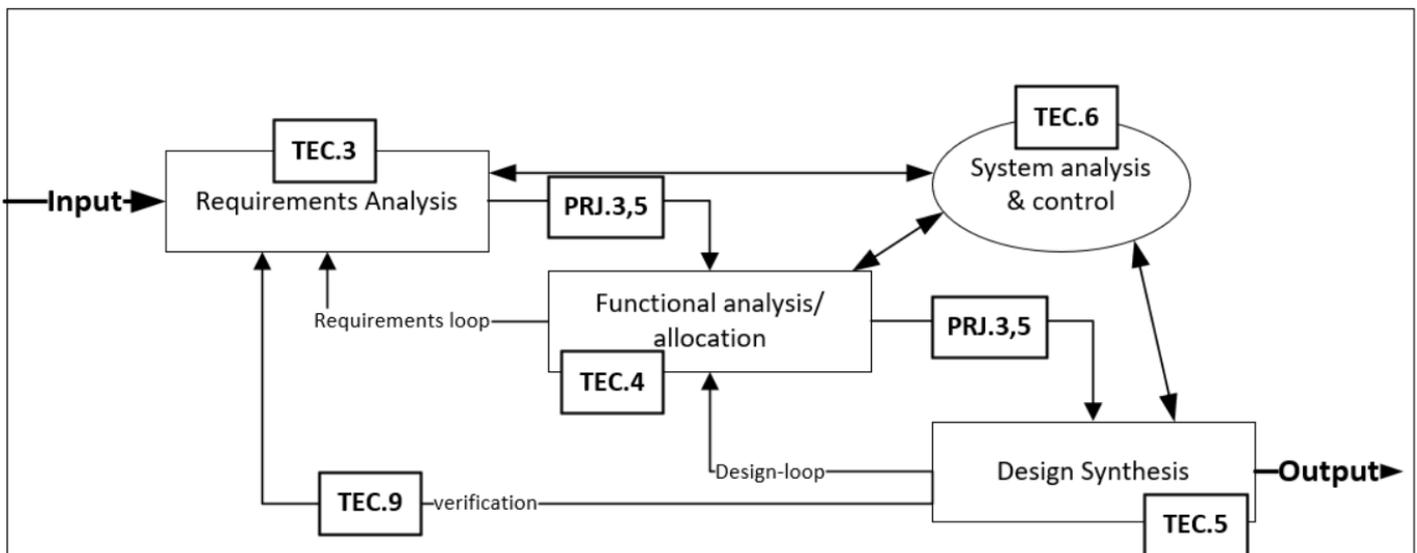


Figure 3 ISO 15288 processes aligned with the US defence SE design processes

Defense (2001) and Graaf et al. (2016) is shown in figure 3. In this figure, it is made clear that the design process is an iterative process which can be continuously followed. Within the SE design process 11 phases/steps are distinguished. When comparing these phases/steps with the ISO 15288 processes, seven ISO 15288 processes are directly overlapping the SE design process as showed in figure 3. The ISO 15288 processes that are overlapping with the SE processes from the US Department of Defence are: TEC.3 requirements process, TEC.4 architecture process, TEC.5 design process, TEC.6 system analysis process, TEC.9 verification process, PRJ3 decision making process and PRJ.5 configuration management process.

The alignments made in figure 3 are derived from comparing the definitions of the US Defence processes with the ISO 15288 processes. When comparing the definitions, a trade of can be made and the most important processes are shown in figure 3. Table 1 shows the processes of the ISO 15288 compared with the US defence SE design processes.

With the allocation of the ISO 15288 processes to the US defence design processes, the ISO 15288 processes are defined within the project design phase of a construction company. With this allocation, the most important ISO 15288 processes regarding the US defence model can be distinguished as the core/actual SE design processes.

2.4 Maturity levels

Organisations can have different maturity levels on the ISO 15288 processes. These maturity levels define how well these processes are implemented within the organisation. With these levels' organisations can define how mature they are regard to the use of Systems engineering. The maturity levels are divided in five levels. The definition of these maturity levels are provided by the guideline for Systems Engineering published by (ProRail et al., 2013). These maturity levels are in line with the maturity levels defined by the CMMI Product Team (2010);

Maturity level 1 is a performed process, this means that the process in the end meets the goal. The processes are chaotic and ad hoc. Within the organisation there is no environment which supports the deployment of the process and the success of the process is highly dependent on the knowledge of the people in the organisation.

Maturity level 2 is a managed process. Within the organisation project teams are deployed. These project teams form the base of success for deploying the process. The project teams define the project approach and ensure that the tasks will be fulfilled. Within the organisation, configuration management, project assessment and control are implemented. The processes are done in line with the policy of the company

Maturity level 3 is an established process. The organisation uses the defined processes to manage their projects and work. The organisation has a standardized set of processes, which is used in all these projects. This means that all processes are executed in the same way. The differences between level 2 and 3 are that on level 2 the processes can differ between de project teams. On level 3 all processes are based on the standard process. Also, the processes are defined more in detail on level 3; for each process the goal, input, start criteria, activities, roles, verification steps, output and end criteria are clearly described. Also, process is more proactively managed.

Maturity level 4 is a quantitative managed process or predictable process. At this level the organisation sets quantitative goals for the quality and performance of the processes. These criteria are used for managing the processes. The goals are derived from the needs of the clients, end-users, organisation and process implementations. The difference between level 3 and 4 is the predictably of the process performance. At maturity level 4 the performance of the processes is controlled with the use of statistics and other quantitative techniques.

Maturity level 5 is an optimizing process. The organisation is continuously improving its processes, based on a quantitative approach of the business goals and needs of performance. The improvement of the processes is innovative, new, process methodologies. The desired process performance is quantitatively defined and continuously adapted based on changing business goals. The difference between maturity level 4 and 5 is the focus on managing the improving of the organisational performance. At level 4 the organisation and the project teams are focussing on controlling and understanding all the sub- processes, which are used to control the projects. At level 5 the organisation is focusing on mapping the overarching performance of the whole organisation by analysing the data derived from the project teams. With these data, the weak spots within the chain of processes and the performance can be derived.

| US Defence SE design processes | | ISO 152288 SE processes | |
|--|--|--|---|
| <i>Process</i> | Definition from US department of Defense (2001) | <i>Process</i> | Definition from ISO/IEC-IEEE (2015) |
| <i>Requirements Analysis</i> | Customer requirements are translated into a set of requirements that define what the system must do and how well it must perform. | <i>TEC.3 Systems Requirements Definition Process</i> | The purpose of the process is to transform the stakeholder, user-oriented view of desired capabilities into a technical view of a solution that meets the operational needs of the user. |
| <i>Requirements loop</i> | This is an iterative process of revisiting requirements analysis as a result of functional analysis and allocation. | <i>PRJ.3 Decision Management Processes</i> | The purpose of the process is to provide a structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives for decision at any point in the life cycle and select the most beneficial course of action. |
| | | <i>PRJ.5 Configuration Management Processes</i> | The purpose of the process is to manage and control system elements and configurations. The process also manages the consistency between a product and its associated configuration definitions |
| <i>Functional analysis /allocation</i> | Functions are analysed and allocated to the requirements. Every function will be allocated into a lower level function. The result is a description of the product or item in terms of what it does and how it has to perform. | <i>TEC.4 Architecture Definition Process</i> | The purpose of the process is to generate system architecture alternatives that meet the system requirements, and to express this in a set of consistent function or views. |
| <i>Design loop</i> | Similar to the requirements loop, the design loop is the process of revisiting the functional architecture to verify that the physical design synthesized can perform the required levels of performance. | <i>PRJ.3 Decision Management Processes</i> | The purpose of the process is to provide a structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives for decision at any point in the life cycle and select the most beneficial course of action. |
| | | <i>PRJ.5 Configuration Management Processes</i> | The purpose of the process is to manage and control system elements and configurations. The process also manages the consistency between a product and its associated configuration definitions |
| <i>Design Synthesis</i> | The process of defining the product or item in terms of the physical elements which together make up and define the item. | <i>TEC.5 Design Definition Process</i> | The purpose of the process is to provide sufficient detailed data and information about the system and its elements to enable implementation consistent with the architectural entities as defined in models and views of the system architecture |
| <i>Verification</i> | For each application of the system engineering process, the solution will be compared to the requirements. | <i>TEC.9 Verification Process</i> | The purpose of the verification process is to provide objective evidence that a system or system element fulfils its specified requirements and characteristics |
| <i>System analysis & control</i> | This process includes technical management activities require to measure the progress and document data and decisions. | <i>TEC.6 System Analysis Process</i> | The purpose of the process is to provide a rigorous basis of data and information for technical understanding to aid decision-making across the life cycle |

Table 1 The US defence SE design processes compared to the ISO 15288 processes

3 METHODOLOGY

To assess the SE maturity model at a construction company, a single-case study method is conducted (Flyvbjerg, 2016; Yin, 2009). By using a single case study, the assessment helps to develop the knowledge on implementing the SE maturity and thereby address the maturity of an average construction company in the Netherlands. The method is discussed in the following sections. First, the goal of the study is explained in detail. In the section thereafter, the data collection method is explained followed by the data analysis.

3.1 Getting Started

The research is conducted at a middle size construction company with 250-300 employees. The company is specialized in large housing projects and utility projects. The company is part of a cooperation between several companies within the technique, civil and building sector, and are overarched by a holding. This means that some processes are organised by the holding. The company in this case-study was one of the instigators of this research.

The context in this research is the shift of responsibilities from the client to the contractor, from carrying out a predefined, structured assignment into solving ill-defined, ill structured, and complex problems in an early stage of the project. (Graaf et al., 2016). SE can help the construction companies to structure the processes within a construction project. The construction company in this case-study is therefore interested in their maturity of SE implementation in the design phase of the project and how to measure the SE maturity.

In this case study, the focus is on two main developments. Creating a SE maturity assessment, as described in section 2. And assess this maturity assessment at a construction company. Which is described in this section 3.

3.2 Data collection

In this case-study, the data is collected by interviewing respondents. These respondents are selected based on the function of the employees. As can be seen in figure 2, the processes of the ISO 15288 are divided in four categories. For these categories different respondents are selected from the company. The process categories PRJ. and TEC. are processes that occur within a project environment. While ORG. processes are overarching processes that

occur within the organisation and not in a specific project. The respondents for the ORG. processes are therefore employees who work in the organisational environment, such as the head of the departments, for example: the chief of the engineering department. For the processes that occur within the projects, project coordinators and project engineers are the respondents. The full list of respondents is shown in table 1. For the process category AGR. one respondent has assessed the processes. While interviewing these respondents, not enough data is collected. Therefore, there was insufficient input to assess a maturity level to these processes. The AGR. processes are therefore not shown in the results.

| Process category | Respondents |
|--|---|
| AGR. Agreement Processes | Supply chain manager |
| ORG. Organisational Project-Enabling Processes | Chief of engineering Quality manager Supply chain manager Project developer Information manager HR advisor |
| PRJ. Technical Management Processes | 2 senior Project engineers 1 senior Project manager |
| TEC. Technical Processes | 3 senior Project engineers |

Table 2 List of respondents

To determine the maturity of the processes, the respondents need to assess a score to the process attributes on every maturity level of the processes. A description of these maturity levels is given in section 2.4. The ISO 15504 has defined attributes for all maturity levels (ISO/IEC, 2008). These attributes differ per maturity level. The respondents can choose to give scores to these attributes between: -- (0-15%), - (15-50%), + (50-85%), ++ (85-100%) for every process attribute. The scores indicate to what extent the process attributes of one specific maturity level appears within the organisation or project (in how many percent of the projects for example). For every process which needs to be assessed, the respondents execute the following steps:

1. Assessing the process outcomes for maturity level 1. These attributes are derived from the ISO 15288 and differ for every process.
2. Assessing the performance management attributes and work product management attributes. These attributes are derived from the ISO 15504 part 6 and are the same for every process.
3. Assessing the process definition attributes and process deployment attributes. These attributes are derived from the ISO 15504 part 6 and are the same for every process.

For example, if the respondents determine that the attribute of a process is addressed in 70% of the projects, the score for this attribute is +. While assessing the process outcomes/attributes, the respondents do also give feedback and/or oral explanation of the given scores. This information is also collected and recorded. This can be used to interpret the scores given by the respondents. Data is also collected by desk research, several documentations is analysed. The company in this case has tried to asses a maturity assessment before, also these data and information is analysed, just like the quality management plans and project documentation.

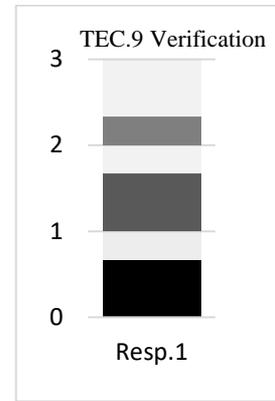
3.3 Data analysis

After assessing the maturity assessment to all the respondents, a lot of data is collected. For every process three or more respondents have filled out the score to all the attributes for every process. All these data must be merged to one maturity score for every process.

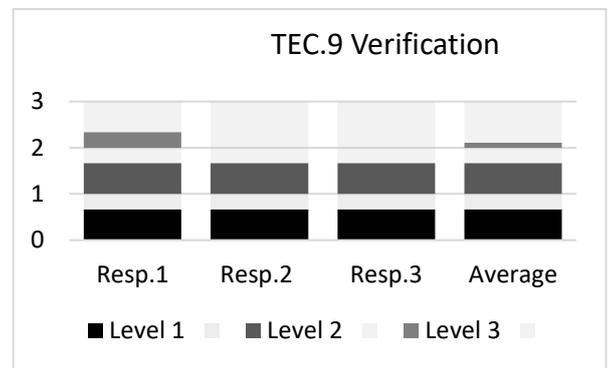
1. For each maturity level the respondents give scores to the process outcomes/attributes. For example, the score for the process outcomes (maturity level 1) for TEC.9 Verification Process given by one of the respondents:

| TEC.9 VERIFICATION PROCESS | | |
|----------------------------|--|---|
| LEVEL 1 | Performed | Put a X in the right cell to give a score |
| | Process outcomes: did the process result in the following process outcomes? | -- - + ++ |
| A) | Constraints of verification that influence the requirements, architecture, or design are identified. | X |
| B) | Any enabling systems or services needed for verification are available. | X |
| C) | The system or system element is verified. | X |
| D) | Data providing information for corrective actions is reported. | X |
| E) | Objective evidence that the realized system fulfils the requirements, architecture and design is provided. | X |
| F) | Verification results and anomalies are identified. | X |
| G) | Traceability of the verified system elements is established. | X |

2. From these scores, an average score for every maturity level is given. Together the scores on all attributes of one process by one respondent will make the following graph:



3. As mentioned in section 3.2, for every process, there are at least three respondents. From the scores of all respondents, an average graph will be made. For the process TEC.9 the following graph is made:



Maturity level 2 cannot be achieved, if maturity level 1 is not achieved. The underlying level always has to be reached before reaching a higher level (ISO/IEC, 2008). For example, if the process PRJ.5 Configuration management has a score of 50% on maturity level 1 and on 80% on level 2. Then the maturity score of maturity level 1 is lower than 80%. If the score on level 1 was 80% and on level 2 also 80%. Then the process reaches a score of maturity level 2. Because the average scores of all attributes per maturity level will almost never reach the 80%, it is important to reduce the influence of the respondent's opinion to the minimum.

4. The response of the respondents needs to be analysed by the researcher. And the researcher needs to make the most objective interpretation (ISO/IEC, 2008). When combining the scores, the average of these scores will be analysed by the researcher to define the final maturity level of the process. The scores of the respondents are the main input for defining the maturity scores. But also other input, like desk research and oral substantiation of the respondents have an important role. The final score of the process TEC.9 verification is determined at 1.5, as can be seen in figure 4.

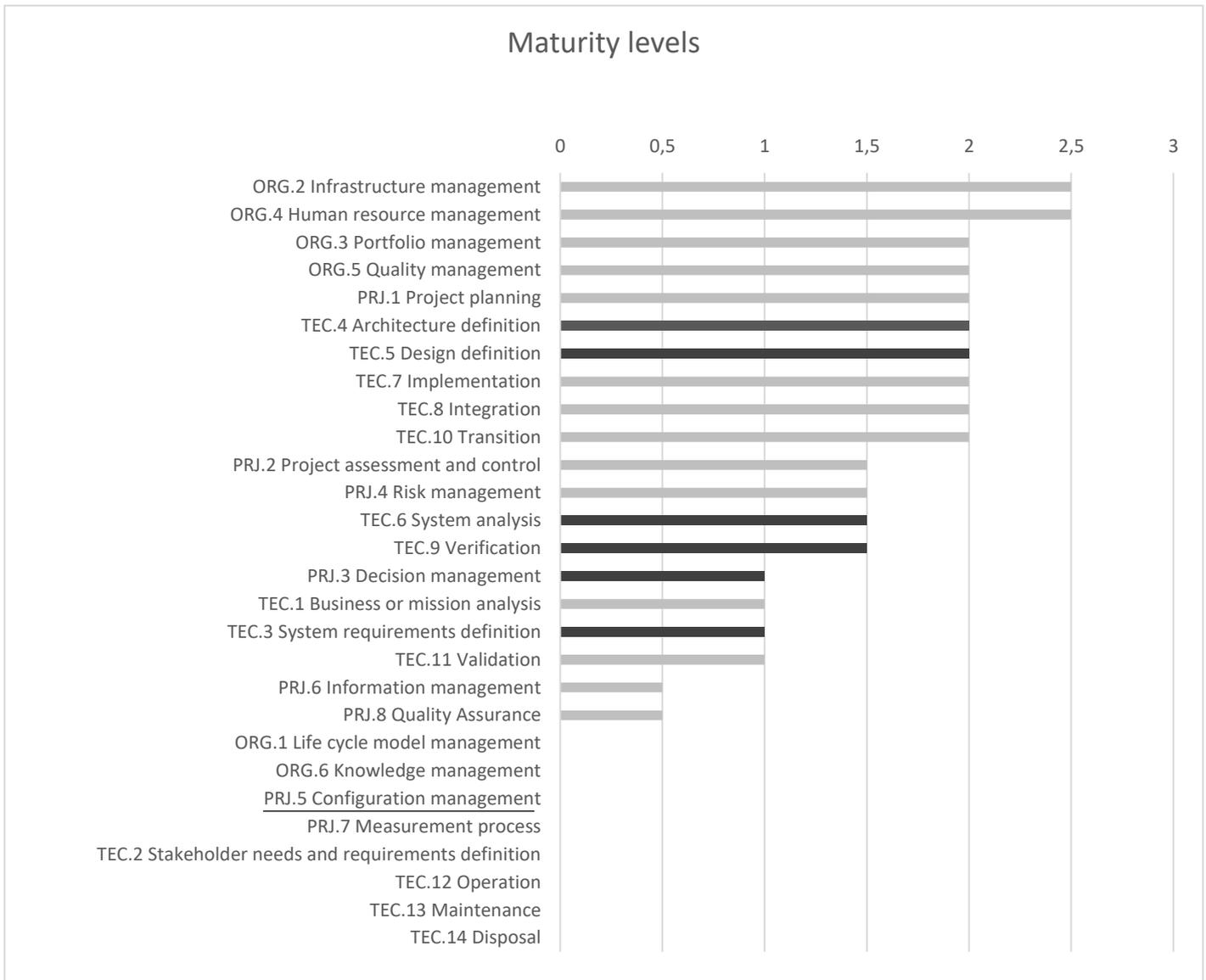


Figure 4 Results of the SE maturity assessment.

4 Results

In this section, the results of the case study are presented. In figure 4 the scores are presented. The processes highlighted with the dark lines, are the processes that are matching with the SE design derived from the US department of Defense (2001). First, the scores will be analysed per maturity level and thereafter more specific the SE design processes will be analysed.

4.1 Analysing the results

All processes have been assessed by the assessor and the employees. The levels are sorted from high to low. The scale of the maturity levels runs from 0 till 3, with steps of 0.5. When a process scores 1.5, it means that it has a maturity level of 1. The half point extra means that the process is already on the right track to a higher maturity level, but does not meet all the requirements for maturity level 2 yet. As mentioned in section 2 of this report, there are 5 maturity levels.

There were no processes that scored higher than maturity level 3, so level 4 and 5 are not mentioned in the graph.

In figure 4 all the processes are given with their maturity level. For each maturity level the argumentation of the maturity level is given.

4.1.1 Processes with maturity level 2 or higher

There are two processes which have a maturity level 2 and have characteristics towards a higher maturity level and therefore get a score of 2.5. These processes are part of the organisational processes. The processes which have a level higher than 2, are processes which are arranged in the holding. The holding is the concern that leads the companies that are member of the concern. These processes are overarching for more companies than the construction company in this case study. This means that there is a standard process for all these different companies. The customized process which deploys

from the standard process, differs for every company, but is based on the standard process

4.1.2 Processes with maturity level 2

The organisational processes: Portfolio management and Quality assurance, both have a high maturity level compared to the other processes. An explanation for these levels of maturity, is that organisational processes are the core of an organisation. When an organisation does not control their organisational processes, then the organisation is not arranged to meet their business goals. The company assessed in this case, is a company that is healthy and is making profit. Also, the respondents mentioned the company is designed in such a way, that all ISO 15288 processes can be executed within the company. This means that the company can facilitate the possibilities to execute the processes.

From the results it is also visible that the TEC. processes which are situated closer to the execution phase, have a higher maturity level. These are the processes like implementation and execution. In these processes, the systems are built. In the case of the building company it means assembling and building the houses/buildings. The explanation for this appearance is most likely that this is the core business for building companies. In the traditional contracts the building companies were responsible for the elaboration of the design and their core business was the construction phase. So, it seems logical that the processes which are close the constructions phase are the processes the companies are more experienced in, which make the companies also more capable in executing the construction phase. Nowadays building companies are getting involved earlier within the designing process. But that situation, early involvement, is relatively new for the building companies. So, the companies are also less experienced in the processes that are further of the execution phase.

Analysing the PRJ. processes, the process project planning has the highest score with a maturity level of 2. This can be explained, because in all projects, planning is an important part. The contractors are required to show a project planning to the client and it also helps the contractor to execute the project. The execution and organisation of the project planning differs per project. This is characteristic for maturity level 2 (CMMI Product Team, 2010).

4.1.3 Processes between maturity level 1 and 2

Processes between level 1 and 2 are performed within the project but are mostly carried out by an individual

and are therefore different within the different projects. The difference between these processes and the processes on level 1, are that the processes between level 1 and 2 are planned and not ad hoc like the processes at level 1. Also, processes on level 1 are most of the time not carried out explicitly. An interesting process at this maturity level is risk management. This process is considered as an important process within the company. But the respondents mentioned that this process is not managed throughout the whole company. Most of the respondents argued that they have no knowledge on how risk management is performed throughout the organisation. So, they do not know if the way they perform risk management is in line with the risk management designed as the company intends.

4.1.4 Processes at maturity level 1

There are four processes with maturity level 1, meaning that these processes are not explicitly mentioned in the engineering and design phase of the company. When these processes are not explicitly managed within the project, the performance of these processes arises indirectly from other handlings of the project team or from individuals within the project team.

The respondents argued that the performance of these processes is depending on skills and expertise of individual persons in the project team. These processes arise mostly from other processes and are then performed by an individual who has experience with this process. For example: the process TEC. 3 system requirement definition. The design process of the company did not contain this process, Due to the implementation of this process in a few projects, there are a couple of persons who have experience regarding the process TEC.3 and they are helping with the implementation of this process. So, if these persons are working on a project, that specific project has the experience of the employee to perform the requirement analysis.

4.1.5 Processes between maturity level 0 and 1

The processes between maturity level 0 and 1 are processes that are not performed in the way the processes are described in the ISO 15288. But some activities or goals in the ISO 15288 are achieved. Within the design process of the company some actions of these ISO processes can be recognized, but not to such extent that all goals of this ISO 15288 processes are met. The processes do score half a point, because the project teams are partially aware of the processes and goals of these processes.

4.1.6 Processes with no maturity level

There are several ISO 15288 processes that did not reach a score in this maturity assessment. This means, not all these processes were known by the respondents, so these processes do not occur within the organisation by purpose, or the respondents do not know these processes. The three processes ORG.6 knowledge management, PRJ.5 configuration management and PRJ.7 measuring processes, were measured, but were rated at level zero by the respondents. There were also 4 technical project processes with no score. These processes were not rated by the respondents. The reason being that the respondents mentioned that these processes did not occur within their organization. The difference with the other three processes with a level zero score, is that the respondents know the technical processes but mention that these processes do not occur within the organization or project. While the other three processes were not recognized by the respondents.

4.2 Scores on the core SE design processes

The maturity levels of the core SE design processes are highlighted in figure 4. This are the processes as determined in section 2.3.3. The highest scores are for the architecture and design definition process. These processes are overarching and supporting processes. The other SE processes that are part of the architecture and design process, have been explained in section 2 with the model of the US department of Defense (2001). The processes with lower maturity level are PRJ.3 'decision making' and PRJ.5 'configuration management', together with TEC.11 'validation' and TEC.3 'requirements analysis'. The project processes PRJ.3 and PRJ5, are processes that are described as supporting by the ISO 15288 (ISO/IEC-IEEE, 2015). This means that decision making, and configuration management are processes that are important to make the other processes succeed in the organization.

TEC.3 requirement analysis and the TEC.11 validation have a maturity score of 1. This means that the processes are maintained by employees with knowledge of the processes and it is not based on the process organisation of the company. The reason is that these processes are not that often used within the design process of a project. In only a small number of projects the use of these design processes is requested. Therefore, urge to implement these processes in the whole organisation is not there. The processes that are connected to the SE design phase, are scoring lower than that SE has not got a prominent role within the company. Also, most of the

respondents argued that there was a lot of misinterpretation and ambiguity around the subject of Systems Engineering. In the following section, improvements for the implementation of Systems Engineering are presented.

4.3 Improvements for the company in this case-study

To improve and create higher maturity within an organisation, management plays an important role. The assessment is executed within the environment of the organisation to assess the maturity of the designed method and processes.

The environment and the process are the responsibility of the management, the method and the tools are the responsibility of the engineering department (Martin, 1994). The company aims for becoming an organisation which is process-based. The growth towards a process-based organisation, maturity level 3 must be reached in the organisation. The results of the maturity assessment and the explanations of the respondents show that most of the processes are firmly based on knowledge of the employees, which are the bases of maturity level 1. To grow towards maturity level 3, which means a process-based organisation, it is important to first grow towards level 2. As the ISO 15288 mentioned, it is not possible to skip a maturity level in the organisation.

The ambition of the organisation to have a process-based design process, can be supported by first implementing the use of Systems Engineering in all projects. So, to grow towards maturity level 2. This ensures that throughout all projects, the same processes are used. Therefore, all employees need to understand Systems Engineering and ensure that the project teams are not relying on the knowledge of the individuals

5 IMPROVING SE IMPLEMENTATION

In this research, three explanations are identified why SE is not implemented to the desired maturity level. There are several improvements that can support the implementation of SE.

5.1 Explicit performance of processes

For Systems Engineering, it is important that all processes are performed explicitly (ISO, 2008). To make explicit choices, clear substantiation of the decisions made, needs to be traceable. Important processes that support the performance of other

processes are the supporting project processes. These SE processes are: TEC.6 Systems analysis, PRJ.3 decision making and PRJ.5 Configuration management. When analysing the scores, it has been found that these processes have a low maturity level, compared to the other ISO 15288 processes. Therefore, these processes need to be more addressed towards the employees in the organisation, to make growth in maturity possible.

5.2 Focus on the processes, not on the outcome

The scores and responses of the maturity assessments state that the construction company is a product-based organisation. The main goal of this construction company is to make buildings. Which has always been the core business of construction companies. The maturity assessment describes the maturity of the technical processes close to the construction phase as most mature. Also, the respondents mentioned that processes that have a product as outcome, for example a design document, are more mature than the supporting processes without clear outcome products. Which is also confirmed by the maturity assessment. The focus within the company is on delivering the outcome at every phase, while there is no focus on how these outcomes are realized (the process). This causes that the process, but also the product outcome, is most of the time depending on the experience of the project team or on individual employees. By focusing more on the process than on the outcome, there will be more structure in the design phase. When the steps made in the process are clear, the outcome will be probably more predictable throughout the whole company.

5.3 Supportive processes

The construction company in this research want to improve their process-based design phase, using Systems Engineering. To grow towards a higher maturity, supportive project processes are very important to improve. Not only for implementing Systems Engineering, but also for improving the technical processes of the company. As stated in the ISO 15504, technical management processes can support the decisions and outcomes of the technical processes and create more structure for the whole organisation (ISO/IEC, 2008). In figure 3, it is also shown that the PRJ. Technical management processes are the steps which can leverage the processes from the one technical process toward the following process. This means, that without the use of these processes, it is difficult to make a substantiated consideration of the decisions that need to be made.

As seen in figure 4, these processes do have the lowest score of the core SE design processes. So, more attention needs to be addressed to these processes which can leverage other processes.

6 CONCLUSION

In this study a maturity assessment is designed to analyse the maturity of systems engineering within a construction company. In this maturity assessment a distinction is made between the ISO 15288 processes, which are processes that are stated as Systems Engineering processes, and where these processes can be allocated in comparison with the design process of a construction company. Also, the ISO processes are allocated on the SE design process, as stated by the US department of Defense (2001), which is used by other researchers to analyse SE within civil engineering companies (Graaf et al., 2016; Graaf et al., 2017).

One of the main conclusions from the maturity assessment is that the construction company in this case study is a product-based organisation. The focus of the company is to deliver products, not only during realisation phase but also during the design proces. In the design phase, these are the design documents. Within the construction phase, it is the building itself. The process to deliver these products, is not clearly visible, and the processes that are supporting in delivering products are on the bottom of the maturity scores. In the last couple of years, getting grip on the processes is getting more important, while the change to a process-based organisation is not yet visible. The focus on supportive process should be getting more attention. Implementing supportive processes, like project processes and organisational processes will improve the control and overview of all other processes. Important is not to focus on all processes at the same time. Customizing the processes to the organisation will make sure that the right processes will be implemented instead of superfluous processes.

8 LIMITATIONS

There were two main limitations in this research. The first limitation was the knowledge of the ISO 15288 processes from the respondents. The way that the ISO 15288 and his processes are designed, caused that the processes were not always understood by the respondents. The processes are described in such a way, that the processes can be used in more branches than only the constructions sector. The respondents in the case study are all experts in the construction sector, this means that the cryptic way of the ISO

15288 is not recognized by the respondents. To ensure that the respondents interpret the processes, an important role was addressed to the researcher to explain to the respondents all the processes in the same context. But it was not always possible to convince the respondents of the right interpretations. An improvement for following assessments is to customize the process description more to the activities of the company, to make the processes more tangible to the respondents.

The second limitation of this research is the score model of the maturity assessment. The respondents must address scores for all attributes, and these scores can be highly influenced by the interpretation and persuasion of the respondents. This goes especially for the processes the respondents are not directly involved in. Therefore, an important improvement can be made in the maturity assessment in terms of reliability. Something that can be done in a follow-up study.

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