A product development success?

Providing insights in improvement of industry's product development maturity

Proof-of-concept design for a Product Development Maturity Optimization (PDMO) model and a Product Development Process Maturity Audit (PDPMA) model

MSc Thesis

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A product development success?

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Preface

Industrial Design Engineers are often connected to the design or improvement of products and systems. That process is completed many times during the courses of Industrial Design Engineering in different manners and with multiple approaches and strategies. As a master student Industrial Design Engineering, I learned a widely applicable skill: to see the predominant problem within its context and find and apply the knowledge required for solving it. During this thesis, I learned how I enjoy – not designing a '*beautiful*' product, but – the multifunctional and multidisciplinary role of placing and evaluating all required information objectively in the right position to add value to industrial and academical stakeholders.

Later years of my educational exploration shifted my interest from design into the more managerial aspects related to development and production. The felicitous Management of Product Development specialization as follow-up of the Bachelor Industrial Design Engineering formed the perfect match. Acting on this interest and finding ways for practical use of optimization ideologies through this research has been a challenging and rewarding experience. I believe that Industrial Design Engineers play a crucial role in utilizing the valuable combination of practical as well as theoretical information for problem solving. This results in the commitment and responsibility to consider and communicate holistic insights and consequences of decisions, an honourable contribution to society through design, production and management practices.

Acknowledgements

With this research, I got the opportunity to gain knowledge and experience related to maturity optimization, product development and performing research. I am grateful for this unique opportunity to complete a master thesis on my main interest. I wish to acknowledge those who played a role in the execution of this research, for their guidance and support have made this research into an enjoyable and inspiring experience.

First, I want to thank the University of Twente for providing me with the resources and facilities for completing this project. In particular, I would like to express my appreciation to Eric Lutters for his professional and meaningful guidance. Insightful questions, critical notes and challenging '*puzzle*' moments formed an essential contribution to the research process and results. The enthusing meetings during – and prior to – this thesis project encouraged me in pursuing my interests, steering this research in the right direction.

I also wish to acknowledge my fellow master thesis colleagues of the University of Twente '*Buitenhorst*' building for the mental support, brainstorm sessions and social companion. Furthermore, I would like to thank the Fraunhofer Project Center team, for giving me the opportunity to experience two maturity audit projects in practice. This provided me valuable insights, contributing to validation of practicability of results and providing realistic benchmarks for existing maturity optimization practices.

My very profound gratitude I express to my family and friends, for their patient and continuous support throughout my years of study and the process of researching and writing this thesis. My special thanks are extended to Fabian Breukers, whose unconditional endorsement, support and patience have been of great value to me.

This accomplishment would not have been possible without you. I am grateful to you all.

Alicia
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Table of Contents

Table of Contents

Abbreviations

Relevant definitions are provided in the footnotes of related pages.

CIP: Change and Implementation part (3rd part of the PDPMA concept model)
DP: Design Principle (Chapter 1.4.4: Development methodology, page 42)
KPI: Key Performance Indicator (definition is stated in the footnotes on the related page)
MLC: Maturity Landscape component (component of the PDMO concept model)
MOC: Maturity Optimization component (component of the PDMO concept model)
MRC: Maturity Route component (component of the PDMO concept model)
MTP: Maturity Test part (1st part of the PDPMA concept model)
OSP: Optimization Strategy part (2nd part of the PDPMA concept model)
PD: Product Development
PDMO: Product Development Maturity Optimization (model)
PDPMA: Product Development Process Maturity Audit (model)

Summary

Companies strive for success – or '*maturity*' as '*the capability to achieve success*' – and act towards that by optimizing the effectiveness and efficiency of value creating processes. Effectiveness represents '*doing the right things*', where efficiency is '*doing the things right*'. The Design Science domain in the academical context aims at providing useful artefacts which guide and structure those processes, resulting in maturity audit models and process structuring models and methods.

Product Development (PD) is one possible value creating process. Surprisingly, existing maturity audit models do not adequately target PD practices for optimization in specific and literature on PD process structuring and optimization does not sufficiently address tailoring the structures to the company contexts. However, uncertainties, sensitivities and stakeholder involvement result in complex multi-criteria decisions concerning optimization projects and process structuring solutions. Objective insights in PD maturity improvement in industry are limited and artefacts for maturity optimization and PD process structuring are not utilized effectively and efficiently.

This research aims at providing insights in improving industry's PD maturity. With those insights, the industry is capable of making deliberate decisions related to PD maturity optimization. This is a twofold research objective. To start with, optimizing a maturity factor (a process with a certain level of maturity) does not automatically result in increased company success. Therefore, insights for deliberately selecting a process for optimization are required. If the PD process is identified as the appropriate maturity factor to optimize regarding to achieving company success, insight in optimization of the PD process are required. This research results in a vision on maturity and two concept models. They form a starting point and illustrate what is possible in the future regarding PD maturity optimization in industry.

The maturity vision states that higher company objectives form the directive for selecting processes for optimization. Since optimizing a process does not automatically lead to success on higher objectives, identifying a top-down maturity context is requires, which allows a bottom-up process optimization for effectively and efficiently optimizing processes towards company success. The Product Development Maturity Optimization (PDMO) concept model is designed to provide insights in the influences of maturity optimization on company success. Through a maturity topology network, it provides insights in the maturity context related to PD maturity. It guides stakeholders in objectively selecting a maturity factor for optimization and a maturity audit can be performed to optimize that specific maturity factor.

Specifically for PD processes, knowledge on selecting appropriate PD process structures for the context is limited. Therefore, a concept model is developed for optimizing PD process maturity: the Product Development Process Maturity Audit (PDPMA) model. The PDPMA model forms one possible solution within the solution domain of the PDMO model. It starts with validating if accreditation of the model is valuable for the context. Then, it relates specific context parameters to relevant model and method parts through corresponding functions, forming relation profiles. These are the input for a tailored change and implementation advice for the company.

For the research results, development and validation standards are used and decisions are substantiated, providing a firm theoretical base. The PDMO model is capable of providing insights in the value of optimizing a specific process in the company context, guiding decision makers to optimization process selection while aiming for company success. The PDPMA model is capable of proposing appropriate solutions for PD process structures and first ideas for iterations of the first step in the PDPMA model are stated. This research does not present fully developed results, but identifies, illustrates and contextualizes interesting opportunities for PD maturity optimization in industry. Recommendations entail further development activities, design testing and performing research contributing to the models' content.

The valuable combination of practical and theoretical knowledge is made accessible to industry after developing the PDMO and PDPMA model into practical tools. Combined, they provide the industry with insights in improvement of their PD maturity and enable stakeholders in optimization projects to make deliberate decisions regarding optimization projects and PD process optimization. The versatile designs allow availability, flexibility and sustainability of the models' content. Optimization project execution with use of the PDMO model and / or PDPMA model allows tailoring the focus and effort to (often fluctuating) needs of industrial stakeholders, contributing to the industry's aim for company success.

This research contributes to the Design Science domain and builds on theoretically firm standards for model development and validation. Research results are represented as generic semantic ontologies – independent of specific instances – exploring maturity assessments for a new application: PD optimization. The PDMO and PDPMA model have three unique characteristics: the focus on Product Development practices, the use of company success and the design for relating context with solutions based on overlapping functions. By providing the industry with insights in the potential value of them, utilization of developed artefacts by the academy is promoted, contributing to the success of the Design Science domain. In conclusion, this research forms a proof-of-concept model development success, proposing designs which provide companies with insights in improvement of their PD maturity.

Samenvatting

Bedrijven streven naar succes en trachten om de effectiviteit en efficiëntie van waardecreërende processen te verhogen. Het '*Design Science*'-vakgebied in de academische context is gericht op het ontwikkelen van modellen en methodes die deze processen effectief en efficiënt begeleiden en structureren. Dit resulteert in auditmodellen voor procesoptimalisatie en processtructureringsmodellen en -methodes.

Productontwikkeling (PD) is een van de mogelijke activiteiten voor waardecreatie in de industrie. Verrassend genoeg zijn bestaande auditmodellen voor optimalisatie onvoldoende gericht op het optimaliseren van PD-activiteiten. Bovendien besteedt de literatuur onvoldoende aandacht aan het afstemmen van de modellen en methodes op de specifieke bedrijfscontexten. Onzekerheid en gevoeligheid in de bedrijfscontext leiden tot complexe beslissingen betreffende optimalisatieprojecten en processtructurering. Daardoor zijn objectieve inzichten in PD optimalisatie in de industrie beperkt en worden optimalisatiemodellen en PD-proces structuren niet effectief en efficiënt gebruikt.

De doelstelling van dit onderzoek betreft het verschaffen van inzichten in het optimaliseren van PD-activiteiten, waardoor de industrie in staat is om weloverwogen beslissingen te nemen. Dit is een tweeledige doelstelling. Om te beginnen leidt het optimaliseren van een proces niet automatisch tot hoger succes van een bedrijf. Daarom *(1)* zijn inzichten nodig in het selecteren van een geschikt proces voor effectieve en efficiënte optimalisatie. *(2)* Als het PD-proces wordt geïndiceerd voor optimalisatie, is een auditmodel voor optimalisatie van dat proces nodig. Uiteindelijk resulteert dit onderzoek in een visie en twee conceptmodellen die elk een deel van de tweeledige onderzoeksdoelstelling bereiken. Ze vormen een startpunt en illustreren wat er in de toekomst mogelijk is met betrekking tot PD-optimalisatie in de industrie.

Hogere bedrijfsdoelstellingen vormen de richtlijn voor het selecteren van processen voor optimalisatie. Aangezien het optimaliseren van een proces niet automatisch leidt tot succes van hogere doelstellingen, is het identificeren van de context rondom PD-optimalisatie essentieel. Dat maakt het mogelijk om een weloverwogen keuze voor procesoptimalisatie te maken, welke effectief en efficiënt bijdraagt aan het succes van een bedrijf. Deze stellingen vormen de visie. Naast de visie, is het PDMO conceptmodel ontworpen om inzicht te geven in de invloeden van procesoptimalisatie op bedrijfssucces. Het begeleidt stakeholders bij het objectief selecteren van een proces voor optimalisatie en een auditmodel kan worden uitgevoerd om dat specifieke proces te optimaliseren.

Kennis over PD-procesoptimalisatie is beperkt. Voornamelijk methodes voor het selecteren van effectieve en efficiënte PD-processtructuren voor PD-processen in een context ontbreken. Daarom is er een concept voor het PDPMA-model ontworpen, welke inzicht geeft in de optimalisatie van PD-processen.. Het PDPMA-conceptmodel vormt een mogelijke oplossing binnen het oplossingsdomein van het PDMO-conceptmodel. Het begint met het valideren of accreditatie van het PDPMA-model waardevol is binnen de context van het bedrijf. Vervolgens relateert het model de specifieke contextparameters aan processtructuren, via overeenkomstige functies. De resulterende relatieprofielen vormen de input voor een strategisch advies voor het bedrijf, gefocused op verandering en implementatie.

De onderzoeksresultaten zijn gevormd vanuit een goede theoretische basis. Het PDMO-conceptmodel is in staat inzichten te verschaffen in de waarde van het optimaliseren van een specifiek proces in de bedrijfscontext. Daardoor kunnen besluitvormers weloverwogen beslissingen maken betreffende optimalisatie gericht op bedrijfssucces. Het PDPMA-model genereert en adviseert over passende oplossingen voor PD-processtructuren. Dit onderzoek presenteert geen volledig ontwikkelde resultaten, maar identificeert, illustreert en contextualiseert interessante mogelijkheden voor PD-optimalisatie in de industrie. Aan de hand van dit onderzoek kunnen verdere ontwikkelingsactiviteiten, ontwerptesten en onderzoeken plaatsvinden die bijdragen aan de ontwikkeling en inbedrijfstelling van de modellen.

De PDMO- en PDPMA-conceptmodellen maken de waardevolle combinatie van praktische en theoretische kennis toegankelijk gemaakt voor de industrie. De ontwerpen stellen bedrijven in staat om weloverwogen beslissingen te nemen met betrekking tot optimalisatieprojecten en PD-procesoptimalisatie. Ze zijn ontworpen met beschikbaarheid, flexibiliteit en duurzaamheid van de inhoud van de modellen als doel. Bedrijven kunnen optimalisatie projecten afstemmen op hun(vaak fluctuerende) behoeften, strevend naar succes van het bedrijf.

Dit onderzoek draagt bij aan het '*Design Science*'-vakgebied en bouwt op een goede theoretisch basis voor modelontwikkeling en -validatie. Het initieert een nieuwe toepassing van auditmodellen, namelijk specifiek voor PD-optimalisatie. De conceptmodellen hebben drie unieke kenmerken: *(1)* de focus op productontwikkelingsactiviteiten, *(2)* het gebruik van bedrijfssucces als leidraad en *(3)* de specifieke methode voor het relateren van de context enerzijds en processtructuren anderzijds. Door de industrie inzicht te geven in de toegevoegde waarde van processtructuren, wordt het gebruik van ontwikkelde modellen en methodes bevorderd wat bijdraagt aan het succes van het '*Design Science*'-vakgebied. In conclusie, dit onderzoek is een PD-succes en doorontwikkeling van resultaten stelt bedrijven in staat om ook succesvol waarde te creëren met productontwikkeling.

1 Introduction

Chapter content

Product developing (PD) companies aspire PD success (PD maturity) and act towards that by adapting PD processes to fit interpretations of the companies environment. Resulting maturity optimization projects – guided by external advice and insights from maturity audit models – aim for increased effectiveness and efficiency through process structuring. Maturity optimization projects are subject to the environment the company operates in and decision making on them requires practical as well as theoretical knowledge. For PD process maturity optimization, limited knowledge is available. This research aims at providing insights in PD maturity optimization with taking into account the changing company context and proposes a concept model for achieving that. This broad objective has a limited model target group and a selected, illustrative solution domain. The maturity audit model development uses standardized model development steps and is approached as a product development process with Cross' PD process model as guide. It is validated by using a standard validation and verification model from R.G. Sargent and D.K. Pace. The report starts with this introduction for providing background and research information. This is followed by defining a vision on PD maturity and a design with three hierarchical levels that support the main objective of this research. Future prospects are stated and final chapters validate, evaluate, discuss and conclude on the research.

1.1 General Statements

This report starts with describing the general statements to provide the reader with a rough overview of the research context and main statements before diving into (more abstract and theoretical) detail. The introductory chapters state the knowledge required for a Maturity vision, which works towards two proof-of-concepts for PD maturity optimization. Definitions are stated in the footnotes, guiding the interpretation of terms during the report.

1.1.1 Product Development and value creation

Companies strive for creating value, resulting in company success. That can be achieved with a wide range of strategies, for example by designing and producing goods or by providing services. The context of this thesis focusses on Product Development[1] (PD) as value creation strategy. The success of a company is determined by how well the company performs – creates value – within the everchanging (PD) environment. Regarding that, companies aim to adapt their value creating practices to the everchanging context, to obtain or retain competitive advantage and assure company success[2].

The capability to perform and achieve an objective (e.g. value creation) in a context is referred to as '*maturity*[3]'. The gap between the aim of the company and the everchanging reality, makes it impossible for a company to operate '*fully mature*', since the environment which determines maturity is constantly changing and the performance of a company occurs in a certain point in time based on an interpreted context of that point in time. Per company it differs how big the gap is between operating '*fully mature*' for the reality of the everchanging environment and how mature a company really operates while aiming at an approximation of the environment at a certain point in time. Increase in maturity would mean increase of company success, since the company can adapt better to the environment. This results in the wish for industry is to increase maturity of value creating practices, specifically for them to be capable[4] of and have insights in how-to optimize their processes[5]. This statement forms the initiation for this research.

1 Product Development (PD): "*the creation of products with new or different characteristics that offer new or additional benefits to stakeholders. Product development may involve modification of an existing product or its presentation, or formulation of an entirely new product that satisfies a newly defined customer want or market niche.*" (BusinessDictionary, 2019).
2 Success: "*the fact that you have achieved something that you want and have been trying to do or get.*" (Oxford Learner's Dictionaries, 2019). *"Achievement of an action within a specified period of time or within a specified parameter. Success can also mean completing an objective or reaching a goal."* (BusinessDictionary, 2019).
3 Maturity: *"the state of being complete, perfect or ready."* Soanes and Stevenson (2006) or *"the state of being fully grown or developed." (Oxford Learner's Dictionaries, 2019).*
4 Capability: "*measure of the ability of an entity (department, organization, person, system) to achieve its objectives, specially in relation to its overall mission.*" (BusinessDictionary, 2019).
5 Process: "*sequence of interdependent and linked procedures which, at every stage, consume one or more resources (employee time, energy, machines, money) to convert inputs (data, material, parts, etc.) into outputs. These outputs then serve as inputs for the next stage until a known goal or end result is reached.*" (BusinessDictionary, 2019).

1.1.2 Deliverables and scope

This research develops and delivers two proof-of-concept[6] maturity models[7] that fulfil the aim of providing insights for industry in how to optimize PD maturity. Within the broad landscape of PD optimization, the concept designs starts with a low maturity – since capability is not assessed initially – and form a starting point in the search for mature designs to increase PD maturity in industry. The maturity of the concept models is tested and evaluation for future applications on a broader scope can be performed.

Only industries with the chance that optimization efforts are beneficial are included within this research' scope, with evaluation for expansion after further development of the proof-of-concepts. As a starting point and directive, this thesis focuses on application in product developing industries other than automotive, one-off or rusted-up. In order to increase the maturity of PD practices for a company, the effort required for improving the maturity must not exceed the benefits. Therefore, industries with a high chance of not meeting this requirement are out of scope, but can be included in application after the concept model has been proven to be mature. In conclusion, this research encourages iterations and scope widening of the proof-of-concept model in the future.

Results of this research will not be quantifiable, nor have Key Performance Indicators[8] (KPIs) to be expressed. Maturity, as well as the term optimization (which relies on increase of effectiveness[9] and efficiency[10]), are per definition relative and dependent on the context. Therefore, only the combination to a context provides means to say something about maturity levels, effectiveness and efficiency increases or improvement potentials. Since the level of detail of the concept is limited to only a proof-of-concept, a direct combination to a specific contexts is not provided. Consequently, the proof-of-concept model does not address measures of those aspects in quantities, but explains future opportunities.

The context of this research can be described roughly with the following key words: *Product Development, Maturity, Capability, Effectiveness & Efficiency, Model, Optimization.*

6 Proof-of-concept (PoC): "*is a small exercise to test the design idea or assumption. The main purpose of developing a POC is to demonstrate the functionality and to verify a certain concept or theory that can be achieved in development.*" (Singaram & Jain, 2019).
7 Maturity models: "*a simplified description of a system, used for identifying and explaining how mature something works or calculating what might happen, etc.*" (Oxford Learner's Dictionaries, 2019). "*Models are systematic (i.e., they deliver rules on how to act and instructions on how to solve problems), goal-oriented (i.e., they stipulate standards on how to proceed or act to achieve a defined goal), and repeatable (i.e., they are inter-subjectively practicable).*" (Braun et al., 2005).
8 Key Performance Indicator (KPI): "*key business statistics such as number of new orders, cash collection efficiency, and return on investment (ROI), which measure a firm's performance in critical areas.*" (BusinessDictionary, 2019).
9 Effectiveness: "*the fact of producing the result that is wanted or intended.*" (Oxford Learner's Dictionaries, 2019). Doing the right things.
10 Efficiency: "*the quality of doing something well with no waste of time or money.*" (Oxford Learner's Dictionaries, 2019). Doing things the right way.

1.2 Orientation

1.2.1 Product development

In order to provide a starting point for this research, this thesis focuses on the process of developing products. In this report, the term '*process*' is often related to Product Development (PD) unless stated otherwise.

Product development as value creation strategy

Product development is one of the strategies in industry to create value. This value can result in, for example, money, goods or recognition, on which the existence and success of a company can be based. Logically, from industry, there is an interest in increasing effectiveness and efficiency of processes such as the PD process, resulting in higher value creation.

Effectiveness represents '*doing the right things*', where efficiency represents '*doing things the right way*'. These terms are per definition relative and highly dependent on the context, e.g. the organization, project, stakeholders and product (*Nieberding, 2009*). Therefore, only the combination to a specific context provides means to say something about effectiveness and efficiency levels and improvement potentials. The effectiveness and efficiency of the PD process directly influence the amount of value creation in this context.

In relation to process structuring

A positive correlation between the effectiveness and efficiency of PD processes and the structuring of PD processes exists. When process steps are chosen intentionally, they can be influenced and communicated and support the heuristic structure of human thought (*Pahl, Beitz, Feldhusen, & Grote, 2007*) (*Dörner, 1987*). This means that the amount of value creation by – and the success of – a product developing company is influenced by the structure of the PD process. Logically, the aim of industry to increase their PD success leads to the search for effective and efficient structures of PD processes.

1.2.2 Process optimization projects and decision making

Standardized optimization projects

The aim for optimization in industry leads to a standardized process of analyses, identifying optimization and selecting and implementing optimizations. Supporting the aim of industry to increase effectiveness and efficiency of processes, optimization projects are performed. These projects roughly follow comparable steps, since they all have comparable objectives to go from a certain situation into an improved situation. First, the current situation is analysed. Subsequently, potentials for improvement are identified and analysis of costs compared to benefits determine the value of implementing an improvement. Improvements for implementation are selected by using stated criteria for added value compared to the costs of them. They need to be changed in the current situation, resulting in increased effectiveness and efficiency of the process. Based on this information, a representation of the PD optimization process is provided in *Figure 1*.

Optimization projects as cycle

Optimization projects can be performed as continuous cycles. A PD optimization project roughly consists of the PD factors as shown in *Figure 1*. In practice, the PD process in place is the '*current situation*'. The PD strategy builds on theory and requires all available knowledge on how to optimize the process of the current situation. This includes detailed information about effectiveness and efficiency and new technologies and potentials for improvements. That information – with for example Design Science artefacts as tools,

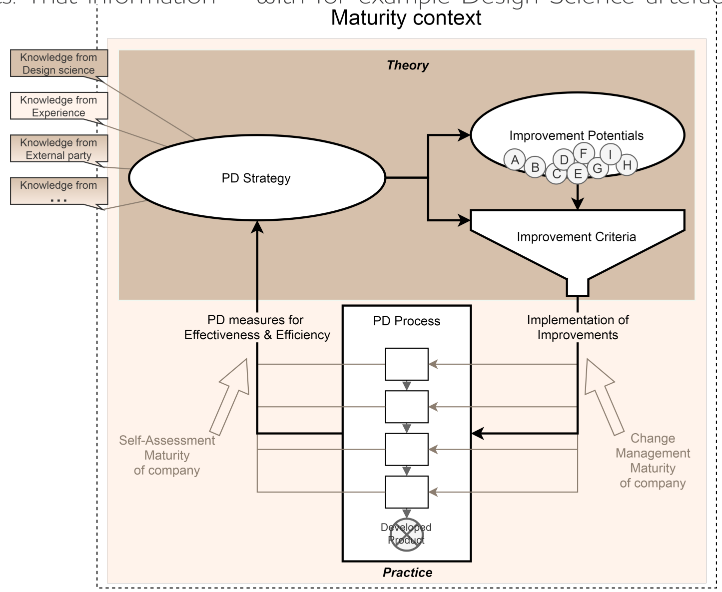

Figure 1 – Visualization of PD maturity - the capability of a company to assess and optimize PD

practical experience and knowledge from stakeholders – is used to create criteria for identified improvement potentials. The criteria form a filter determining whether or not to implement the improvement potentials in the current situation. Aiming at continuous competitive advance, optimization processes can be continuously striving for effective and efficient processes.

Decision making regarding to optimization projects

In and before each optimization project, myriad decisions are made, influencing the company context and being influenced by the company context. Uncertainty of the context causes unknown results if the results are sensitive to those uncertainties. Consequently, decision making on processes and optimization is difficult due to the existing combination of sensitivity and uncertainty. For optimizing processes, uncertainties in the context combined with sensitivity of decision outcomes cause difficulties in having insights in all influences and effects of making a certain decision. Making a decision with insights in uncertainties and sensitivities enables stakeholders to make deliberate decisions appropriate for the company. Consequently, decision can be based on what the company wants to risk or invest in order to obtain an effectiveness and / or efficiency increase.

Stakeholder involvement in processes and decisions, results in biased perspectives influencing the credibility of the decision outcome. Criteria for decision making can be created from a wide range of perspectives, since multiple stakeholders of maturity optimization projects have variating (individual) objectives. However, for company success and competitive advantage, the criteria for decision making are soundly stated in the company strategy[11], determining what to risk while striving for company success.

For objective decision making, theoretical knowledge and practical knowledge both are required (*Figure 1* shows the optimization cycle which crosses both, theoretical and practical sides). Insights in uncertainties, sensitivities and perspectives require practical knowledge of the company context. In order to gain insights in the process structures which are suitable for the context, theoretical knowledge is required. This valuable combination of knowledge is difficult to obtain. However, it allows the translation of uncertainties (or '*unknown unknowns*') into '*known unknowns*', increasing the capability to indicate the outcome of a decision. Consequently, stakeholders on optimization projects which posses the previously mentioned combination of theoretical and practical knowledge, are more mature in making decisions deliberately.

11 Company strategy: "*a plan that is intended to achieve a particular purpose.*" (Oxford Learner's Dictionaries, 2019), in the company context primarily related to 'company success' as purpose.

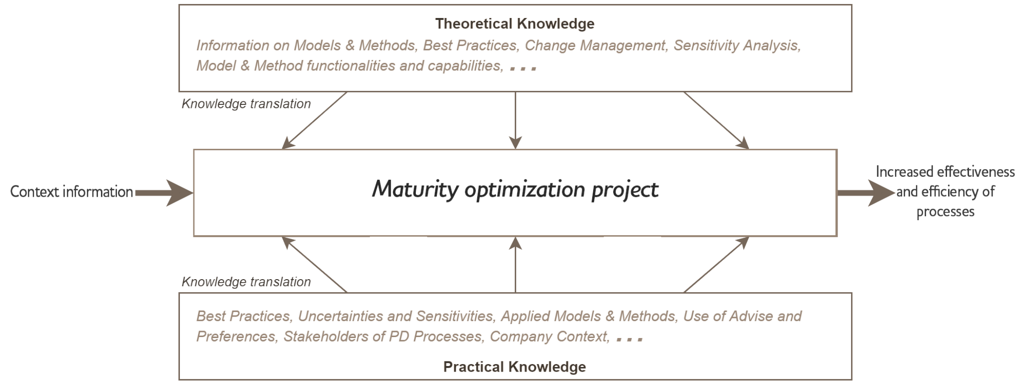

Figure 2 - For process optimization both, theoretical and practical knowledge are required

Figure 2 provides a visualization of an optimization project that requires the valuable and difficult combination of practical and theoretical knowledge. Regarding maturity optimization projects, practical information consists of, for example, best practices from experience, uncertainties, sensitivities, applied models and methods in industry, use and implementations of change and advice documents, and the specific company context surrounding the process. Theoretical knowledge consists of, for example, literature and information about models, methods and methodologies, best practices, change management strategies, sensitivity analyses and capability and maturity assessment models. The effectiveness and efficiency of PD practices and the result of optimization projects is determined by the combination of those knowledge sources. With that reason, the academy[12] cannot develop an effective and efficient PD process structure without practical knowledge of the context and the industry cannot optimize their PD maturity without use of e.g. design theories, guiding literature and developed artefacts.

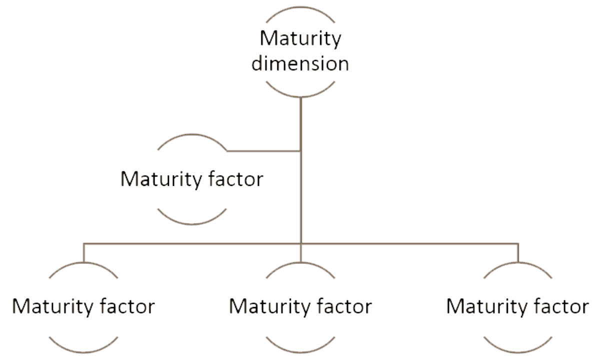

Figure 3 - Representation of a maturity context, maturity factors contribute to the maturity dimension on top

12 Academy: "*a type of official organization which aims to encourage and develop art, literature, science, etc.*" (Oxford Learner's Dictionaries, 2019), in this research primarily related to the Design Science domain.

1.2.3 Maturity assessment and decision making

Maturity dimensions, factors and levels

For performing optimization projects, the company has a certain capability of performing individual steps in that project. The capability to perform a step in an effective and efficient way is called '*maturity*'.

"Maturity implies an evolutionary progress in the demonstration of a specific ability or in the accomplishment of a target from an initial to a desired or normally occurring end stage." (Mettler, 2011).

For example, capability of the company to change the current situation and implement improvements, can be called the change management maturity, and the capability of the company to objectively assess effectiveness and efficiency of PD processes in an effective and efficient way is the self-assessment maturity of the company. Likewise, high PD maturity refers to the capability of a company to perform PD practices effectively and efficiently. Imaginably, many locations for improving capability exist. In other words, many locations for optimizing maturity can be addressed, referred to as maturity dimensions[13] in this report.

A maturity dimension exists of maturity factors[14], which contribute to the main maturity on that location. For example, as identified by *Mettler (2001)*, tree maturity factors exist as commonly used basis for maturity assessments in the field of social systems. These are identified from a highly abstract view with social systems as scope. He states that lower maturity dimensions exist of maturity factors, for example concerning process or structure maturity. Every lower location pursues more specific and detailed maturity objectives, contributing to the higher objective of the maturity dimension (*Figure 3*). Automatically, high maturity of a maturity factor is a required but not sufficient condition for high maturity of the maturity dimension above it, since the capabilities – or maturity levels – of the maturity factors combined determine the capability of the maturity dimension. The exact distribution of contributions between maturity factors depend fully on the context. This research uses that concept of maturity dimensions being supported by maturity factors, but adds the note that a maturity factor can be a maturity dimension on its own on a lower level, having maturity factors on a lower level as well. A visualization of this construction is shown in *Figure 4*.

13 Maturity dimension: "*dimension is an aspect, or way of looking at or thinking about something.*" (Oxford Learner's Dictionaries, 2019). A maturity dimension can be described as "an aspect of maturity".
14 Maturity factor: "*one of several things that cause or influence something*" (Oxford Learner's Dictionaries, 2019), in the maturity context: one or several maturity aspects that cause or influence maturity on a higher level.

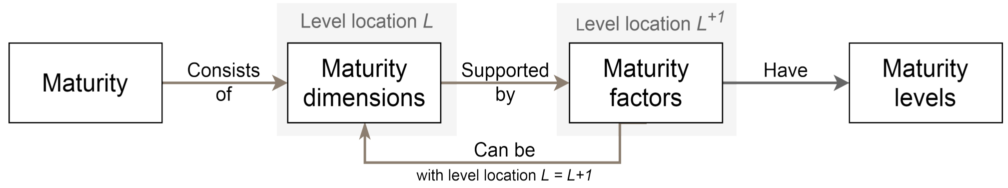

Figure 4 - Visualization of the relations between maturity, maturity dimensions, locations, maturity factors and maturity levels

Since maturity builds on effectiveness and efficiency of maturity factors, it requires a relation to a context to define meaningful levels of maturity. The maturity level[15] indicates the capability on a specific dimension and is determined by the capability, which is determined by the effectiveness and efficiency. As stated in the previous chapter, the effectiveness represents '*doing the right things*', where efficiency represents '*doing things the right way*'. These terms are per definition relative and highly dependent on the context, e.g. the organization, project, stakeholders and product (*Nieberding, 2009*). Therefore, only the combination to a specific context provides means to say something about maturity levels on maturity locations. Since the context brings uncertainties, sensitivities and perspectives, quantifying a maturity level can be complex. Furthermore, the direct interpretation of a quantified maturity level forms a risk, since the context is everchanging and a maturity level interpretation is only sensible with unequivocal insights in that context, which is unrealistic. Therefore, using quantified maturity levels without sufficient contextualization forms a risk for erroneous interpretation. Instead, added value for the company lies in received objective insights for change management, leading to implementation.

1.2.4 Design Science contributing to process structuring

Artefact development for process structuring

The search for structuring PD processes and optimization projects in a way that results in increased effectiveness and efficiency, is supported by the study of Design Science[16]. Design Science contributes to process optimization by providing theoretical knowledge on how to structure processes and perform projects effectively and efficiently. In recent years, the study of Design Science has focused predominantly on developing artefacts[17]

15 Maturity level: "*defined and ordinal scale for measuring the maturity of an organization's process and for evaluating its process capability. The levels also help an organization prioritize its improvement efforts.*" (Paulk, Curtis, Chrissis, & Weber, 1993).
16 Design Science: "*the design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artefacts. Knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artefact.*" (Hevner, 2004).
17 Artefact: "*March and Smith's differentiation of constructs, models, methods, and instantiations as artefact types (1995) is commonly accepted.*" (Winter, Design Science research in Europe, 2008).

– such as models and methods[18] - for industry to use for e.g. designing, developing and producing products and optimizing corresponding processes. *Hevner et al. (2004)* define Design Science as a combination between the understanding of and knowledge about a problem and its solution domain. With that understanding, optimization and structuring of processes take place. Building and application of artefacts in a company intends to extend capability boundaries through design oriented research. He states that Design Science:

"... seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artefacts" (Hevner, 2004).

Design Science contributes to the industrial search for effective and efficient processes. This research locates itself within the Design Science domain for its practice being able to guide, provide insights in and structure processes and contexts.

Design Science develops artefacts for problem-solving in the engineering technology field. The roots of Design Science lie in engineering technology, which makes use of artefacts. Artefacts in the engineering context consist of vocabulary and symbols, abstractions and representations, algorithms and practices, and implemented and prototype systems to provide guidance and understanding of processes, systems and situations (*Mettler, 2011*). They are shaped as tactile constructs, models, methods, instantiations or design theories to achieve that purpose and put across structuring theories (*Hevner, 2004*) (*Tuunanen, Peffers, Gengler, Hui, & Virtanen, 2006*) (*Vahido, 2006*) (*March & Smith, 1995*).

Models and methods for processes

Models and methods form the solution domain for artefacts supporting process improvement. Models and methods are more closely interrelated to each other and to process structuring than other artefact types resulting from Design Science (*Winter, 2008*). They are widely examined and developed in the research field and are proven to structure processes and process execution and optimization. Models and methods either are descriptive[19], explanatory[20] or predictive[21]. All forms "... *reflect the state of a particular*

18 Method: "*a particular way of doing something.*" "*An established, habitual, logical, or prescribed practice or systematic process of achieving certain ends with accuracy and efficiency, usually in an ordered sequence of fixed steps.*" (BusinessDictionary, 2019).
19 Descriptive model: "*says how something is actually used or done, without giving rules for how it should be used or done.*" (Oxford Learner's Dictionaries, 2019).
20 Explanatory model: "*gives the reasons for something; intended to describe how something works or to make something easier to understand.*" (Oxford Learner's Dictionaries, 2019). "*I.e., they deliver a depiction of causal connections to better understand reality*" (Mettler, 2011).
21 Predictive model: "*tells what should be done.*" (Oxford Learner's Dictionaries, 2019). "*I.e., they recommend an efficient solution state of a future reality.*" (Mettler, 2011).

application domain whether it is the exact description of the current situation or a suggestion for a more efficient or ideal target state." (*Mettler, 2011*). A model is defined as a representation of philosophies or strategies proposed to show how (PD) processes may be done, using mainly state descriptions (*Evbuomwan, Sivaloganathan, & Jebb, 1996*). It focuses on the result perspective and implies procedural aspects, where methods focus on procedural aspects and imply results, with specification of activities as focus (*Winter, 2008*). The characteristics of models and methods contribute to process structuring – an often pursued goal in industry for achieving competitive advantage and company success.

The value or success of a model or method is determined by the utility of it in practice, strongly related to the effectiveness and efficiency of PD and optimization processes. That definition of the value of artefacts puts '*utility*' in the centre of Design Science research' interest (*Hevner, 2004*). Methods and models can be certified as reasonable tools for specific uses and functionalities, if proven to be useful and utilized in that specific context (*Dhrymes, et al., 1972*). This term, '*useful*', is subjective and directly determined by the increase of effectiveness and / or efficiency achieved by utilizing the artefact in the company context. '*Utility*' is strongly related to the amount of attention a model or method receives. By forcing attention on the usefulness of an artefact, utility is the result, leading to success of the artefact developed in Design Science practices.

Models and methods for maturity assessments

Optimization projects in industry are common practice and valuable for making decision on improving the effectiveness and efficiency of processes. They are often shaped as maturity assessments or maturity audits[22]. Maturity assessments provide advice and insights for decision making for optimization. Based on the sequence of steps that optimization projects follow, a change and implementation advice results from the assessments. Companies base decisions on the opportunities for change, of which positive cost-benefit results lead to implementation and an improved level of maturity. Therefore, strengthened by the interests and needs from industry, the term process maturity is more and more recognised as measurement for assessing capabilities of companies for optimizing processes and achieving objectives.

Maturity audit models are applied as derived approaches for increasing the capability of a maturity dimension. Maturity assessments and audits guide the optimization process in the shape of models and methods, often developed during Design Science practices in academy or by external companies. Derived maturity assessment models are increasingly

22 Maturity audit: "*an official examination of the maturity of something.*" (Oxford Learner's Dictionaries, 2019).

applied, both as approach for continuous improvement (*Ahern, Clouse, & Turner, 2004*) as well as for self or third-party assessments (*Hakes, 1996*) (*Fraser, Moultrie, & Gregory, 2002*). These are performed mainly on process level and combine state descriptions (i.e. levels of maturity) with a number of key practices (i.e. potentials for improvement and activities for implementation) to achieve certain goals (perform more effectively or efficiently or solve new emerging problems) (*Mettler, 2011*). The main objective is to derive an approach (e.g. in the shape of a model or method) for increasing the capability of a specific domain within an organization (*Ahern, Clouse, & Turner, 2004*) (*Hakes, 1996*) by using maturity models as evaluative and comparative basis for improvement (*Tekwe, et al., 2004*) (*Spanyi, 2019*).

Decision making on optimization approaches for capability improvements is sensitive to multiple uncertainties in e.g. the company context. Maturity audit models as Design Science artefacts are used for providing insights in capability improvement in company contexts. Influences on optimization of processes exist of for example *(1)* the process structure (defined by artefacts such as models or methods), *(2)* the company context and *(3)* the determined objectives for the future, including sometimes divergent company objectives. The objective for decision makers is to decide and balance those influences based on a comprehensive set of criteria (*Bruin, Rosemann, Freeze, & Kulkarni, 2005*). Contributing to this aim, maturity assessment models provide overview and structure for the approach and process, resulting in higher effectiveness and efficiency of both. Furthermore, they aim to provide insights for decision makers to objectively compare influences on and consequences of optimizing a process capability. The Design Science artefacts intent to close the gap between the industrial need for structure and insights, and the broad field of existing general artefacts.

Most of the developed maturity models provide means for positioning a selected unit of analysis on a pre-defined scale (maturity levels), with some of them reaching the level of a compliance standard (*Mutafelija & Stromberg, 2003*). The objective interpretation of the context is the reason for maturity optimization projects often being performed by external companies. They intend to objectively assess the current maturity and define potentials for improvement, avoiding conflicting interests by using a maturity model – which is developed externally to the assessed organization – as measurement tool (*Fraser, Vaishnavi, 1997*). The models differ per topic and are available in contexts as: production automation, lead time reduction, industry 4.0 applications and quality assurance (*Mettler, 2011*). Artefacts developed for PD process optimization are not evidently mentioned in literature.

1.3 Gap indication

Although an extensive collection of artefacts has been developed over time, utilization of artefacts is limited. This chapter elaborates on the gap between artefacts and limited utilization.

1.3.1 Gap between specific industry and generic academy

Selecting models and methods for specific contexts

The PD context within a company determines the effectiveness and efficiency of certain models and methods within that context. Per project, details and company contexts differ and no project is executed in an identical manner (*Nieberding, 2009*). These context differences determine the '*fit*' or '*appropriateness*' of a model or method in that context and influence the effectiveness and efficiency of the process. Consequently, a first difficulty is indicated: selecting the right (combination of) models and methods for generic industrial contexts, since every situation requires a different solution.

Knowledge on the effects of the context on the selection of artefacts is limited. Research on best practices for the effective and efficient use of models and methods in industry exists, but the interpretations and findings remain superficial, data is often pertaining to a limited amount of and only a certain type of companies without sufficient context descriptions (this statement results from a literature review (*Cooper & Kleinschmidt, 1995*) (*Griffin, 1997*) (*Kahn, Barczak, & Moss, 2006*) (*Barczak, Griffin, & Kahn, 2009*) (*Barczak & Kahn, 2012*) (*Kahn, Barczak, Nicholas, Ledwith, & Perks, 2012*) (*Rossi, Kerga, Taisch, & Terzi, 2014*). They do not comprehensively underpin the path to the results, making them not directly suitable for industrial application. *Chorn (1991)* agrees that researchers are focussed on evaluating situations, strategies and styles seeming capable of consistently producing good performance. He proposes to:

> *"Abandon the search for universally appropriate strategies or management styles" and "... recognise that any strategy* (process structure) *is only appropriate in a given set of competitive conditions* (context)*." (Chorn, 1991).*

In research as well as in industry, knowledge about effects of contexts on effective and efficient utilization and selection of models and methods is insufficient. Consequently, decision making on process structuring is often based on limited knowledge and intuition, leading to immature optimization processes.

Translating general models and methods into specific structures

There is limited knowledge on translating the general literature of the Design Science domain into practical information for the industry. Once models or methods are found to be suitable for a company context, a second difficulty appears. A considerable body of research exists, proposing models and methods on the product development process. Researchers in the Design Science field agree that models and methods should be adapted to the context for enabling effective and efficient implementation and use (*Chorn, 1991*) (*Nieberding, 2009*). Surprisingly, only limited amount of studies propose how such an adaptation process is performed (*Nieberding, 2009*), hindering the industry to use the models and methods in practice.

Due to the abstraction of processes, tailoring them to specific structures for industry is difficult. Processes often are only similar on a very high level of abstraction, causing the literature and development of models and methods to be concentrated principally on a high level of generality. On that high level of abstraction, every PD process is based on a certain flow of logic that drives the development from the product idea to the stages resulting in production. A logic result of that is generalization of models and methods in literature. But, for guiding and utilization in and providing value to the industry, a more tailored and specific depiction of processes is required. Therefore, models and methods need to contain a certain level of detail to be specific enough for implementation in practice.

Fragmented knowledge in processes

Practical and theoretical knowledge are both required to close the optimization cycle. For optimization projects, many stakeholders are involved with information and knowledge scattered over project locations and levels. The PD process optimization cycle, as shown in *Figure 1*, builds on theory and requires all available knowledge on how to optimize the process of the current situation. Therefore, the results of the optimization process is highly dependent on the knowledge and information used to built and perform it. The combination of practical and theoretical knowledge is difficult to obtain, due to the fragmentation of the knowledge among stakeholders and disciplines, hindering optimization projects to be executed effectively and efficiently.

1.3.2 Limitations of maturity audit models and methods

External companies and maturity audits

Insights in models and methods developed by external firms is often confidential. A high amount of recent work exists on the development and application of effective and efficient maturity assessments or audits for optimization projects in general (*Grant and Pennypacker (2006)* state examples of these). A large contribution to development of maturity models and methods is given by project management consulting firms, playing a leadership role in maturity audits designed for identified fields for improvement (*Grant & Pennypacker, 2006*). With that, maturity audit models form a more applied topic in industry than the Design Science topic concerning abstract models and methods developed for structuring PD processes. Often, external companies take the role of interpreter for the theoretical information on optimization projects and transform it into the practical information of optimization potentials, which the industry can apply. However, many structures and design details of maturity models and methods are confidential and not available for secondary users. Within a great part of developed assessment models, research methods and underlying design decisions are not disclosed (*Mettler, 2011*). Consequently, the company receives advice on '*how-to*', but the '*why-to*' is not included.

Besides the missing '*why-to*' insights, utility as measure for success results in a biased solution domain of maturity audit models and external auditors focus on utilizing their own models and methods. Maturity audit models developed to create desired insights, often use a limited source of models and methods as solution space. Since the success of models and methods depend on utility, often a '*push*' strategy for specific (often self-developed) models and methods evolves. This results in biased and subjective advice towards companies, without insights for the companies on the reasoning behind decisions and validation of choices for certain model or method solutions. Consequently, advice from external companies often provides '*falsified certainty*' to decision makers, since *(1)* results are based on the standardized outcomes of the maturity models and methods – without including effects of uncertainty, sensitivity and perspectives – *(2)* are not tailored to the company context and strategy and *(3)* do not provide the required insights in reasoning behind the created advice.

1.3 Gap indication

Knowledge, application and theoretical backbone

The results of maturity audits are too generic for the companies and specific, practical steps for implementation are often not included. After improvement potentials are identified, gaps between the '*current*' and '*intended*' situation within a company need to be closed by change management and improvement implementation activities (*Pfeffer & Sutton, 1999*). However, many models do not specify the path for effective execution of these activities. This gap is called the 'knowing-doing gap' and can be difficult to close if not all required knowledge concerning the models and methods is available in the optimization project.

Besides the biased solution space of included models and methods, maturity audit models focus predominantly on production, manufacturing, industry 4.0 and Information Technology subjects. In other words, there is a limitation in processes where maturity audits are developed for. Notably, the PD phase is only targeted to a limited extend. However, an extensive amount of value is created during the PD phase for a large amount of companies, forming the relevance of this research. Furthermore, the relationships between and influences of higher levels of maturity are often neglected and form the focus of a new, growing base of research supporting that aim (*Grant & Pennypacker, 2006*).

For existing maturity audit models, the most important critique is their poor theoretical basis (*Biberoglu & Haddad, 2002*). Projects in companies with favourable results form the inspiration for deriving best practices, while there is no agreement on '*one true way*' for assuring a positive outcome (*Montoya-Weiss & Calantone, 1994*). *Becker, Knackstedt and Pöppelbuß (2009)* state requirements for assuring a better theoretical base in maturity audit model development. The keywords of the requirements are stated and provide guidance during this research.

Requirements for a firm theoretical backbone

Comparison with existing maturity models
Iterative procedure
Evaluation
Multi-methodological procedure
Identification of problem relevance
Problem definition
Targeted presentation of results
Scientific documentation

1.4 Research

This chapter starts with summarizing the findings of previous chapters. From those findings, an objective is derived forming the value proposition of this research. However, this highest objective does not fit within the limitations and boundaries of the thesis assignment. Therefore, as a starting point, a smaller research objective is derived which contributes to achieving the highest objective. The resulting limited solution domain of this research is formed into a research question, of which the answers are evaluated for their added value for stakeholders. Limitations are stated and development and validation methods are determined.

1.4.1 Research directive

Highest objective

Summarizing previous chapters, *Table 1* lists the findings of the orientation and gap indication chapters on which the highest objective is based. An objective is stated with the identified gaps numbered and related to the aspects within that objective. With the findings in mind, the orientation and gap indication substantiate evidently the need for:

decision makers in industry (gap #3) to have objective (gap #4, 6, 9) and detailed insights (gap #1, 5, 7) in PD maturity optimization (gap #8), tailored to their specific PD practices (gap #2).

Table 1 - Summation of the results from orientation and gap indication chapters, forming the highest objective

#	Gap
1	Detailed insights for process model and method selection are often not available but are necessary since the context influences results much
2	Tailoring general models and methods to the company context requires specialized knowledge which is limited
3	Knowledge for performing and selecting models and methods is scattered along stakeholders, if present at all
4	Disciplines, personal experiences and perspectives bias model and method selection
5	Detailed insights in process structures and reasoning behind results are missing or confidential
6	Process results are often limited to biased and pre-defined solution domains
7	After identification of improvements, the knowing-doing gap is restraining companies from optimized processes
8	Optimization projects and audits are not available for PD practices
9	Maturity assessments are often designed on a poor theoretical base

Resulting from that statement, the highest objective is formulated as:

Provide industry with objective and detailed insights for improving product development maturity.

"Provide industry..."

This part of the research question ensures the value of the results for the companies and applicability in industry. Previously, the limited utility of models and methods in practice is mentioned. Therefore, this research includes this focus.

"... with objective and detailed ..."

This section relates to the added value of tailoring the models and methods to the company context in a structured way. Added value to industry as well as to academy is provided in this step.

"... insights ..."

The insights in optimization need to be communicated to the companies for them to objectively decide on potentials for implementation. Insights require a certain logic or level of underpinned results, relating to the transparency of the information behind the insights, on which objectively decisions can be based by providing knowledge of e.g. sensitivities, uncertainties and perspectives. The word '*insights*' represents the information required by the company for making deliberate decisions on PD optimization.

"... for improving..."

This section refers to the implementation of PD improvements. This research is not dependent on whether optimization potentials are implemented or not, but only provides insights enabling stakeholders to make improvement decisions deliberately.

"... their product development ..."

Other phases in the value creation chain (i.e. production or logistics) may also be optimized with use of other maturity audit models and optimization strategies, but this research focuses specifically on PD practices. The author is specialized in the PD process and its existing models and methods and will not focus on discussing optimization strategies and maturity audits on other phases.

"... maturity"

Improving maturity per definition entails increasing the effectiveness and efficiency of processes, which is related to structuring processes (*Chapter 1.2.1: Product development*).

Many models and methods are developed for structuring and guiding the PD process, as discussed in *Chapter 1.2.4: Design Science contributing to process structuring*. They have proven to contribute to effectiveness and efficiency of processes, dependent on the context. Due to the large amount of existing models and methods, the author prioritizes research on the selection process for optimizing PD process maturity above creation of new models and methods. Therefore, this research focuses on using reconfigurations of existing models and methods. This leads to increased value creation when companies meet the requirements that will be discussed later in the scope definition (*Chapter 1.4.3: Scope and limitations*). The improvement of maturity forms the value proposition towards the industry and the main reason for the existence of this research.

Solution domain

Ideally, this idea results in a utilized and mature model or method which has proven to be able to guide and structure all steps required for improving PD maturity in industry, performed in the wide application scale of the product developing industry. Making PD maturity optimization insights available for industry is the key deliverable, objective tailoring of solutions to context aspects is the key challenge and objective decision making on PD maturity optimization by the company is the aimed key result.

This research focuses on optimizing one dimension of PD maturity: PD process maturity, and provides overall insights in influences on PD maturity optimization. This thesis is limited to the length and depth of a master thesis. In the orientation, the many dimensions of maturity are discussed, with the relations, influences and contributions between maturity locations (*Chapter 1.2.3: Maturity assessment for decision making on process optimization*). High PD maturity is influenced and determined by all maturity factors contributing to that dimension. Stated before: high maturity of a maturity factor is a required but not sufficient condition for high maturity of the maturity dimension above it. Therefore, all maturity dimensions involved require comprehensive research. This will not fit the master thesis duration. Consequently, this research focuses on optimizing one dimension of PD maturity: PD process maturity, which involves the structuring of the PD process with use of tailored models and methods. However, other involved maturity dimensions play their role in this research as well. These will be examined for their theoretical influence, but will not be identified and examined comprehensively.

A twofold design problem is initiated in previous chapters (*Figure 5*), *(1)* objective selection of an appropriate maturity dimension for optimization must be guided and *(2)* insights for PD process maturity improvement must be provided. This research will not result in a fully

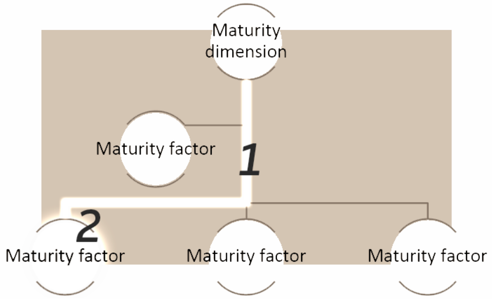

Figure 5 – A twofold design problem: (1) selection of an appropriate maturity factor for optimization and (2) optimization of the PD process as maturity factor in specific

developed model or method, but is limited to developing two proof-of-concept models for these design problems. Models and methods for optimizing a maturity dimension have been studied in detail and their function directly supports the highest objective of this research. However, models and methods for PD maturity dimensions are not successfully utilized yet, although the need exists as identified in earlier introductory chapters. This function of optimizing one PD maturity dimension can be fulfilled by a wide range of design solutions, but since duration and depth of this research is limited, exploring all design solutions is unrealistic. Therefore, in a first attempt, this report develops and evaluates one concept model for its capability to contribute effectively and efficiently to achieving the main objective. It is immature for that capability until the contrary is proven. This means that a first (immature) idea is provided and maturity can be tested and evaluated after designing the concept model in more detail. After validation of the designed concept model, the result of this research is a design of a proof-of-concept model (also referred to as 'the design' in this report) for improving PD maturity within industry, focusing on PD process optimization.

Table 2 - Research objective and sub-questions

Research objective	Develop a proof-of-concept model for providing industry with insights in PD maturity optimization	
#	**Sub-questions**	**Chapter**
1	What influences and determines PD maturity?	**2: Maturity vision**
2	How to validate if **PD maturity** optimization is valuable in a company context?	**3: The PDMO concept model**
3	How to assess and optimize **PD process maturity** in a company context?	**4: The PDPMA concept model**

Research objective

The research objective is derived from the earlier stated objective, with respect to the limitations stated above. Derived from that, the sub-questions are stated that require insights to achieve the research objective. All are provided in *Tabel 2*.

1.4.2 Research value

Research stakeholders

This research is not trying to be the final word on the subject of PD process optimizations or on PD maturity. It is not critical, challenging or contradicting towards existing models and methods and ways they are implemented in industry, but proposes a different perspective on selecting (parts of) existing models and methods for the company context and providing the companies with insights towards an increased PD maturity.

From the Design Science research guidelines (*Figure* 6), two stakeholders are identified that play major roles and gain value out of maturity audit model development:

- The academy is limited to providing theoretical information in the Design Science field, with only limited pathways to industrial implementation of the designed artefacts. They strive towards developing successful artefacts, but for achieving that, utilization of those artefacts in industry is necessary.
- The industry does not have knowledge and insights for selecting an effective optimization focus and adapting designed artefacts in a mature way for their context, although that would benefit for company success.

This research attempts to take first steps in closing the previously identified gaps. It provides insights in the selection of maturity dimensions for optimization and how to adapt them to the industry, with respect to influences of the company context on effectiveness and efficiency of designed artefacts in the Design Science domain. This is designed with the broad levels and dimensions of maturity in mind – supported by and contributing to academic literature – and results in proof-of-concept models aiming for utility in industry.

Value to academy

This research is committed to the fields of Design Science, contributing mainly to the subjects product development, process optimization and maturity assessment. For being valuable for Design Science domain, the guidelines of *Figure* 6 are used. It adds a new perspective to the search for closing the gap between the existing literature on general models and methods and the industry's search for specific process guidance in their PD context. This is achieved by developing two proof-of-concept models which *(1)* provide insights for adapting models and methods effectively and efficiently to company contexts, with related insights in the roles of e.g. uncertainties, perspectives and sensitivities and *(2)* provide insights in influences and decisions on maturity dimension selection for PD maturity optimization.

Nr.	Guideline	Description
1	Design as an artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation
2	Problem relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems
3	Design evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods
4	Research contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies
5	Research rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact
6	Design as a search process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment
7	Communication of research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences

Figure 6 - Design Science research guidelines (retrieved from Wendler, 2012)

The results of this research encourage the industry to recognize and use the existing models and methods, by providing objective insights in the added value of (parts of) models and methods for industry. This enables critically reviewing existing PD practices and advocates for the industry to see the value of models and methods for their context. Increased use of models and methods is valuable to Design Science practitioners, since success of model and method designs is strongly related to utility. This research proposes two proof-of-concept models which illustrate and identify opportunities for future research. Furthermore, an unexplored application for maturity assessment is proposed in the context of PD with a clarifying, broad view on influencing maturity levels and dimensions.

Value to industry

With further development of this model, insights are created on how effective and efficient a company develops products. Instead of forcing a PD project into a pre-defined process shape or to perform the process on a gut-feel or experimental level, process structuring is improved based on specific context requirements and aspects, enabling improvement of the PD process maturity. It contributes to the industry's search for effective and efficient value creation through product development, resulting in a high PD maturity. This research provides insights for decision making on PD maturity optimization, increasing insights in '*how-to*' and '*why-to*' do the right things, the right way. These insights result in knowledge for the company, contributing to improved effectiveness and efficiency of PD processes, aiming for a higher PD process capability. Higher PD process maturity is a required (but insufficient) condition for PD maturity, contributing to increased company success.

This research improves the PD maturity of companies by providing insights in how to select appropriate maturity dimensions for optimization, and how and why to structure the PD processes, with respect to the context. These insights for optimization can be developed into practical tools, making insights available to the industry in a transparent, underpinned way, with priorities and respect to e.g. perspectives, uncertainties and sensitivities. This is valuable information for the company in order to optimize their processes and e.g. benchmark PD processes to other companies. Both, understanding of the project context as well as the theory behind the methodologies are used to create the insights. This results in the valuable combination of practical and theoretical knowledge, encompassing information on optimization opportunities which otherwise would have stayed hidden or could be misleading. This optimization process is presented in the well-known shape of a maturity assessment, acknowledged and recognized by companies for their effectiveness and efficiency.

1.4.3 Scope and limitations

Research scope

The research is limited to the extend of the master thesis assignment, defining the research results as a starting point for PD maturity optimization. In this chapter, identified sources for limitations are discussed to provide a scope that functions as a starting point for achieving the highest objective. *Chapter 1.4.1: Research directive*, already discussed the highest objective of the research and limiting boundaries of the master thesis assignment, resulting in a research objective functioning as illustrative starting point for further research on the PD maturity optimization topic. The insights and information of the previous introductory chapters instantiate the wideness of the application, solution space and design opportunities for this research. If the research limitation did not exist, a full design of a model could be developed for the objective to increase the maturity of all PD practices for companies, which is not realistic within the scope of the assignment. Further limitations are listed beneath and discussed in further extend. Consequences and future opportunities of research limitations are discussed in *Chapter 7.2.4: Validity influenced by scope and limitations* and *Chapter 7.3: Recommendations.*

Limitation of the industrial context

The industrial context where the proposed models will be applied in, is limited to avoid a too generic design. For the design, the applicability and scope for the target group (the industry), may exist of a large and broad group of companies for which increase of PD maturity might be useful. Industry overall is a very broad scope with variations and context differences, forming an enormous landscape of possible focus target groups. This askes for limitation of the industrial contexts for application of the design. Without this limitation, a PD maturity model design would be applicable on only a very high and abstract level or requires many complex configuration steps in order to tailor it to specific context variations. However, general models and methods have been proven to be utilized inadequately in the specific context and need to be understandable for the stakeholders in industry as stated in *Chapter 1.3: Gap indication*. This provides means for the existence of this limitation.

As starting point, the application domain is limited to companies that develop tangible, technical products to create value. Fulfilling the research objective can be valuable for any PD project, irrespective of size or industry and especially tailored to e.g. size and industry. However, in the broad scope of the industry, a starting point is created by focusing only on companies that develop tactile, technical products to create value. For the PD maturity optimization to be valuable for the company, the effectiveness and efficiency of the PD process must have a direct influence on the value creation of the company. Then, optimization of the PD process has a high chance of directly contributing to increased value creation.

Application of the results is limited to only small and medium companies and engineering projects, without taking into account higher organizational influences. To define the starting point further, this thesis focuses on the context of industries other than automotive, one-off or rusted up, are considered for the context of this thesis, because in order to increase the maturity of the PD practices for a certain company, the effort required for improvement must not exceed the benefits. Therefore, industries with a high chance of not meeting this requirement are left out of scope, but can be included in application after the concept model has been proven to be mature.

The author is aware of higher organizational influences of parent organizations on single companies. However, these are not covered in full extend and focus of this research is exclusively on the company level in which the product development process is executed. This limitation is placed due to research time restrictions and avoidance of generality in

solutions. Concerning inclusion of higher organizational strategies and contexts, the design is evaluated for extension – including these as well – after maturity of the concept model has been proven (*Chapter 7.2.4: Validity influenced by scope and limitations*).

In-scope and out-of-scope scenarios are provided. Examples of context aspects of suitable applications and not suitable applications for this research are mentioned. As discussed previously, this scope is set only to provide a starting point for this research. If proven to be valuable, extension of the scope is possible.

Scenario – In-scope

A company creates value by developing tactile, technical products. The company has grown over time and the PD process is necessarily adapted and grown slightly with the growth of the customer demands. Insights in the complete PD practice and its maturity are lost in the process, resulting in indeterminant processes. Consequently, loss of insights in effectiveness and efficiency cause loss of insights in how to increase them. A maturity assessment objectively targets PD process maturity as optimization focus dimension and examines the current PD process for potential improvements, resulting in structured, tailored and underpinned insights PD process optimization allowing the company to improve their PD process maturity. This contributes to the increased PD maturity and the value creation through effective and efficient PD of the company.

Scenario – Out-of-scope

- The company is restricted from choosing or optimizing PD processes, i.e. by regulations, costs or company strategy; or,
- The company does not develop tactile and technical products; or,
- The company does not generate value by developing products; or,
- The company does not see the value in optimizing the PD process maturity.

Limitation of the model and method solution space

The artefacts – models and methods – included as solution space of the designs are limited and form only illustrative examples. The design must include existing models and methods for PD process optimization as solution domain and for guiding and structuring maturity optimization projects. The solution space of developed models and methods in literature concerning the PD process context and maturity assessments is large. Without limitation, all Design Science artefacts need to be studied comprehensively to use as solution space for the proof-of-concept model. Only a selection of models and methods is appropriate for the previously described target group. Consequently, limitation of the solution space of models and methods is required. For providing a starting point and illustration of the solution domain this research only uses examples or illustrations of (parts of) models and methods. These illustrations are again limited to familiar, prescriptive, engineering models and methods, suiting the target group limitation and fulfilling a guiding and structuring role.

The models and methods in this research stem from engineering domains regarding PD practices, to the fit of those models and methods to the scope of technical and tactile products. However, with further development of the proposed design, other types and categories may be implemented conveniently, such as models and methods from the enterprise engineering perspective (*Preez, Essman, Louw, Schutte, & Marais, 2010*). The indicated solution domains in this first design idea may be proven incomplete or overcomplete in further iterations implying a sensitive limitation in the model solution domain. Including other models and methods in future research is discussed in further extend in *Chapter 7.2.4: Validity influenced by scope and limitations* and *Chapter 7.3: Recommendations.*

To form a starting point, the solution domain is limited to utility of prescriptive models and methods. Descriptive models of the development process are unstructured and focused on the detailed cognitive processes (*Nieberding, 2009*). Mainly the unstructured characteristic restricts descriptive models from being useful in this research. Therefore, focus is on prescriptive models for their structuring, guiding and well-specified functions. This fits best with the research objective and highest objective from *Chapter 1.4.1: Research directive.*

The terms '*models*' and '*methods*' are used interchangeably. The author acknowledges the distinction between models and methods and the descriptions and existence of both are included in this report. However, for the majority of the theory in this research, the distinctions in the name (or the '*label*') of an artefact (whether it is a model or a method) has often no influence on the illustration and meaning in the described context of this report. Therefore, models and methods in this research are often mentioned both. Where distinction is required for explanatory reasons, they are labelled accordingly.

Limitation of literature sources

Used literature sources may bring limitations with them, which need to be taken into account during design. The literature and information that contributes to this research, are influenced by perspectives, assumptions, personal preferences and disciplinal characteristics. Without taking these into account, literature sources take their limitations with them in this research, resulting in subjectivity or imbalances in results. Sensitivity of these limitations on design results are taken into account in the requirement chapters and are validated and discussed in *Chapter 7.2.4: Validity influenced by scope and limitations.*

A pre-defined set of company context aspects is used in this research as illustrative starting point. In the orientation, the relevance of company context aspects and their influence on PD model and method selection and adaptation is emphasized. As a starting point and illustration on company context aspects, the identified context describing terms of *Nieberding (2009)* are used as inspiration and supplemented where seemed necessary. Sensitivity of this limitation on the results are evaluated and discussed in *Chapter 7.2.4: Validity influenced by scope and limitations.*

The research is limited to one-dimensional maturity assessments, focusing on process maturity[23] only. Literature describes multiple dimensions on which maturity assessments can be based. *Paulk et al. (1993)* and *Fraser and Vaishnavi (1997)* identified process maturity as a (one-dimensional) maturity assessment focus. *Gericke et al. (2006)* explored object maturity[24] as dimension and *Nonaka (1994)* determined that people capability[25] can be a maturity dimension as well. This research is limited to the development of a maturity assessment model design focussed specifically on process maturity. Therefore, aspects of the other dimensions are not particularly taken into account in this research. This is not expected to harm the results since the objective is to optimize the PD process maturity. However, with PD processes and process maturity, uncertainties and influences from context aspects concerning people and products may arise. These are included in the pre-defined company context aspects as described in the previous paragraph and are not expected to affect the validity of this research.

Maturity dimensions and factors together with maturity audit models are often based on a limited theoretical foundation. Product Development maturity model development is a

23 Process maturity: "*to which extent a specific process is explicitly defined, managed, measured, controlled, and effective.*" (Paulk et al., 1993; Fraser and Vaishnavi, 1997) The author adds '*efficiency*' of the process, since effectiveness without efficiency is not deemed to be sufficient for process maturity.

24 Object maturity: "*to which extent a particular object like a software product, a machine or similar reaches a predefined level of sophistication.*" (Gericke et al., 2006).

25 People capability: "*to which extent the workforce is able to enable knowledge creation and enhance proficiency.*" (Nonaka, 1994).

relatively new domain. As stated by *Bruin, Rosemann, Freeze and Kulkarni (2005)*, gathering sufficient evidence for deriving a comprehensive overview of maturity dimensions and influences, requires a large collection of supportive literature. Limited knowledge and literature on maturity assessments for the PD domain causes the illustrated maturity dimensions and factors being based on a limited theoretical foundation. However, since the design will be a first iteration and starting point for further development, inaccuracies of the identified maturity dimensions can be revised and adjusted after more requirements or theoretical foundations become available. In this research they function solely as illustration. These immature illustrations of realistic dimensions are validated and evaluated in *Chapter 7: Concluding remarks*.

1.4.4 Development methodology

Maturity Audit model as suitable solution

The appropriateness and applicability of using a maturity audit model as concept for fulfilling the stated objective, can be assessed by cross-referencing the findings with design principles of maturity audit models in literature. As an example, Pöppelbuß and Röglinger (2011) compared maturity audit models and stated general design principles of them. In *Appendix 8.1: Principles of maturity models*, relevant PD maturity information from the introduction is linked to those design principles and listed in topics that the designs need to address. This overlap in 'required functionalities' as stated in the introduction on one hand and 'provided functionalities' of firmly developed maturity assessment models on the other, provide insights in the suitability of using maturity audit models in the research' context.

Following from the cross-check in the appendix, the basic design principles provide the required information about the maturity audit model to the target group in a format they well understand. The target group is familiar with the use of prescriptive engineering models and methods directed by their disciplines, guiding them in decisions and processes. A prescriptive use purpose is therefore chosen as most suitable for this context. This comparison indicates that the theory of *Pöppelbuß and Röglinger* matches in the origin with the objectives of the design for this research. With that, it indicates that a maturity audit model is appropriate as proof-of-concept design to start with for achieving the objective.

Maturity model development

Only limited information is available on developing theoretically sound maturity models, which are rigorously tested and widely accepted (*Bruin, Rosemann, Freeze, & Kulkarni, 2005*). *Mettler (2011)* defined a framework of decision parameters and development steps for maturity audit development, the framework is filled in and provided in *Appendix 8.2: Model development standards*. Bruin, Rosemann, Freeze and Kulkarni (2005) state phases for model development (*Figure 7*). The combination of the Design Science guidelines (*Figure 6*), the filled-in framework of *Mettler (2011)*, the model development phases of *Figure 7* and the listed model requirements for a firm theoretical backbone (*Chapter 1.3.2: Limitations of maturity audit models and methods*), enhance the validity of the research results. Development is executed up-to concept design with inclusion of validation. The standards for model development are used during this research to guide the development towards valid research results.

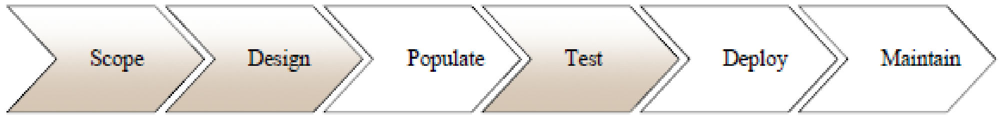

Figure 7 - Model development phases as identified by De Bruin, Rosemann, Freeze and Kulkarni (2005)

Concept model design as product development process

Model development is seen as a product development process. In the years of practicing and researching PD in the field of Industrial Design Engineering (IDE), the author experienced a variation of PD process structures applicable for this research project, which can be seen as solving a design problem. For selecting a structure, the context of the research project is described in *Appendix 8.2: Model development standards*, by roughly addressing the context aspects as identified by *Nieberding (2009)*.

Three existing product development process structures are evaluated based on the context description and visualized in *Appendix 8.2: Model development standards*: *(1)* Suireg's model for the product development process (*Suireg, 1981*), *(2)* IDC's development process for construction projects (*Nieberding, 2009*) and Cross' Model of the development process *(Cross, 1994*) are used to compare to the context.

Cross' product development process structure combines best with the context of the research. The relatively limited project size and team size, and the maturity and capability of the designer indicate utility of flexible and not too strict models. The complexity of the product and hierarchies require a certain form of '*design thinking*' or '*feedback loops*', allowing improvement and iterations on ideas, although only a concept is developed. A major aspect in the assessment and '*success*' evaluation of the research results by the organization is performed based on the documentation in a report and paper (this report combined with a paper), providing means to focus on a high quality of documentation.

With this focus on flexibility, evaluation and documentation, the choice for Cross' product development structure (*Figure 8*) is made, where '*Communication*' represents mainly documentation of results and communication of the process to the organization (the supervisor of this research project). In the model visualizations, the steps that are included in the scope of this research are coloured according to their function. Red represents structuring information, yellow represents idea generation and blue is result evaluation. The grey steps are out-of-scope for this research, as is the represented feedback loop.

The model of Cross states '*Exploration*' as first step, which is mainly performed in the previous chapters (*Chapter 1: Introduction*). The first steps entail exploration of existing theory and stakeholders. Based on that, the '*Generation*' step is performed, where requirements can be stated following in concept generation. A twofold design problem is initiated in previous chapters, *(1)* objective selection of an appropriate maturity dimension for optimization must be guided and *(2)* insights for PD process maturity improvement must be provided. The first part requires a more abstract theory behind influences of maturity dimensions on company success. For developing such concept model, a vision can lead to implications for practice (*Chapter 2: Maturity vision*). This vision must state the theory behind objectively selecting dimensions for improvement, which needs to be visualized and executed by a first generated concept model (*Chapter 3: The PDMO concept model*). In parallel – if PD process maturity is selected as dimension – a second model needs to guide the stakeholders in in optimizing their PD process (*Chapter 4: The PDPMA concept model*). Therefore, the '*Generation*' phase of Cross' model will be performed twice and '*Evaluation*' must be performed with respect to each model separately, as well as evaluating their contribution to the highest objective (*Chapter 7: Concluding remarks*). After communication of the concept through this report and a paper, evaluation of the process is performed in *Chapter 7.1.1: Research process evaluation*.

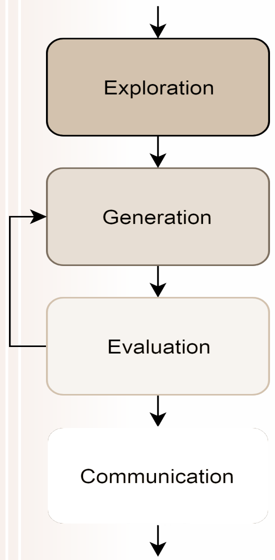

Figure 8 - Visualization of Cross' development process structure (Cross, 1994)

1.4.5 Validation and verification approach

The concept models require a theoretically sound validation technique for assuring validity of research results. The introductory chapters of this report stated the limited theoretical base behind model and method development, resulting in criticized views on validity and utilization of them (*Chapter 1.3.2: Limitations of maturity audit models and methods*). Therefore, extra attention is put on validating the concept designs. *R.G. Sargent (2010)* and *D.K. Pace (2004)* performed comprehensive research on '*Conceptual model Validation*', which is used as a standard for validation in this research.

Each design chapter will locally validate and discuss results for a small part of the concept models. These validations however, do not validate the model on higher design hierarchy levels. Consequently, a structured global analysis of the design is required. *R.G. Sargent (2010)* developed a well-defined approach for validation and verification of models and methods. *D.K. Pace (2004)* identifies and summarizes major modelling and simulation challenges for validation and verification, with providing indications on addressing them. The combination of both provide sufficient knowledge for validating and verifying the concept designs in a general and standardized manner. The main approach and validation techniques are summarized in *Appendix 8.6: Validation Techniques*. The recommended procedure for validating models as determined by *Sargent (2010)* is adjusted to fit the design phase of the research results. These are described in *Chapter 7.1: Global validation and evaluation*.

The validation approach that *R.G. Sargent* suggests as "*recommended procedure*", includes detailed model designs and computer simulations as well. Since this report represents concept models, only the steps concerning this level of design are taken into account for validation, resulting in a listed validation approach (*step 4* is considered as being performed in writing respective validation chapters in this report).

The validation procedure as adapted from *R.G. Sargent (2010)*:
1. Specify the basic validation approach and set of validation techniques
2. Define required accuracy for results of output variables and validation techniques
3. Test assumptions and theories with selected validation techniques
4. Develop validation documentation for the concept level validation

1.4.6 Report structure

The report structure is based on the shape of an hourglass. It starts with describing abstract background information which is required for understanding detailed parts of the concept models. The structure is visualized in *Figure 9*. Consequently, this report does not represent a chronological order of activities performed during the development process, but explains the designs based on a logic flow of information required to understand them. Readers unfamiliar with the theory behind maturity audits and models are advised to read the abstract summary of the concepts (*Chapter 5: Concepts summary*) before reading the design chapters (*Chapter 3: The PDMO concept model* and *Chapter 4: The PDPMA concept model*). The summarizing chapter contextualizes the detailed and theoretical information from the design chapters, guiding the detailed puzzle pieces in the bigger picture while reading the design chapters.

The second, third and fourth chapter start with stating the Maturity vision, subsequently explain the PDMO concept model and end with explaining the PDPMA concept model. The author has chosen to start with a high level of abstraction by explaining the vision behind maturity optimization and PD maturity dimensions (*Chapter 2: Maturity vision*). With that information, the functions and design of the PDMO model are explained, since that design is a tacit representation of the Maturity vision (*Chapter 3: The PDMO concept model*). One component of this model is designed further, resulting in the designed concept for the PDPMA model. This design is explained and illustrated in *Chapter 4: The PDPMA concept model*.

These design chapters present the information about the designs in a consecutive order: Directive, Design and Local validation. '*Directive*' entails the sub-objectives the design is contributing to, a representation of the vision and the requirements. '*Design*' explains and illustrates the designed solution with use of textual descriptions and visualizations. '*Local validation*' evaluates the design on a local level for its capability to achieve the sub-objective by fulfilling the requirements. These design chapters explain the designs with a relatively high level of detail. This may hinder the understanding of the abstract, basic idea as presented in the vision. Therefore, the design chapters end with a more abstract view on the designs, as summary of the proposed concepts (*Chapter 5: Concepts summary*).

Thereafter, the designed concepts as a tools in industry are described, with a cost estimation, tasks for further developments and utility in practice (*Chapter 6: Future prospects*). Subsequently, the concluding remarks start with validating the PDPMA concept model and the PDMO concept model for achieving the research objective. Thereafter, the research process is briefly evaluated (*Chapter 7.1: Global validation*). The discussion

addresses the research objectives, scope and limitations, assumptions, added value of the research and the validity of the research results (*Chapter 7.2: Discussion*). Based on all previous chapters, recommendations for further research and validations are stated (*Chapter 7.3: Recommendations*). *Chapter 7.4: Conclusion* concludes on the research with stating the relevant findings, validity and general research results. The used literature is stated in *Chapter 7.5: References*. Additional material is documented and includes the chapters where is referred from (*Chapter 8: Appendices*).

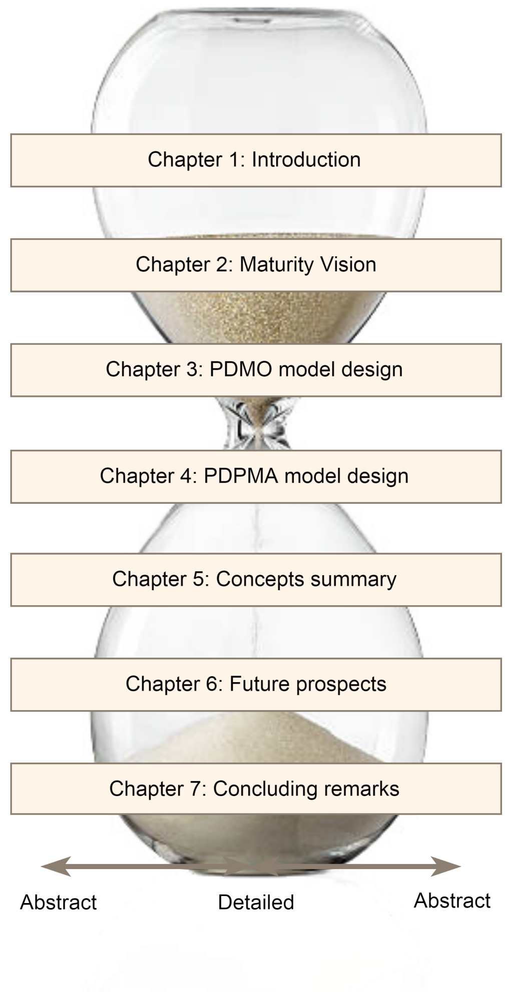

Figure 9 - Hourglass representation of the report structure with its chapters

2 Maturity vision

Chapter content

Maturity optimization projects can target many processes. However, optimization of a maturity dimension does not automatically effectively and efficiently contribute to company success. For selecting a specific maturity dimension (targeting a certain process) for optimization, deliberate decisions must be made, subject to uncertainties, sensitivities and biases of the company context. The company strategy states the company's highest objectives in order to attain company success. Together with the everchanging context, they need to form the perspective on which decisions for maturity optimization projects must be based. Identification and selection of maturity dimensions in a maturity context then follows a top-down approach, where process optimization follows a bottom-up approach. A vision can be translated into implications for practice, guiding and communicating maturity insights. Utilization of a tool which supports this vision, provides industry with insights in selection of low level maturity factors for optimization using the company strategy and company context as directives. This results in objective selection of processes for optimization, contributing effectively and efficiently to company success. A concept for a tool supporting this vision is designed as the Product Development Maturity Optimization (PDMO) model.

2.1 Vision on maturity

This research outlines how PD processes can be optimized to facilitate the company strategy's perspective which aims for company success. The Maturity vision discusses this view and the reasons behind it.

A vision enables translation into specific objectives and implications for practice. By specifying and initiating the vision for optimizing maturities with company strategy as directive, a first major step towards improved maturity optimization for industry is made. A vision can be translated into specific objectives and enables designing a model that leads the objectives into implications for practice. Currently, there is no univocal vision wherein maturity dimensions can be objectively targeted by decision makers for optimization. The situation now shows companies making optimization decisions primarily based on trends, intuition, available resources and experience of individuals. Consequently, there is insufficient awareness about the higher objectives of the company, the vision that all maturity dimensions contribute to one main goal. This main goal for a company is presented in the company strategy and should form the basis for all decision making aiming for company success. There is no coherence between the optimization projects on one hand and other influencing maturity dimensions on the other hand.

This research aims at all decision makers understanding and acting towards the broader Maturity vision where company success is the highest objective for optimization projects. This allows companies to strive for an optimization project to be fully in service of the highest objectives of the company, which is defined in the company strategy with the ultimate goal of company success. A vision on focussing maturity optimization follows automatically when reasoned that the company strategy defines the company's main objective, and the capability of performing that objective is the highest dimension of maturity, aiming for company success. This main maturity is supported by maturity factors, which in their turn are supported by lower locations of maturity. This endeavour requires all involved decision makers to see and understand this broader Maturity vision with all influencing maturity dimensions included and the main maturity objective on top. Only then decision makers can objectively identify, understand and select a maturity dimension for optimization.

A vision enables translation into practical, well-defined targets. But what does it look like: a broad Maturity vision for objective decision making on maturity dimension targeting? What insights do we need to achieve that? How do we ensure that today's insights are usable now and in the future as well? What to change for optimizing the PD Maturity? How do we get to specific change management for optimization? Who is stakeholder of that process? De designed Maturity vision provides answers to these questions.

2.2 Vision on PD maturity optimization

2.2.1 Maturity levels and locations

For insights in the maturity dimensions in a company, the maturity context needs to be defined. In this research, maturity contexts defined with maturity dimensions are used as guidance and a representation. The dimensions provide context for communication and specification of the optimization project, scope and intended results, since optimizations and assessments are meaningless without a context they are applied to (*Mettler, 2011*). Implementing results from optimization projects leads to change on one of the maturity factors (a lower maturity dimension). The objectives of the maturity factors contribute, support and give shape to the objectives of the higher maturity dimensions, as stated in the introduction. The higher locations lay close to and support the overall maturity: the capability to effectively and efficiently fulfil the highest objectives and vision of the company. Therefore, in order to optimize (change) on a certain maturity factor, the higher dimension is leading and it is preferred to change lower maturity factors towards higher maturity dimensions. This directly implies that location (dimension or factor) and level of maturity are indispensable factors in defining the context and aim of optimization projects.

Providing an example of maturity factors based on the PD context representation visualized in the introduction in *Figure 1*; the capability of the company to change the current situation and implement improvements can be seen as the '*change management maturity*' of the specific company and the capability of objectively assessing the effectiveness and efficiency of PD processes in an effective and efficient way can be seen as '*self-assessment maturity*'. Those are two maturity factors contributing to and supporting PD maturity as higher dimension. Many more supporting maturity factors for PD maturity are possible and inclusion or exclusion is dependent on the company context and perspectives on maturity.

Maturity factors are the focus for optimization projects. However, a high maturity factor is not automatically a high maturity dimension. For example, with low '*self-assessment maturity*', the '*change management maturity*' may be very high but still results in ineffective and inefficient PD practices, since the company will not be able to assess their processes for optimization of the PD practices. Consequently, optimizing '*change management maturity*' in that situation is ineffective. Encapsulated, a high maturity factor is a necessary but not sufficient condition for a high maturity dimension. This results in the assumption of this research that PD process success is a required but not sufficient prerequisite for PD success.

2.2.2 Lower locations as focus for optimization

Lower maturity factors need to be identified with company success as maturity dimension on top. Maturity is strongly related to objectives (since maturity is the capability to achieve an objective) and structures for achieving the objectives (since structuring processes and projects contributes to high capability). This line of thoughts on relations between company success and process structuring is visualized in *Figure 10*. Within this figure, the amount of contribution of certain processes to the higher objectives are not linear or similar. So, contribution of all is required in order to improve the higher dimension's objective and effective and efficient contribution of one process is therefore a required but not sufficient condition for achieving that aim.

Optimizing maturity factors through a bottom-up approach, increases effectiveness of optimizations if higher maturity dimensions are the directives for the optimization projects. Since all processes contribute to company success for ensuring effectiveness, the maturity '*bottlenecks*' – maturity factors of which the '*as-is*' maturity level differs much from the '*aspired*' maturity level – influence the overall maturity much. By optimizing a randomly chosen process (for example due to optimization based on intuition or trends), maturity improvement is not guaranteed – as shown in the example stated previously – and time and resources are likely to be spent ineffectively. Therefore, deliberately selecting a maturity factor for optimization is a necessity for effective and efficient optimization towards company success.

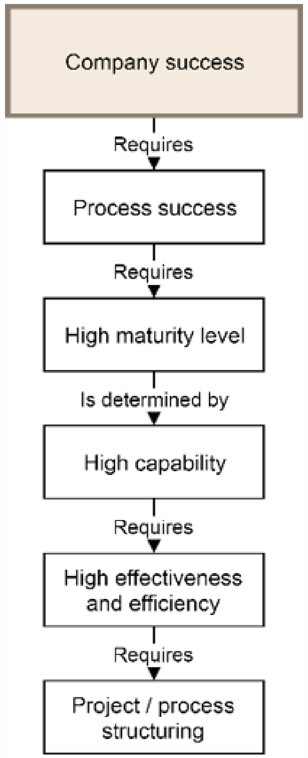

Figure 10 - Representation of the line of thoughts concerning general relations between successes and measures in a company context

A logic approach for increasing the PD maturity in general, follows automatically after determining that the company strategy represents the main objective of the company (company success), where PD is a supportive component thereof (PD success). The influences from and on PD maturity play an major role in the development of a PD maturity optimization model. For identifying influences on and from PD maturity, assumptions need to be made about what domains within the company context influence the PD maturity and where company strategy (or company success) is located in this maturity context. For effective projects, contribution to the highest company objective, company success, must be aimed for. The objectives of

2.2 Vision on PD maturity optimization

lower locations contribute, support and give shape to objectives of higher locations, which are required – but not sufficient – conditions for company success as highest objective.

A visualization of the vision is shown in *Figure 11*. As highest objective, the company objective is used, as represented in the company strategy. The company objective is supported by sub-objectives (supporting strategic objectives), such as PD success. These supporting strategic objectives are supported by processes which have aim at contributing to a sub-objective. Due to uncertainties, sensitivities and perspectives in the context, insights in the contribution of processes to the highest objective are limited (*Figure 11*, left part of the image). By visualizing and providing insights in the context influences, deliberately one maturity factor for optimization can be selected (*Figure 11*, right part of the image). By performing optimization projects, preferably the lowest maturity factor (process or structure) is changed and improved to contribute to optimized maturity on one location higher. On its turn, that higher dimension can be improved as well to contribute to the objective of one dimension higher, and so on.

In conclusion, for avoiding risks of ineffective optimization, focus must be on improving lower maturity locations (processes and process structures) with the main objective (determined by the company strategy) as directive. In other words, identification and selection of maturity dimensions in a maturity context follows a top-down approach, where process optimization follows a bottom-up approach.

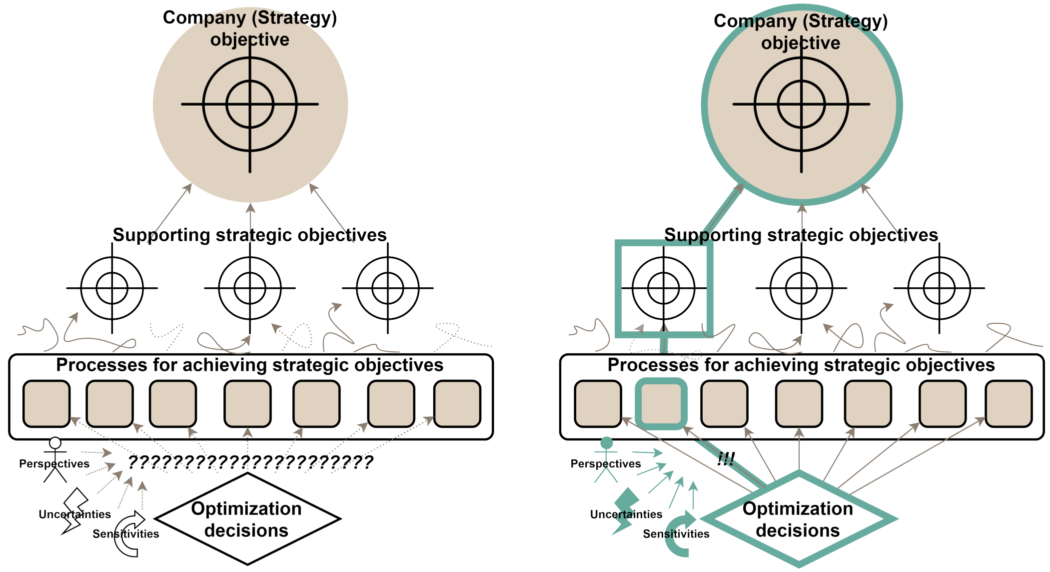

Figure 11 - Visualization of optimization without (left) and with (right) the vision

3 PDMO MODEL DESIGN

Chapter content

Stated gap indications and limitations – combined with the vision – form the basis for design requirements of the PDMO model. The PDMO model consists of three components – all influencing each other – forming a triangle shape. The Maturity Landscape component (MLC) provides objective insights in related maturity dimensions and levels within the company context. It uses an universal topology representing maturity dimensions in a network shape. This allows the maturity context to be identified. The Maturity Route component (MRC) guides decision makers in selecting a maturity dimension as target for optimization. With a maturity profile as tool, levels of maturity for maturity dimensions can be indicated and aimed for, and – based on the context and company strategy – optimization of one specific process can be chosen. The Maturity Optimization component (MOC) guides stakeholders in effectively and efficiently structuring processes towards increased process maturity. The MOC exists of a wide range of maturity audit models to achieve that objective. The maturity audit models in the MOC are specifically designed to optimize a certain process maturity, resulting in underpinned, well-defined and detailed insights for optimization.

3.1 PDMO model directive

3.1.1 Summarizing prior findings

The gap indication and prior knowledge form the design requirements[26]. Development of a solution is often based on requirements, which state functionalities of the design contributing to achieving the highest objective. Therefore, stated requirements for the design should take into account and address existing difficulties and objectives as stated in *Chapter 1.3: Gap indication* and *Chapter 2: Maturity vision*.

The findings from *Chapter 1.3: Gap indication* are summarized and linked to the numbers of the gap as stated previously, in *Table 1*. That chapter stated multiple difficulties which limit the effectiveness and efficiency of PD practices. Structuring takes place with use of Design Science artefacts, often with models or methods. However, difficulties of selecting models and methods for a context are not well addressed, due to *(1)* developed models and methods being too general for the generic context, combined with the often appearing assumption in industry exists that project time is too limited to spend on model and method selection. *(2)* Information on translating them into generic structures is limited or not existing at all and *(3)* the required mix of practical and theoretical knowledge is not achievable in industry. Consequently, without objective insights on models and methods selection and application in the generic context, decision makers on optimization projects do not have overviews for objective optimization project selection. *(4)* Disciplines, perspectives and other differences between stakeholders in that decision process have biases causing subjectivity in decisions on utility of models and methods and focus processes for optimization. Furthermore, *(6)* external companies developed models and methods themselves or have partnerships with artefact developers, causing biased advice based on 'utility' of certain models and methods. Consequently, *(5)* solution domains are often limited, without the information of this and previous limitations being available to the company. Besides that, *(7)* implementation in the generic context is often not addressed, resulting in a 'knowing-doing' gap. *(8)* Models and methods for optimization projects are not focussed and available for PD processes in specific and *(9)* the theoretical base behind maturity audits is often roughly based on best practices and not theoretically sound. These difficulties in selecting and tailoring models and methods and objectively selecting the process for optimization projects need to be taken into account in requirement development.

The findings from the Maturity vision are summarized as well (*Table 3*). *Chapter 2: Maturity vision* stated a vision and theoretical frame for achieving the highest objective: providing insights in optimizing PD maturity. This is done by *(I)* focusing on the company strategy

26 Requirement: "*something that you need or want*", or "*something that you must have in order to do something else*" (Oxford Learner's Dictionaries, 2019).

as source for objective information during the decision making process. Decision making stakeholders for optimization projects all need to focus on company success as higher objective, which is achieved by *(II)* defining and communicating this vision of a broader maturity landscape and maturity dimensions influencing higher and lower dimensions of maturity. Based on those insights, targeted and substantiated decisions on PD maturity optimization can be made. For this research focus is put on maturity dimensions related to PD process maturity, but it is necessary for decision makers to know that more maturity aspects exist outside that scope. Furthermore, *(III)* optimization projects need to focus on the lower dimensions, since they are closely related to the context and need to take into account higher, influencing maturity dimensions. Optimizing a maturity factor does not automatically result in an improved maturity level of the higher maturity dimension. In other words, a mature factor is a necessary but insufficient condition for a mature dimension, and therefore it is required to start with optimizing lower locations of maturity with the company strategy as directive. For this research, PD process success is a required but insufficient condition for PD success and PD process optimization must be based on the company strategy as leading perspective in decisions.

Table 3 - Summarized findings from the maturity vision

#	Stated objectives from Chapter 2: Maturity vision
I	The strategy is the leading perspective during the decision making process, then company success is the focus as highest objective
II	The broad maturity landscape in this vision is defined, communicated and known to all stakeholders in the decision making process for maturity optimization
III	Optimization focus is primarily performed bottom-up with inclusion of influencing company context aspects and works toward the higher dimension objectives (for this research concerning the PD process with PD practices as higher dimension and company success as highest dimension)

3.1.2 Vision based PDMO model idea

Prior findings determine the requirements for a Product Development Maturity Optimization (PDMO) model design, of which a concept is developed. The PDMO (concept) model is a futuristic yet realistic design of a guiding and structuring model, aiming at providing insights in selecting the appropriate maturity dimension for optimization (*Figure 5, (1)*). However, it is unrealistic to develop the full PDMO model within the boundaries of this research, as stated in *Chapter 1.4.3: Scope and limitations*. Therefore, this research focuses on development one proof-of-concept for the PDMO model. Thereafter, a proof-of-concept maturity audit model for optimizing PD process maturity is designed (the PDPMA model), as described in the next chapter (*Chapter 4: The PDPMA concept model*). But, as stated in the difficulties, random and unsubstantiated decisions on what maturity dimension to optimize is ineffective. Therefore, this PDMO model uses a higher level of abstraction for a practical concept design of the Maturity vision.

The PDMO model consists of three components (*Figure 12*). Based on the Maturity vision, a rough and immature design for the PDMO model is proposed, which is a simplified, immature and abstract view on PD maturity optimization. As first step, the need to identify influencing maturities in the generic context is addressed (as stated in the sub-questions of the research chapter). This results in a Maturity Landscape component (MLC – *Figure 12*, the green hexagon) on which the Maturity Route component (MRC – *Figure 12*, the blue hexagon) provides insights for a target maturity dimension for maturity optimization (answering sub-question two of the research chapter). Based on that selection, a specific optimization project can be started for optimizing that maturity factor (the Maturity Optimization component, MOC – *Figure 12*, the brown hexagon). If the maturity route targets the PD process, a developed Product Development Process Maturity Audit (PDPMA) model can be executed. Therefore, the PDPMA model forms a small part of the solution domain of results in the PDMO model.

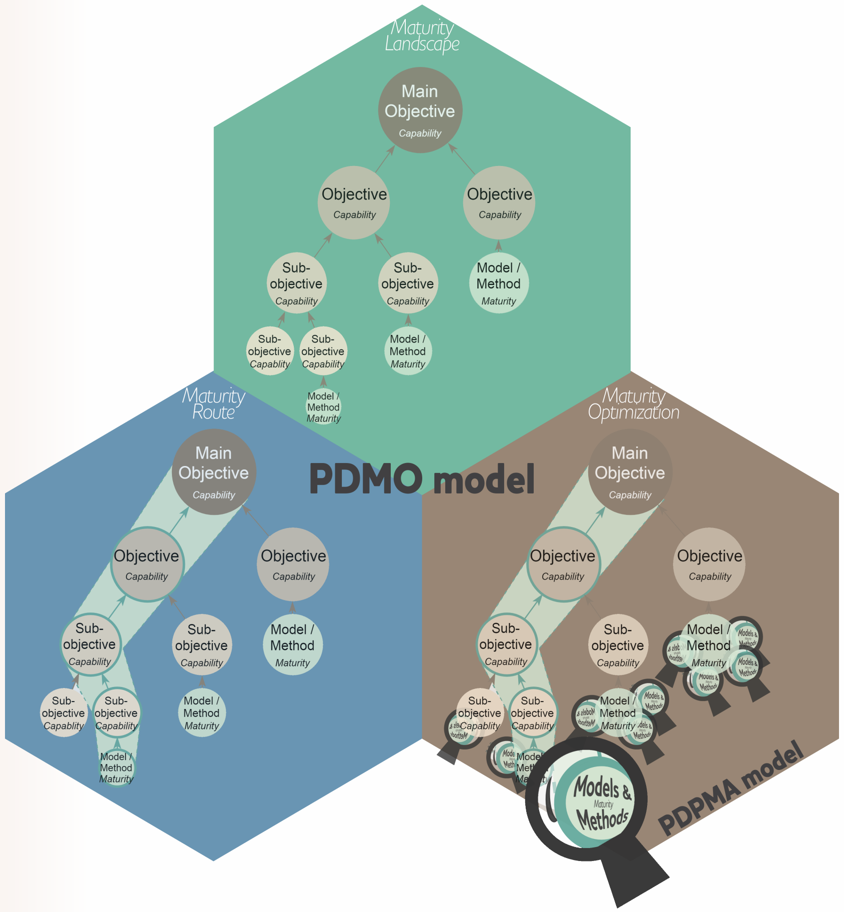

Figure 12 - Symbolic representation of the PDMO concept model idea

3.1.3 Objectives and requirements

The design of the PDMO concept model has as aim to optimize PD maturity overall and is developed based on requirements supporting that aim. It needs functionalities to communicate and complete the vision and close the identified gaps. The information from the introduction, research and vision chapters form the basis for three sub-objectives that need to be fulfilled by the design's components. *Table 4* lists these sub-objectives.

Based on the sub-objectives, the requirement specification for the Product Development Maturity Optimization (PDMO) model is stated. The requirements are limited in detail and have a guiding function during the design process. They function more as a design brief than for measuring detailed results. Since the resulting design will be limited in detail to a proof-of-concept model (*Chapter 1.4.1: Research directive*), it would be inefficient to develop strictly measurable and detailed requirements which are not measured or used for their detail in this research. Therefore, this limited depth of PDMO model requirements is chosen for performing the intended function of guiding the design process towards achieving the sub-objectives and research objective.

Table 4 - Summation of respectively the research objective and sub-objectives derived from sub-questions stated in Chapter 1.4.1: Research directive

Research objective	Design of a Proof-of-concept model for PD maturity optimization in industry	
#	**Sub-objective**	**Chapter**
1	Provide objective insights for all stakeholders in influences and relations of maturity levels and locations on the PD process maturity dimension.	**3.3.1: MLC Directive**
2	Provide objective insights for all stakeholders to indicate a maturity optimization focus level and location, of which the PD process maturity is one dimension.	**3.4.1: MRC Directive**
3	Provide objective insights for all stakeholders to select and implement optimizations tailored to their context	**3.5.1: MOC Directive**

3.1 PDMO model directive

Sub-objective 1: Requirements

Provide objective insights for all stakeholders in influences and relations of maturity levels and locations on the PD process maturity dimension.

- Provides an available, universal language for industry and academy for communicating maturity contexts;
- Provides structure in relations and influences between maturity levels, locations and relations for objective information for benchmarking, context communication and stakeholder perspective alignment;
- Provides a tailored maturity scope for specifying optimization projects within a generic company context.

Sub-objective 2: Requirements

Provide objective insights for all stakeholders to indicate a maturity factor for optimization, of which the PD process maturity is one factor.

- Provides objective comparison of maturity levels of maturity dimensions;
- Provides insights in the 'aspired' maturity level, by using the company strategy as directive;
- Provides insights behind gaps and similarities resulting from comparison of maturity dimensions.

Sub-objective 3: Requirements

Provide objective insights for all stakeholders to effectively and efficiently structure processes towards increased process maturity.

- Provides insights in the value of optimizing PD process maturity in generic contexts;
- Provides insights in the effectiveness and efficiency of PD process structures for the context;
- Provides companies with the insights for optimization.

3.2 PDMO model idea

3.2.1 Design, components and parts

Three groups of requirements form three components, which can be split in parts if required. Design solutions for the stated requirements are broad and still complex for identifying a single suitable concept model. For solving this, strategies developed in the systems engineering discipline guide breaking the problem into solvable sub-problems. As a result, the concept design exists of three components with more detailed functions and requirements. These may be split again in parts, which again will have smaller objectives for identifying more specific and detailed solution domains. A representation of this design hierarchy is provided in *Figure 13*.

Validation of the parts takes place locally, with the component objectives in mind and validation of the components takes place with the objective of the design in mind. Consequently, the complete design hierarchy contributes to achieving the highest objective. Maturity of components does not guarantee maturity of the complete design, which implies the need for validations on multiple design levels. Every following chapter that explains a design component, has validations on local levels and are validated in general in later chapters (*Chapter 7.1: Global validation and evaluation*) to ensure this cross-level validity.

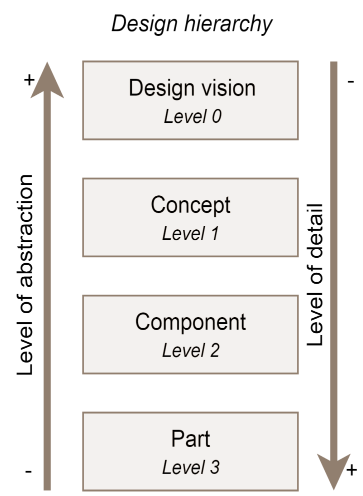

Figure 13 - Design hierarchy with design levels, levels of abstraction and levels of detail

3.2.2 Three components for PDMO model design

The PDMO model (*level 1* design) consists of three components (*level 2* designs).

- Maturity Landscape component (MLC, *level 2*): The first group of requirements results in a certain maturity landscape structuring related maturities to PD process maturity.
- Maturity Route component (MRC, *level 2*): The second group determines the route for maturity optimization focus, with PD process maturity as possible outcome.
- Maturity Optimization component (MOC, *level 2*): The third group provides insights for optimizing a specific maturity dimension within a generic context. For this research, this is limited to the design of the PDPMA model, for specific optimization of only the PD process maturity dimension.

These three result in a triangular model, in which all three components are connected. The MLC as well as the MRC both influence the MOC, since the MLC determines what objectives are used as higher directives and what maturity dimensions influence the PD process maturity, and the MRC determines if it is effective to perform the MOC for a specific context. Other way around is the MLC influenced by both, the MRC and MOC, and the MRC is influenced by the MLC as well as by the MOC. Therefore, these three need to interact between each other, resulting in a triangular shaped construction of the components for the PDMO concept model, as shown previously in *Figure 12*.

The optimization strategy and test strategy, follow different directions in this model (*Figure 14*), strategy directions are represented as arrows in the triangle). In this PDMO model triangle, optimization projects follow a counter-clockwise cycle. First the context of the maturity optimization influences the maturity scope (MLC) of that specific context, then the maturity route (MRC) is performed to identify a target maturity dimension for optimization, and after that the specific optimization can be performed (MOC) and changed context aspects influence the maturity landscape (MLC) again. Validation strategy of the model or for evaluating the selected maturity dimension for optimization, follows a clockwise cycle starting with the MOC back to the MRC and with the maturity context of the company as result. The triangle shape indicates a unique characteristic of this model: within the maturity optimization context, strategy does not follow one top-down or bottom-up approach, but influences from both sides. In the optimization strategy as well as in the test strategy, the same components exist what proves cohesion between performing and testing the model functionalities. The added value of the output per component for a certain company is dependent on the utilization context and the objectives the model is used for. These objectives are closely related to the company strategy and the utilization context is the company context.

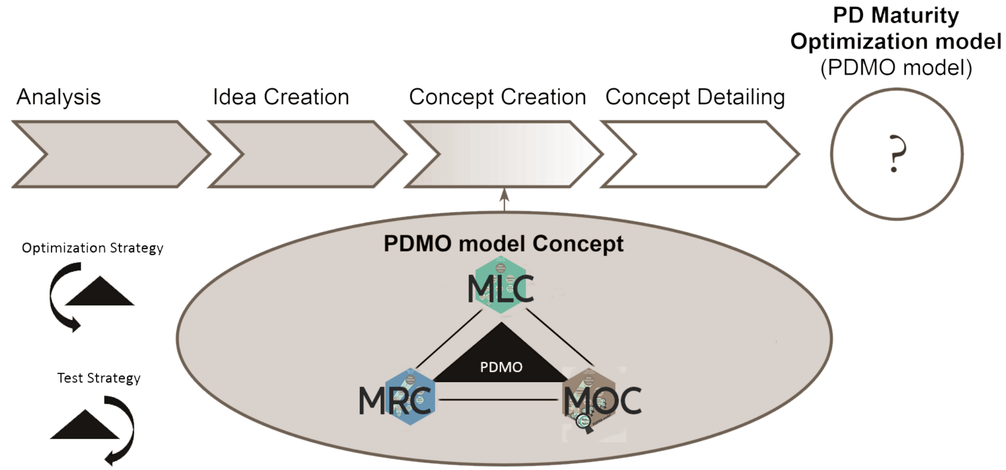

Figure 14 - Representation of the PDMO triangle; Strategy does not follow one direction, but adapts its path to achieve different objectives

The three components combined form the *level 1* design, each concept component on its own is a *level 2* design in the design hierarchy (*Figure 13*). In the PDMO model design, the components function in a triangle shape as explained before. However, for explaining the model in this report, the sequence of steps of the 'optimization' strategy is used, representing the components in the following order: *(1)* MLC, *(2)* MRC, *(3)* MOC. However, this sequence is not set and depends on the aim of model utilization, as explained previously. Since the research objective concerns optimization, the optimization strategy cycle represents the component designs best.

3.3 PDMO model design: MLC

3.3.1 MLC Directive

The complex web that characterizes the landscape of maturity dimensions in product developing companies needs to be visualized and mapped to communicate insights of the maturity landscape to the specific company. This demand trumpets the use of a universal topology on which maturity contexts can be identified and mapped. The Maturity Landscape Component (MLC) (*Figure 15*) functions as limited starting point for such an universal topology on which vision representation and maturity scoping can take place. The MLC provides a maturity representation for communication in academical and practical contexts. In order to fulfil the sub-objective, requirements are stated as directives for the MLC design. The design is limited to a network with only illustrative examples of maturity dimensions and does not claim to be the final representation of maturity dimensions.

MLC objective

Provide objective insights for all stakeholders in influences of maturity levels and locations on the PD process maturity dimension

MLC requirements

- Provide an available, universal language for industry and academy for insights communication
- Provide structure in relations and influences between maturity levels, locations and relations for objectiveness
- Provide insights in the maturity context defined by the company contexts

3.3.2 MLC Design

A network visualization method provides insights in and communicates the universal topology. The MLC illustrates a starting point in development of an universal topology for maturity dimensions concerning PD maturity. It uses a dynamic, network-based visualization method for maturity dimensions, maturity factors and relations between them. A representation for this network for PD maturity is shown in *Figure 16*. The input, output and insights created by the MLC can be communicated and easily adapted in a transparent and accessible way by using a network as visualization method.

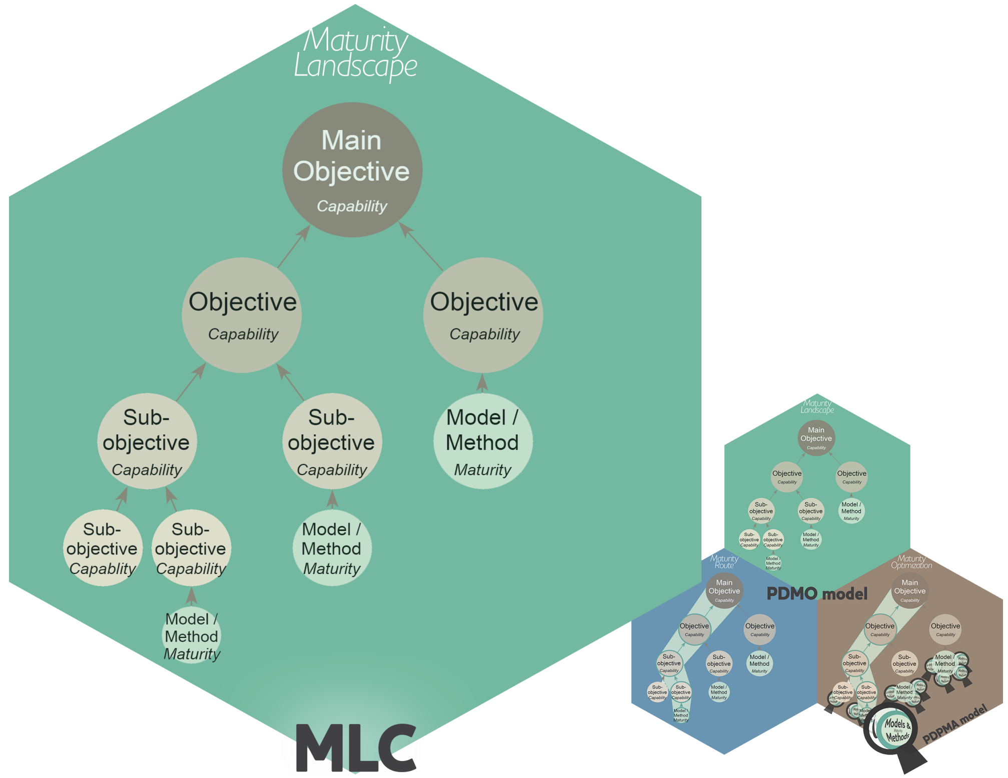

Figure 15 - Abstract visualization of the Maturity Landscape Component (MLC)

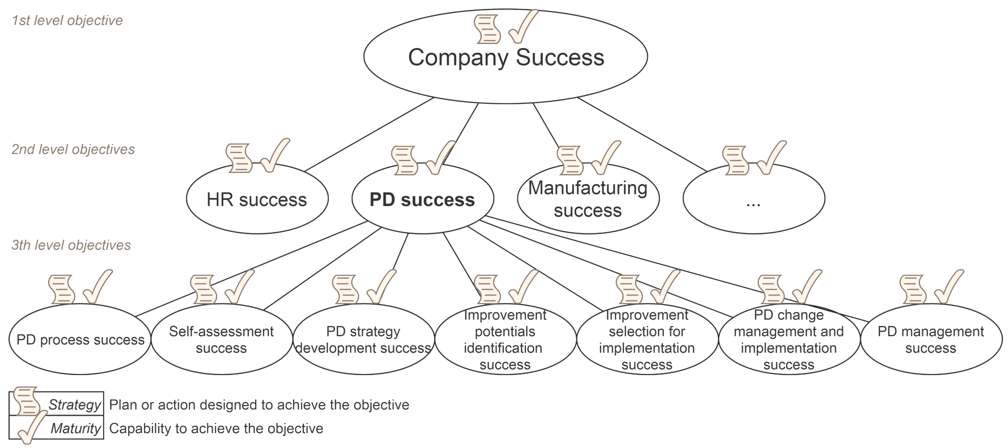

Figure 16 – Representation of the MLC network with 'success' as jargon for application in industry

The focus must be on a small network tailored to the context. Effectiveness of a network depends on the network size (*Moody, Farland, & Moll, 2005*). The large and complex web of maturity dimensions will result in a network that mainly captures a gross topology. Smaller networks however, focus on detailed elements of the network structure. For the industry and decision makers, these detailed elements are required for creating relevant insights, such as the specific maturity dimension contributing to PD success. Therefore, smaller, more detailed networks of maturity contexts perform the function of the MLC better. However, for application, a wide range of maturity dimensions might exist and a selection of them related to the company context is required before a smaller network can be selected to form the maturity context.

Readability is a necessity for creating and communicating insights. Aesthetic features assist in that. For making a selection, readability of the larger network is a must. In larger topologies, aesthetic features contribute to that. *Davidson and Harel (1996)* and *Moody, Farland and De Moll (2005)* are some of the researchers stating aesthetic principles contributing to readability of networks. Colours, sizes, shapes, edge crossings, visualizing nodes above edges and visualization contrasts are aspects they identified as hindering or contributing to readability. The maturity context needs to take these into account.

Network functionalities of grouping information, suggesting adjustments and providing flexibility, result in a versatile design. Automated information structuring methods allow grouping related maturity dimensions based on criteria which the user can define. This enables the user to quickly identify dimensions for a context with relations to influences on and of other dimensions. Besides that, dynamic networks allow nodes and relations to change based on changing contexts and functions. Consequently, boundaries of the network and applications are kept flexible and extendable when required. It allows context aspects, company strategies and maturity dimensions to be complemented and adjusted easily to new literature, insights and contexts after they become required and available.

A recognition and understanding of terminologies for the stakeholders is required. With a network, the MLC provides a broad and flexible topology of recognizable and general terminologies for maturity dimensions for companies to identify connections and dependencies in their context and for academy as universal ground for communication and relating maturity dimensions to literature. A strategy is created to guide the path towards success and the maturity levels of dimensions indicate the achieved success. For the terminology to be understandable for the stakeholders in industry as well as usable for academy, the topology for industry is based on '*successes*' to understand the main objectives of every dimension. These objectives are recognizable and closely related to

3.3 PDMO model design: MLC

processes, more than the term '*maturity*', and therefore easier to understand for industrial stakeholders. However, theory and literature communicate with terms as '*capability*' and '*maturity*' more often. Therefore, the academic topology is uses '*maturity*' instead of '*success*' for the same dimensions. Then the jargon is adapted for the purpose of understanding from intended stakeholders.

The required input for the MLC consists of the existing processes and 'success dimensions' in a company. The scope a maturity context is based on a rough estimation of where optimization might be beneficial and possible. The large topology can be used as inspiration for identifying company objectives with processes as maturity factors and maturity dimensions in between. The selection of processes that suit within the context combined with the objectives as stated in the company strategy form the maturity context topology in a network shape. An example of a maturity topology for a certain company context is provided in *Figure 17*.

Maturity factors on a certain level do not have equal contributions – or importance – to the objective of the maturity dimension above (as might seems in the representation of *Figure 17*). The flexibility of a network enables the user to create a maturity dimension or factor and relations, even if that relation is based on only an unsubstantiated indication for existence. The output of the MLC is used by the MRC. Indications for capability concerning the identified maturity factors need to be available for the MRC. Processes, identified by relevant stakeholders, that include '*achievable*' context information are '*valid dimensions*' that are used in the MLC and other components as tailored maturity context.

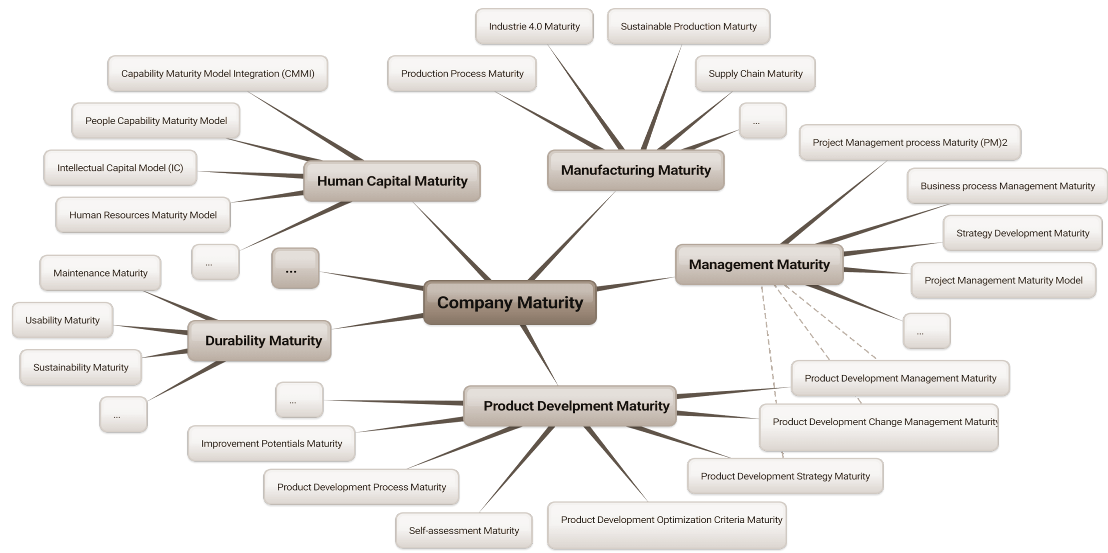

Figure 17 - Example of a visualization for a maturity context

3.3.3 MLC Validation

The local validation is a *level 2* validation. The sub-objective is to: Provide objective insights for all stakeholders in influences of maturity levels and locations on the PD process maturity dimension. This concept design is a dynamic, network-shaped model and encourages involved stakeholders to think pro-actively on maturity dimensions in their company context. With the broad topology as inspiration, stakeholders can identify relations between company objectives, sub-objectives and supportive processes. The process of identifying relations forms the basis for gaining insights in maturity optimization, since it identifies potential targets for optimization for the company context. PD maturity and PD process maturity are two of the dimensions that fit in this concept design. Therefore, this concept model supports the sub-objective of the MLC, as well as respects other potential maturity dimensions, not directly related to PD maturity.

Effectiveness and efficiency validation

Throughout the research, effectiveness and efficiency of designs and processes are returning topics. Therefore, a validation can not be sufficient without taking effectiveness and efficiency of the design into account. Effectiveness of a design is determined by the way the design fulfils the requirements, and the way of the requirements being directly supportive to the sub-objective. One way to measure effectiveness is done by so-called '*Measures of Effectiveness*[27]' (MOEs from the field of Systems Engineering). These establish "*how well something achieves the purpose for which it is intended*" (*Sproles, 2002*). This intention is a measurable version of the sub-objective and requirements and entails the concept being available, versatile and capable of structuring maturity dimensions tailored to the specific contexts. For the MLC, the MOE is determined from company perspective, since utilization of the model results in model success and relies on their view on the design. The MOE is defined as: '*The amount of decision making stakeholders (relatively) being aware of the roles, relations and effects of maturity dimensions on optimization projects in their company context*'. This effectiveness cannot be measured in the concept phase, but needs validation after development and use. However, the design can be evaluated for fulfilling the stated requirements as indication for how effective it is.

The efficiency can be seen as the '*budget*' directly adding value to achieving the sub-objective, divided by the '*budget*' spent in total for performing the design. Efficiency of the design is therefore directly related to the context and quantities of efficiency for this design can not be given. However, an approximation of the value for performing parts of the model can

27 Measure of Effectiveness (MOE): "*a management tool by which stakeholders can determine if a solution will meet their needs, MOEs are mission or purpose oriented and are a reflection of the stakeholders standards for success.*" (Sproles, 2002).

be given. The process of identifying maturity dimensions in a context requires a sufficient amount of effort from the stakeholders for them to complete the thinking process and be aware of maturities of processes and relations to higher objectives. It may occur that stakeholders fill in too many maturity dimensions for the relevance of the company context, decreasing the efficiency of performing this process or do not take enough effort for them to lead to useful insights. However, the network allows opportunities and functionalities for quicker selection of dimensions and tailoring them to suit the context. Furthermore, with the maturity dimensions created once in a company, that maturity context – already reused in the MRC – can be (re-)used for other purposes as well.

Requirement validation

The requirements for the MLC contain three key themes, which are discussed in sequence.

- '***Available and universal***': The network is chosen as suitable candidate for communicating information about relations and maturity dimensions to stakeholders. A visualization contributes to the aspect 'availability' of information, as long as the network is compatible with software. The requirement 'universal' is partly met, in the next paragraphs, more detail about the decision to focus on 'Available' more than on 'Universal' is explained.
- '***Structuring dimensions***': A network-based method is chosen as suitable candidate for structuring the maturity dimensions and relations concerning PD maturity. The flexibility of the network allows practical as well as theoretical knowledge sources to insert and adjust information concerning maturity dimensions. This has a risk factor of causing unreliable and unstable information, since a large stakeholder group has rights for adjusting information.
- '***Context tailoring***': A maturity scope is created in collaboration with stakeholders of processes in a specific company. These stakeholders have the most valuable practical knowledge, which they can structure with use of the theoretical model concept as presented for the MLC. The process of performing the MLC is proven more important than the resulting maturity scope, as the results will seem logical after the process of identifying the MLC input is performed, but relevant before major decisions are made. Awareness of maturity dimensions and higher objectives for stakeholders is the main objective to achieve insights in the relations between them.

Decision validation

Two different jargons are used for understanding of both stakeholders and maximizing utilization. The requirements '*Available*' and '*Universal*' language work contradicting. This results in a required decision between *(1)* having multiple different terminologies in the network (e.g. one for academic and one for industrial stakeholders) contributing to '*Available*', or *(2)* having one terminology, contributing to Universal. The first option is chosen, since understanding and underpinning of results is a major focus point in the research and a key value in the vision. Since '*utility*' determines the success of the final concept design and utilization of the model has as mixed target group the industry and academy, focus is put on selecting one design variant with '*success*' as recognized terminology and one with '*maturity*' as recognized terminology. Using one terminology would increase the univocal, generic communication, but decreases understanding by the industrial stakeholders, which results in decreased utilization of the final design.

The MLC purpose is not to function as '*digital twin*[28]', but to providing indications is sufficient for the objective. The output information of the MLC is closely related to the input of the user, bringing risks of providing inaccurate or unreliable input information. Consequently, the MLC is a relatively simple tool that structures thoughts on maturity dimensions and relations to higher company objectives, only by structuring and providing examples of the input information. It aims for creating insights in maturity dimensions related to specific company contexts, which has no measurable '*good*' or '*wrong*', but tries to represent the context '*as-is*', as good as possible. The process of identifying the maturity dimensions specifically is resulting in insights in maturity relations and dimensions for stakeholders. The information created by the MLC is no direct ground or foundation for decision making and will seem logical after filling in. Evaluating the MLC with logic sense will be sufficient for validating the outcome, since no direct decision making process is relying on the MLC and unreliable results do not cause the maturity optimization process to be of less value.

The MLC is '*all about the journey*'. Active thinking on the maturity context contributes to spreading the Maturity vision. The risks of unreliable input information does not cause the model to be useless. The objective is to gain insights in the dimensions of maturity within a specific company context. Identifying maturity dimensions makes the stakeholders aware of existence of dimensions and demands more comprehensive thoughts about the maturity context. Direct stakeholders of processes are often well-aware of the processes they are involved in. For them to envision processes, organizational hierarchies and project steps, enables making criteria and selecting relevant processes in the organization. The author suggests that the "*journey*" of identifying and evaluating processes is more effective than an "*eyes on the prize*"-focus where the '*best*' topology needs to be created. The process-focus results in actively thinking and discussing possible maturity dimensions.

28 Digital twin: "*digital twin means an integrated multi-physics, multiscale, probabilistic simulation of a complex product, which functions to mirror the life of its corresponding twin.*" (Glaessgen & Stargel, 2012).

3.4 PDMO model design: MRC

3.4.1 MRC Directive

A maturity profile allows dimension targeting for optimization. Many maturity optimization projects are born from the desire to optimize a process and increase the maturity of processes. However, this decision on optimizing a certain process is often unsubstantiated and based on intuition or model availability. Stakeholders and advising external companies focus on the process itself, not the effectiveness and efficiency of optimizing that process as contribution to the higher company objectives. The vision states the need to provide insights in maturity dimensions to make a deliberate decision on how to effectively and efficiently optimize processes, contributing most to the higher company objectives.

The Maturity Route Component (MRC) (*Figure 18*) is developed as limited starting point for creating maturity profiles per specific company, based on the maturity context. These profiles provide insights for making deliberate decisions on selecting a process for optimization. Within the PDMO model, the MRC builds on the output from the MLC in determining effective and efficient optimization project targets. The design is limited to a visualization method to provide illustrative examples of maturity dimensions with maturity levels and the company strategy as directive, for creating a route towards a deliberately selected maturity factor. The result is not the final word on selecting optimization processes, but contributes to objectively identifying influences on that decision making process and proposes a target indication.

MRC objective

Provide objective insights for all stakeholders to indicate a maturity factor for optimization, of which the PD process maturity is one factor.

MRC requirements

- Provides objective comparison of maturity level indications on maturity locations;
- Provides use of company strategies as directive;
- Provides insights behind gaps and similarities resulting from comparison.

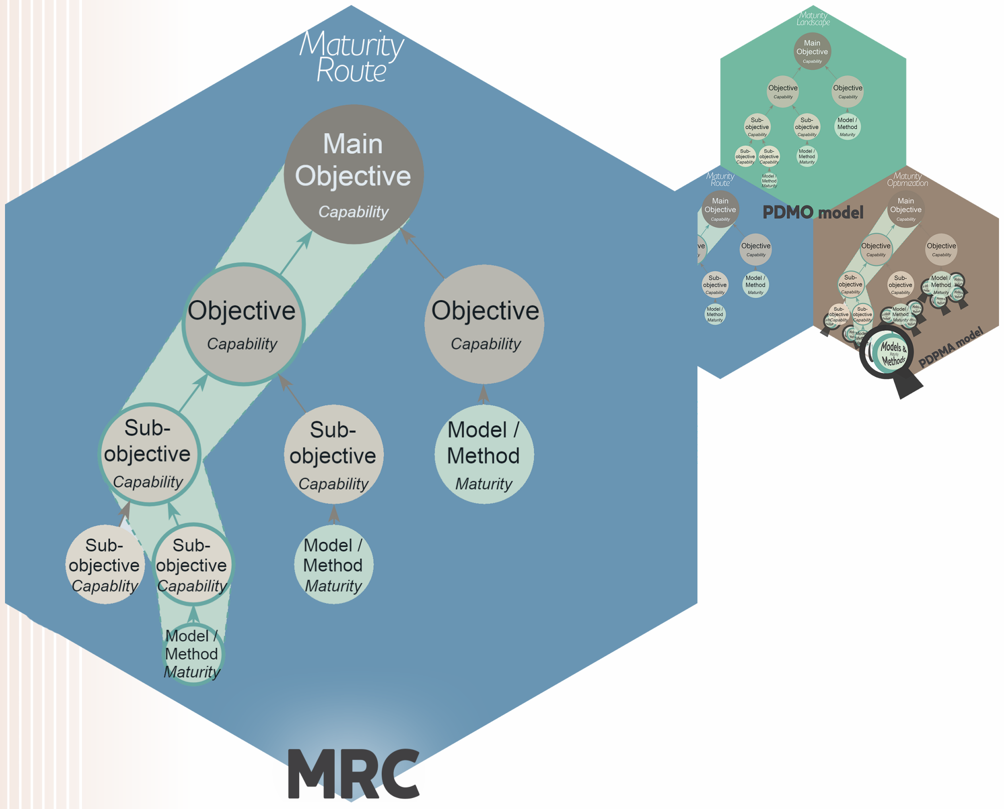

Figure 18 - Abstract visualization of the Maturity Route Component (MRC)

3.4.2 MRC Design

Roadmap function

The MRC is designed as roadmap[29]. It is built to get from the current situation of selecting processes for optimization based on indeterminant decisions, to step-by-step selecting maturity factors for effective and efficient optimization, resulting in one maturity factor as target for optimization. For achieving this goal, a roadmap can be used. Roadmaps are instruments helping to align the objectives of a company to the changing context the company is located in, where (e.g.) underpinned investment decisions can be based upon (*Guo, 2010*). The perspective of the future use and changing context plays an important role in it, resulting in avoidance of short-term solutions that do not serve the higher objective of achieving company success. With company maturity as highest objective, a company can place their maturity dimensions in previously mentioned perspective to gain insights in how far certain maturity factors are deviating from the main objectives they strive for.

29 Roadmap: "*a plan for the future, usually with a particular goal.*" (Oxford Learner's Dictionaries, 2019).

A roadmap provides an overview of steps required to achieve an objective, often in shape of a document or image (*Brindle, 2013*), as does this concept component. Certain information is required before other information can be received, referred to as 'steps'. For example: as first step, influences of the company strategy on PD Maturity need to be identified before, as second step, focus for optimization on one level deeper can be selected.

Since there are no specific approaches described in a roadmap, all stakeholders and disciplines can contribute to achieving the stated objectives in their own way. A roadmap then functions as general communication tool, using the objectives as unpolluted and understandable language. For the PD Maturity, the achievement of objectives means that sometimes e.g. the specific PD processes need to be optimized and other times that e.g. implementation of improvement potentials needs to be optimized. With that characteristic, a roadmap, can be a continuous process of executing steps with the required stakeholders. For example, for certain maturity dimensions, main stakeholders are process experts, as for a different dimension main stakeholders may be distribution experts.

Towards maturity profiles

The MRC is a roadmap which forms a maturity profile with use of stacked radar charts for selecting appropriate maturity factors for optimization. The design of the MRC can be seen as a roadmap that leads to a maturity profile of the specific company. It uses radar charts for routing maturity optimization targets throughout relevant maturity dimensions in a company context. Current decisions on selecting maturity factors for optimization may be sensitive to trends, new knowledge, stakeholder decisions, perspectives, behaviour and company context. These external factors are not known for certain, which makes it important to have awareness of the uncertainties and existence of these aspects within use of the roadmap. Therefore, the roadmap needs a language to communicate uncertainties and influencing dimensions objectively to stakeholders.

One language for the stakeholders is required. A roadmap does not force a certain approach to achieve objectives, therefore this stays open. Benefit is that stakeholders from multiple disciplines can understand the main and sub-objectives. However, for determining a specific approach to achieve stated objectives, the language plays an important role. Such a language must be understandable for the relevant stakeholders of the optimization project. Stakeholders of the PD context within the research scope are from engineering and management disciplines. Resulting approaches and change management from the roadmap can use jargon understandable by more specific stakeholder groups, but the roadmap itself should be independent of such disciplinal differences.

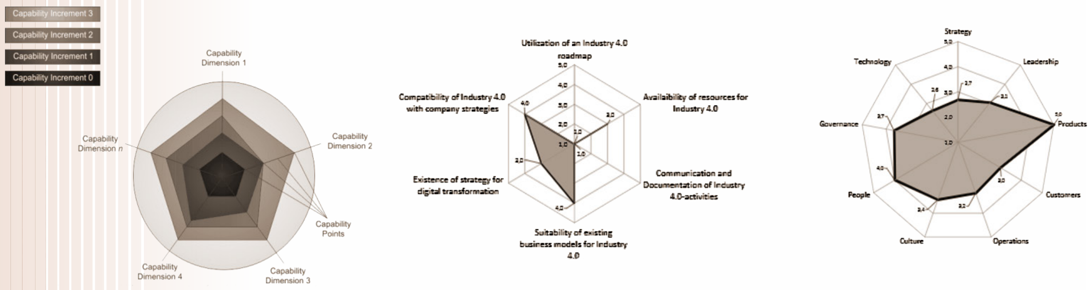

Figure 19 - Visualization of radar charts used for Industry 4.0 maturity assessment result interpretation (retrieved from: Schumacher, Erol and Sihn (2016))

Radar charts are used for objectively profiling and comparing maturity factors on dimensions. For communicating the roadmap, visualization ideas of *Schumacher, Erol and Sihn* are used (*Schumacher, Erol, & Sihn, 2016*). They use a radar chart visualization method for communicating *Industry 4.0* maturity assessment results. It visualizes maturity levels for maturity dimensions and factors in a transparent way, of which examples are shown in *Figure 19*. This solution for communicating maturity dimensions and levels is known by the stakeholders group of the engineering and management disciplines and allows flexible information visualization.

The resulting design is an accumulation of radar charts, piling as many maturity dimensions as required by the context. The designed radar chart visualizations form a maturity profile for a specific company. These enable determining a route for optimization targeting and benchmarking of maturity dimensions to other contexts or scenarios. An example of such a maturity profile is given in *Figure 20*. Maturity factors contributing to the maturity location are visualized around the dimension, providing insights in the influences of them on the higher dimension. Distances between the dimension and the factor indicate the amount of influence on a dimension. For every maturity factor, an indication of the current maturity level and the aspired maturity level must be found. This can be performed with use of e.g. existing maturity tests or quick scans for the certain dimensions, but is not a topic this research continues on in more detail. The gap between the current and aspired level indicate the need for optimizing that specific maturity factor. The current and aspired maturity levels are filled-in in the maturity profile (*Figure 20*), examples for the maturity dimensions '*company maturity*' and '*PD maturity*' are provided in *Figure 21*.

For avoiding subjective weighting factors due to uncertainties in the context, the company strategy is used as directive, as preached by the Maturity vision. After indicating the current maturity levels for relevant dimensions, aspired maturity levels are identified. Perspectives and biases of stakeholders may influence the objective identification of aspired maturity

3.4 PDMO model design: MRC

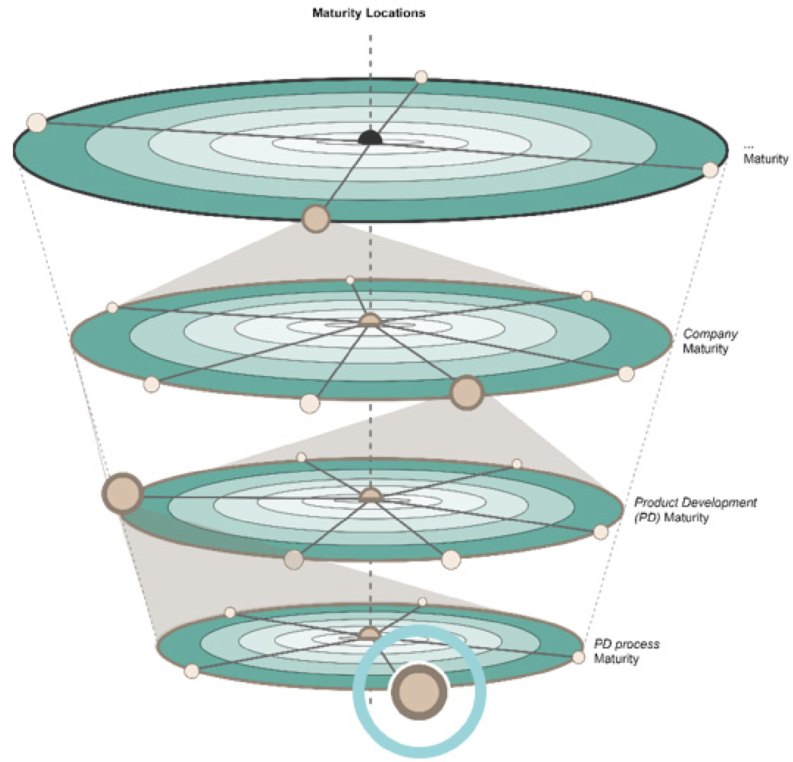

Figure 20 – Representation of the maturity locations and dimensions as basis for underpinned and structured decision making for maturity dimension optimization targeting

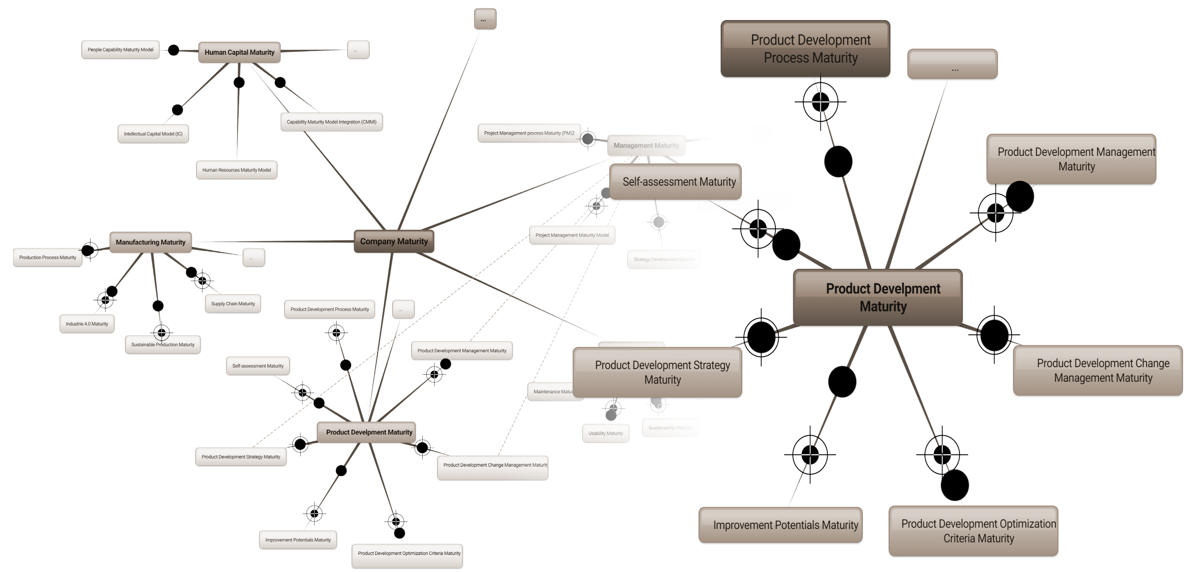

Figure 21 - Visualization of an example radar chart for Company

levels. For this reason, the design tries to avoid using weighting factors determined by a single group of stakeholders. Instead, it focuses on using the company strategy as final directive and perspective for deciding on an indication for the aspired maturity level.

Appropriateness of optimizing a certain maturity factor then depends on the company context and is indicated by objective interpretation of the company strategy. For achieving this, information about the company strategy is required and needs to be objectively interpreted in terms of decision criteria for maturity optimization. By using the company strategy for indicating the aspired level of maturity, sensitivity of uncertainties and perspectives can be mapped without influencing the outcomes and hanging weighting factors on them. If a maturity level on a certain dimension or an aspired level is uncertain, it can be left open intentionally or it can be approximated from the company strategy's perspective.

Identifying indications for dimension optimization

This design does not use set quantifications of maturity levels. Since the context brings uncertainties, sensitivities and perspectives, quantifying a maturity level can be complex, as stated in the introduction. Furthermore, the direct interpretation of a quantified maturity level forms a risk, since the context changes per definition and a maturity level interpretation is only sensible with unequivocal insights in that context, which is unrealistic. Therefore, set quantifications of maturity levels form risks, specifically with the uncontextualized weighting factors and do not benefit this research. For this reason, only indications of maturity levels are provided, if multiple maturity factors have comparable gaps between the current and aspired situation, detailed assessment of the gaps with inclusion of the detailed context and company strategy can be performed to decide for optimization.

The maturity level gaps throughout the maturity factors determine the maturity route. The maturity route is created by comparing the maturity level gaps (between the '*as-is*' and '*company strategy aspired*' levels) on one maturity dimension and identifying the spoke (maturity factor) which is the bottleneck and effective and efficient to target for optimization. One dimension deeper, this maturity factor has become a maturity dimension on its own with its own identified spokes (maturity factors), level gaps and target factor for optimization, based on the same company strategy determined criteria. This maturity route creation is visualized in *Figure 20*. The search for a deeper dimension stops after applicable and useful maturity audit models for optimizing that specific maturity dimension (process level) are available or the process can be optimized effectively and efficiently without using existing models.

3.4 PDMO model design: MRC

Uncertainties in maturity dimensions and levels, can be added and deleted if proven to better represent reality. The model is still usable for the defined maturity factors as spokes, without detailed information about uncertain ones. Filling in estimated values for uncertainties allows comparison of influences of uncertainties on results, and forms insights in iterations of maturity routes. Often experienced combinations of uncertainties for specific contexts can be combined in scenarios for quickening the process of optimization targeting.

Flexibility in the amount of spokes or dimensions on a maturity location still allows comparison of maturity profiles on comparable spokes or dimensions. It does not require all dimensions to be filled in for still contributing to creation of scenarios or identification of often appearing maturity optimization routes for certain contexts.

For optimizing maturity dimensions, optimizing multiple at once is ineffective, since results cannot be related to the applied changes and risk of changing unnecessary aspects is high. So, the visualization of the maturity dimension radar charts forms a maturity profile for the specific company after their '*as-is*' and aspired maturity levels are identified. For determining maturity level indications for current processes, required tools already exist in the shape of maturity tests of maturity audit models and maturity quick scans. However, for determining the aspired maturity level, an extra focus must be put on using the company strategy as directive, which automatically comes to attention as it is integrated at the top level of the design. The routing process after that follows automatically by comparing the gaps between those maturity levels per maturity factor, based on criteria from the company strategy.

3.4.3 MRC validation

Effectiveness and efficiency validation

For the MRC, the following MEO is defined: '*The amount of decision making stakeholders (relatively) that would make an investment deal with their private money, for performing a project for optimizing the maturity dimension selected by them, in return for company interest.*' As with effectiveness validation of the MLC, this *MOE* is a measurable version distracted from the MRC objective and requirements and entails the concept fulfilling requirement *1*, *2* and *3*. The perspective of the industrial stakeholders is leading, utilization of the model in their eyes results in objective selection of a maturity dimension for optimization. The effectiveness cannot be measured in the concept phase, but needs validation after development and use.

Efficiency of the design is directly related to the context. Consequently, quantities of efficiency for this design can not be given. However, since a maturity context is already created in the MLC, efforts for creating the insights with using the MRC mainly consist of indicating maturity levels. For doing so, an overdeveloped list of maturity dimensions is less valuable and efficient than an dimensions list on a more abstract level. Most efficient is the level of abstraction that provides enough insights in the differences between relevant maturity dimensions and no insights that are not necessary to identify a suitable maturity optimization focus dimension. This rule however, forms a risk for efficiently executing this MRC design. Further research for how this equilibrium can be found is required, expected is that this can be achieved best by performing the MLC and MRC in multiple contexts and evaluate indications for the efficiency for each context. This can be done based on the used maturity dimensions compared to the identified maturity dimensions after each round.

However, an approximation of the value for performing parts of the model can be given. The process of identifying maturity dimensions in a context requires a sufficient amount of effort from the stakeholders for them to complete the thinking process and be aware of maturities of processes and relations to higher objectives. It may occur that stakeholders fill in too many maturity dimensions for the relevance of the company context, decreasing the efficiency of performing this process or do not take enough effort for them to lead to useful insights. However, the network allows opportunities and functionalities for quicker selection of dimensions and tailoring them to suit the context. Furthermore, with the maturity dimensions created once in a company, that maturity context – already reused in the MRC – can be (re-)used for other purposes as well, such as IT system development or organization structuring.

Requirement validation

The requirements for the MRC contain three key themes, discussed in sequence in this section.

- '***Comparison of maturities***': The radar chart visualization method is chosen as candidate for comparing maturity factors on maturity dimensions based on their maturity levels. Comparison can be performed on multiple locations of maturity, providing insights in the route towards company success as highest objective. Summarizing, this requirement is fulfilled by the design.
- '***Company strategy as directive***': For objective determination and comparison of maturity factors based on maturity levels, indications for levels must be provided by the stakeholders. However, since uncertainty, sensitivity and perspectives cause biases, the company strategy – as representor of the aim for company success – must be directing the level indications and selection decisions. This design does not yet clearly state how this should be performed, making stakeholders aware of the company strategy as directive, but not forcing them to apply that vision. Therefore, this requirement is partly met by the design, and external guidance must ensure that interpretations of the company strategy comply with the set maturity levels and selection steps.
- '***Indications for selection***': With filling in current and aspired levels of maturity, the biggest 'gaps' from company strategy perspective select the maturity factor on one location deeper in the radar chart pile. By using a roadmap that leads the stakeholders through the steps with selecting one maturity factor as focus at a time, clear indications for selection are provided and this requirement is fulfilled by the MRC design.

Decision validation

Instead of a model or method, the MRC is designed as a roadmap on which stakeholders know what the intention is of the steps, but can perform the steps in their own manner. This functionality, combined with the focus on the future context and flexible determination of required stakeholders, results in the objective of the MRC being met with the design. Methods for information structuring are provided, but using and filling in the content of the design is free for the stakeholder to adjust to their preferences. Consequently, the roadmap successfully guides stakeholders towards implications for practice (insights in the selection decision).

Utilizing radar charts for maturity visualization is applied more often. However, stacking the radar charts visualizes the route to selection of one maturity factor for optimization. By providing the route towards the '*answer*' as well, insights behind selection options are given. Therefore, this information structuring method provides the required insights for deliberately selecting maturity factors for optimization, which is a unique objective for maturity assessments.

The MRC requires indications of current and aspired maturity levels on maturity factors. This needs to be performed by the stakeholders. However, attaining indications for levels of maturity is difficult without prior knowledge on maturity optimization. Therefore, guidance by an external company or experienced maturity assessment practitioner is required for executing this MRC concept.

For indicating the current maturity level, uncertainties, sensitivities and perspectives play their part. For indicating aspired maturity levels, the selection decision is even more sensitive to these variances. Therefore, the company strategy is used to interpret the future as good as possible. Uncertainties and variables which cannot be indicated, can be left open in the design without influencing the results much. However, without indications of maturity factors and levels of maturity, no results appear at all, which is a risk of the design. Expert guidance must be aware of this risk and an appropriate '*minimum required content*' must be defined before interpreting the MRC information.

3.5 PDMO model design: MOC

3.5.1 MOC Directive

After the maturity profile allows deliberate selection of a maturity factor for optimization, a maturity audit needs to be executed to optimize that specific factor. As stated in the introduction, many maturity audit models exist for a broad field of maturity factors. All are within the solution domain of the Maturity Optimization component (MOC) design (*Figure 22*). This design is not developed in detail, since literature on selecting maturity audit models targeting certain maturity factors exists. However, gaps in this solution domain exist (*Chapter 1.3.2: Limitations of maturity audit models and methods*), which can not be filled within the scope of this research. Therefore, the second design part of this research (*Chapter 4: The PDPMA concept model*) develops a proof-of-concept for a PD Process Maturity Audit (PDPMA) model as starting point for filling this gap. The MOC can use any developed maturity audit model that can be useful for optimizing a specific maturity factor.

MOC objective

Provide objective insights for all stakeholders to effectively and efficiently structure processes towards increased process maturity.

MOC requirements

- Provides insights in the value of optimizing certain maturity in specific contexts;
- Provides insights in the effectiveness and efficiency of process structures for the context;
- Provides companies with the insights for optimization.

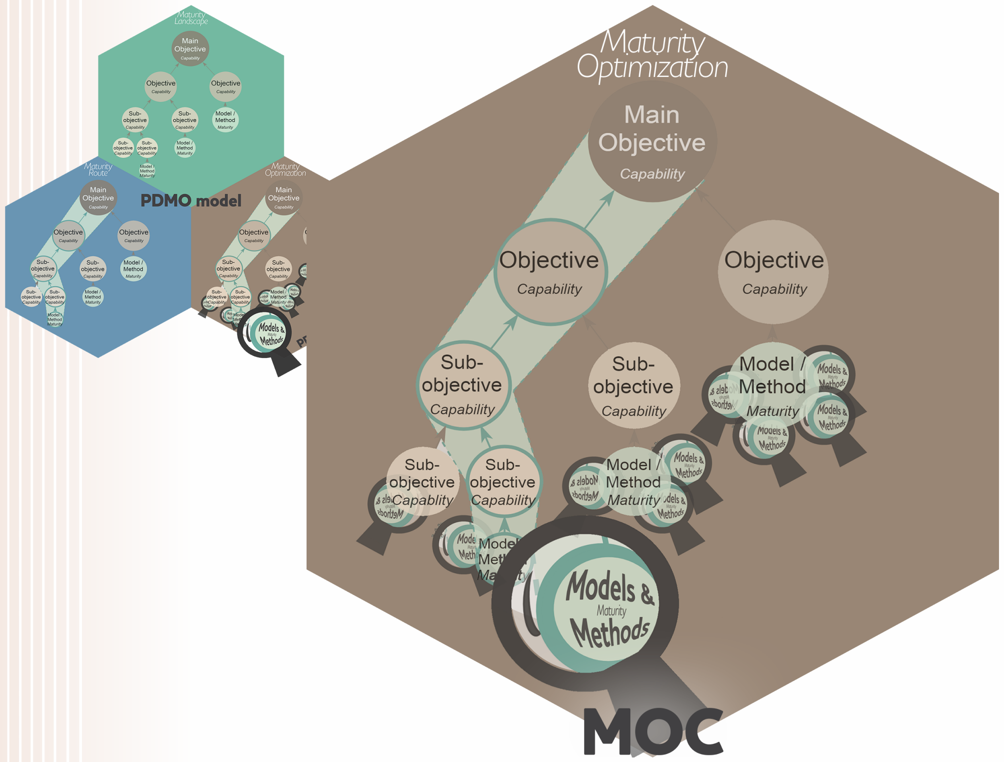

Figure 22 - Abstract visualization of the Maturity Optimization Component (MOC)

3.5.2 MOC Design

Any validated (process-based) maturity audit model can be a solution for the MOC design to achieve the objective of an improved process. However, as stated in the introduction, not every model is effective and efficient to use in the company context and tailoring of the Design Science artefacts (such as maturity audit models) is required. The MOC requires a method for selecting appropriate maturity audit models, which forms a completely new domain of research. Due to the limitations of this research, no detailed concept design is formulated. Instead, ideas for evaluating appropriateness of a maturity audit model for a context are used, comparable to the design of the Optimization Strategy part (OSP) of the PDPMA concept model, discussed and explained in later chapters (*Chapter 4.4: PDPMA model design: OSP*).

Since literature does not describe set standards for selecting maturity audit models for a context, the MOC design must guide in selecting an appropriate maturity audit model for the specific context and selected maturity factor. Maturity audit models follow a logic flow that forms an entity into an optimized version of it. An entity in this case, can be

any maturity factor detailed enough to stand in close relation with the practical context. Maturity audit models are designed with an intention of optimizing a pre-defined entity, for example information technology structures in a company. This functionality provides means for classification of maturity audit models for selection based on target entities.

Through classification – the first functionality of the MOC design – stakeholders are able to filter maturity audit models on the selected maturity factor. In parallel, a criteria is placed on validity of the models. The MOC design must have the functionality of filtering them based on validity. This filter can be based on any standard validation theory, for example Sargent's theory for model validation and verification. Utilization of standard validation theories allows filtering based on those outcomes.

The selection of a maturity audit model, requires further selection. In example, this can be performed by relating them to the context. Based on overlapping functionalities of the maturity audit model on one side and the context on the other side, a selection can be substantiated and insights behind that selection can be visualized. However, this chapter does not address this aspect in detail, since it is discussed in later chapters (*Chapter 4.4: PDPMA model design: OSP*) and that design idea forms one possible solution out of many.

For optimization of the PD process maturity in specific, a concept for the PDPMA model is developed and discussed in the next chapter. The design is based on standardized model development approaches and contains three common steps of maturity audit models, a test for validating added value of maturity audit execution, a tool for identifying optimized situations and a change and implementation advice for the company.

3.5.3 MOC Validation

The MOC is not designed in detail in this research. Since a focus for optimization is deliberately determined, the step towards finding and executing a suitable maturity audit model is small. A detailed design for guiding that selection would add less value for the industry than the focus on PD process maturity optimization would add. Therefore, the decision is made to not further investigate the MOC design, but focus on PDPMA model development instead, providing a basis for development of other maturity audit models as well. Summarizing, the PDPMA concept model development provides first steps towards closing the gap between the limited application domain of existing maturity audit models on one side and the broad application domain where maturity audit models can add value as well on the other side.

4 PDPMA MODEL DESIGN

Chapter content

Existing maturity audit models as solutions for the MOC – focussing on the PD process maturity dimension – are limited in application domain. Therefore, development of a concept Product Development Process maturity audit (PDPMA) model is performed that fits within the solution domain of the MOC design. The model uses a Maturity Test part (MTP) to validate if PD process maturity optimization is beneficial for the specific company context. After validating that proceeding with the PDPMA model is valuable – positive accreditation – the Optimization Strategy part (OSP) relates company context aspects to parts of existing models and methods. By enabling exploration and simulation of context situations and the effects on specific process structures, it guides in identifying the aspired structure for the PD process. Furthermore, it provides insights in influences of context uncertainties and sensitivities on effective and efficient utilization of existing (parts of) PD models and methods. A design brief for a Change and Implementation part (CIP) is written which aims for translating optimization strategy outcomes into implications for practice based on the company strategy and current situation within the company. A change and implementation advice is the deliverable for the company, which provides structured MTP and OSP insights as underpinning of CIP results.

4.1 PDPMA model directive

4.1.1 Generic three-step maturity audit models

The basis for the Product Development Process Maturity Audit (PDPMA) model design is a maturity audit model since set standards are developed for those artefacts and they are known for their capability to guide and structure optimization projects. These models guide the steps between an existing and an aspired situation. From the introduction and research in maturity audit model development, relevant key themes are stated for this design. These are listed to indicate required knowledge on topics that the design needs to address.

Key themes:

Effectiveness and efficiency of PD processes through structuring
Decision making criteria with company strategy as directive
PD process structuring with existing (parts of) models and methods
Context influences on effective and efficient model and method utility
Role of uncertainties and their sensitivities for decision making
Visualization methods (network visualization in specific)
Communication methods for change and implementation

The PDPMA model consists of three parts. The design follows a standard three-step approach for maturity audit models, of which each step focusses on one specified sub-objective to get from one situation to an optimized situation. The steps are used as standards and are designed as '*parts*' on *level 3* in the design hierarchy, together forming the PDPMA model. A first step generally determines whether it is beneficial in the company context to perform the optimization and to continue with executing the maturity audit model. Then a second step is performed identifying solutions for the context and based on decision criteria, a selection of improvements for implementation can be made and advice for change management and implementation is communicated (*Figure 23*).

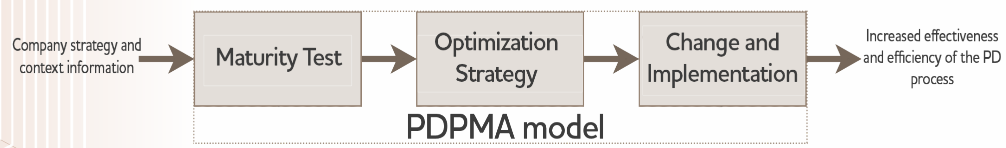

Figure 23 - Representation of the level 3 PDPMA model parts within the PDPMA model design

4.1.2 Objectives and requirements

Since the PDPMA model is a selected part of the MOC solution domain (*Figure 24*), the PDPMA objective is slightly changed to focus on PD process maturity in specific instead of including other models for maturity factor optimization as well. The requirements of the MOC are directives for the PDPMA model design. These requirements can not be fulfilled at once by the PDPMA model. In order to develop a theoretically sound concept design resulting in an utilized model after further developments, a more detailed requirement specification is necessary to define the solution space in more detail. Therefore, PDPMA model requirements are stated as foundation for the design.

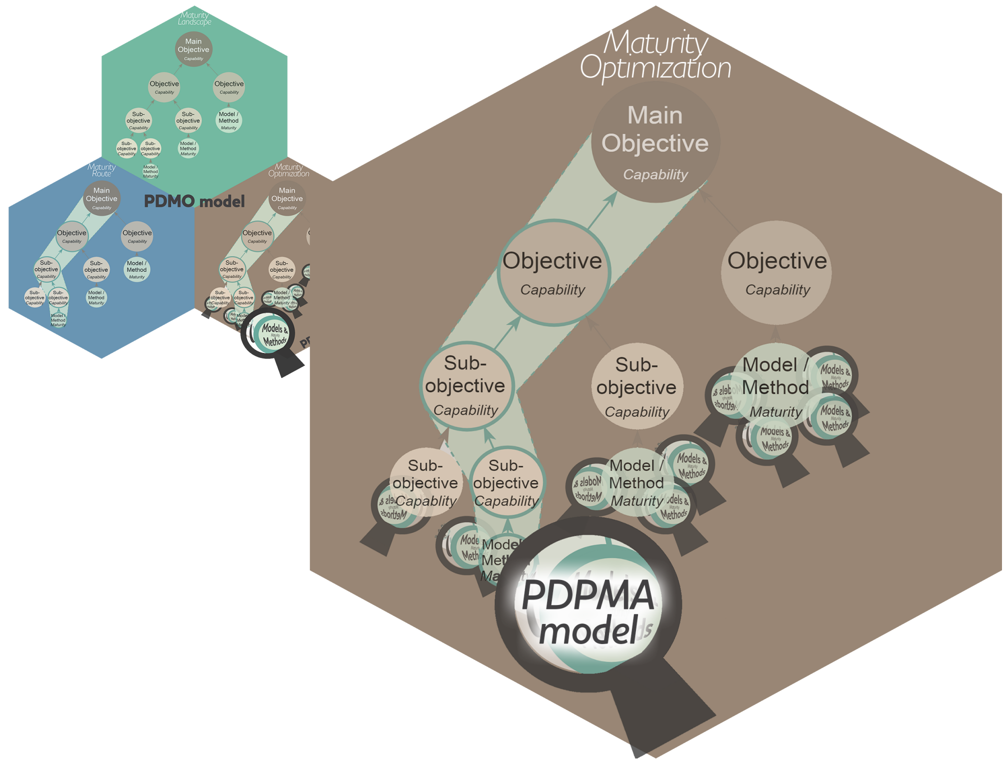

Figure 24 - The PDPMA model as part of the MOC solution domain

Table 5 – PDPMA model part objectives

#	Sub-objective	Chapter
1	Provide companies with information about whether or not to continue with performing the PDPMA model for optimizing the PD process.	**4.3.1 MTP Directive**
2	The main objective is to develop a concept that provides detailed insights in the relations between company context aspects at one side and (parts of) models and methods on the other side.	**4.4.1 OSP Directive**
3	Provides companies with insights in how to effectively and efficiently change PD processes towards the desired situation as identified by the OSP	**4.5.1 CIP Directive**

The PDPMA model objective

Provide objective insights for industry to effectively and efficiently select and implement a reconfiguration of existing models and methods tailored to their PD process, towards increases PD process maturity

MOC requirements

- Provide insights in the value of optimizing PD process Maturity in context
- Provide insights in the effectiveness and efficiency of PD process structures and opportunities for optimization
- Provide companies with the insights for change and implementation of optimizations

For fulfilling the PDPMA model requirements, three parts are designed that follow the three general maturity audit model steps:

- *Maturity Test part* (MTP, *level 3)*: The first MOC requirement results in a tool for answering the question whether it is beneficial – or effective – to continue with the comprehensive steps of the PDPMA model for optimizing PD process maturity.
- *Optimization Strategy part* (OSP, *level 3*): The second MOC requirement results in a tool for relating specific company context aspects to (parts of) existing models and methods for creating insights in influences on each other, and proposes an appropriate optimization solution based on the reconfiguration of existing models and methods.
- *Change and Implementation part* (CIP, *level 3)*: The third MOC requirement results in a design brief that allows selecting and implementing effective and efficient changes in the current situation to achieve the improved situation.

Sub-objective 1: Requirements

Provide companies with information about whether or not to continue with performing the PDPMA model for optimizing the PD process.

- The design of the Maturity Test part (MTP) should help to answer the question '*yes*' or '*no*' to proceed with executing the complete PDPMA model. This decision is based on the benefit and value of improvement for a specific company context.
- The design communicates insights behind why it is beneficial or not to proceed with the complete PDPMA model to decision makers of optimization projects. This requires more detailed insights in how the previously proposed requirement is fulfilled.
- The design of the Maturity Test can be developed into a practical tool for applicability and feasible utilization in industry.
- Input and output information of the Maturity Test design take into account complementing and adjusting information to new literature, insights and contexts. Source limitations do not influence reliability and utility of results.
- The design of the Maturity Test should meet these directives for the selected scope discussed in the introductory chapters (*Chapter 1.4.3: Scope and limitations*).

Sub-objective 2: Requirements

The main objective is to develop a concept that provides detailed insights in the relations between company context aspects and (parts of) models and methods.

- The design of the Optimization Strategy part generates an effective and efficient process structuring solution (referred to as '*the OSP output*') for a specific contests (referred to as '*the OSP input*'). It uses contest aspects with uncertainty and sensitivity as parameters for adapting results to the company strategy.
- The design of the OSP proposes a solution which is detailed enough to validate the principle of the OSP concept with its solution generating function (e.g. by benchmarking different outputs for variating inputs).
- The design communicates insights behind why a specific solution is presented with the given input and forms an effective and efficient solution. It can be developed into a practical, feasible tool for utilization in industry.
- The information that is used for and by the OSP must be able to be complemented and adjusted to new literature, insights and contexts. Source limitations do not influence reliability and utility of results.
- The OSP design should meet these requirements for the selected scope as discussed in the introductory chapters (*Chapter 1.4.3: Scope and limitations*).

Sub-objective 3: Requirements

Provides companies with insights in how to effectively and efficiently change PD processes towards the desired situation as identified by the OSP

The design of a suitable and tailored change and implementation advice is dependent on the context and OSP results. Therefore, the detailed CIP design cannot be gabbed into firm requirements, since the requirements are determined by the optimization objectives, the company and the utilization context. However, broad requirements on a general level can be provided. These are determined in the chapter itself. Since the design of the CIP requires adaptation and no general design can be provided, the CIP will be developed into a design brief in this research. Consequently, the Industrial Engineering domain can develop detailed designs that suit the requirements of the specific context and user needs.

Some general requirements include:
- Requirements for creating the change and implementation content
- Requirements for communicating the content into an advice
- Requirements assuring the fit of the results to the stakeholders

4.2 PDPMA model idea

The PDPMA model guides users in ten (10) sub-steps from a maturity test to tailored change and implementation advice on PD process optimization.

First, *(1)* the MTP evaluates whether optimizing the PD process maturity dimension is valuable in the context. Decision criteria for that are based on the company strategy. In parallel, *(2)* it helps identifying uncertainties, sensitivities and perspectives in the context, influencing *(3)* the decision whether or not to continue with performing the comprehensive PDPMA model. After both favour continuation of next steps, *(4)* the OSP relates the detailed context aspects to detailed parts of existing models and methods *(5)* to form a range of solutions tailored to the context. *(6)* Scenarios and context variations can be benchmarked and influences of decisions on process structures are visualized. The CIP *(7)* identifies the gaps between the proposed solution and the current situation. It *(8)* provides guidance for deciding on what to implement and change in the current situation through prioritization and *(9)* how to change it. The decision criteria for this step are determined by the company strategy. As last step, the CIP *(10)* communicates the insights to the management of the company for documentation of and spreading the insights. The next chapters explain the three PDPMA model parts in more detail.

4.3 PDPMA model design: MTP

4.3.1 MTP Directive

An evaluation is required which identifies if and why a context would benefit from PD process optimization. The MTP guides the accreditation[30] decision for further PDPMA model execution. Not all companies would benefit from increasing the effectiveness and efficiency with use of the PDPMA model. If it is appropriate to perform the complete PDPMA model for a context, is tested in the Maturity Test Part (MTP), which this chapter proposes a concept design for. This design performs an accreditation for the PDPMA model execution. '*Accreditation*':

"is a management decision ... of those responsible for consequences from the use of results from the model or simulation" (Sargent, 2001).

The main objective of this part is to determine if the company can increase effectiveness and efficiency of the PD process through PD process optimization, by creating insights in context influences and maturity dimension influences on PD processes.

MTP Objective

Provide companies with information about whether or not to continue with performing the PDPMA model for optimizing the PD process.

MTP Requirements

- The design of the Maturity Test should guide in answering the question '*yes*' or '*no*' to proceed with the complete PDPMA model.
- The design communicates insights behind why it is beneficial or not to proceed with the complete PDPMA model to decision makers of optimization projects.
- The design of the Maturity Test can be developed into a practical tool for applicability and feasible utilization in industry.
- Input and output information of the Maturity Test design take into account complementing and adjusting information to new literature, insights and contexts.
- The design of the Maturity Test should meet these requirements for the selected scope discussed in the introductory chapters (*Chapter 1.4.3: Scope and limitations*).

30 Accreditation: "*a management decision of those responsible for consequences from the use of results from the model, 'should it be used'? Acceptability criteria are determined by the company strategy*" (Sargent, 2010).

4.3.2 MTP Design

A step wise MTP design

The MTP starts with identifying what situations are beneficial for continuing PDPMA model execution and is designed around that. In order to answer the question if it is beneficial in a context to perform the PDPMA model comprehensively, this research starts by looking at the situations which result in being beneficial to perform the PDPMA model comprehensively. This is limited to two situations. *(1)* PD process maturity optimization contributes effectively to company success and therefore is optimizing that dimension efficient, and *(2)* PD process maturity can be optimized in the specific context. The second question can be untrue for multiple reasons. For example, regulations may fix the freedom of adjusting the process structure, or budgets assigned for optimization may be insufficient (this is strongly related to the scope of this research to not include industries which are e.g. rusted-up, *Chapter 1.4.3: Scope and limitations*). In order to find when optimization is valuable for a context, these two aspects must be validated. In other words, these two criteria being '*true*' results in a positive accreditation decision of the PDPMA model.

The Maturity Test Part (MTP) design therefore starts with two steps. The first step tells to *(1)* validate if PD process maturity is the right dimension to optimize for a context, and the second step states to *(2)* validate if the PD process maturity can be optimized in the specific context. After that, a third step *(3)* combines the two answers to one single answer on the question: "*Whether or not to continue with PDPMA model execution*". This decision node is visualized in *Figure 25*. The MTP guides the three steps by more detailed activities.

The steps are divided into a stepwise activity plan for achieving the MTP objective. The activities that need to be performed are listed, contributing to fulfilling the three steps.

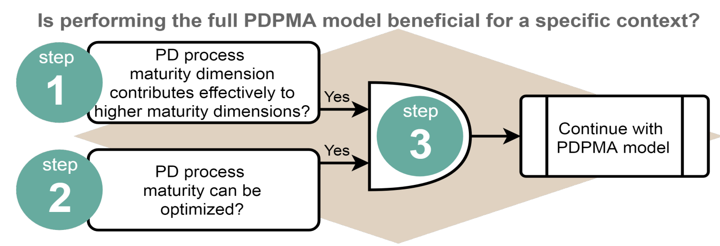

Figure 25 – Representation of the decision node where 'whether or not to continue with the full PDPMA model execution' depends on two context conditions

1) *Validate PD process maturity as dimension*

a. Indicate, evaluate and identify maturity levels of maturity factors on the same maturity dimension and above the PD process maturity dimension (resulting in a maturity context, which as well can be copied from the MLC)

b. Determine the maturity dimensions sensible for optimization (for example by using the results of the MRC) with criteria indicated by the company strategy, contributing to achieving company success

c. Answer the question true or false: "*The company strategy indicates that PD process maturity is the dimension to optimize, contributing to company success.*"

2) *Validate PD process optimization opportunities*

a. Indicate, evaluate and identify abstract uncertainty levels and locations in the company context

b. Indicate, evaluate and identify abstract sensitivities of the identified uncertainties on abstracted outcomes

c. Place uncertainties with their sensitivities in the "*uncertainties-sensitivities table*" (which is described in the next paragraphs)

d. Determine criteria for deciding on '*usefulness*' of improving PD process maturity related to the "*uncertainties-sensitivities table*", indicated by the company strategy

e. Answer the question true or false: "*Based on the identified uncertainties and sensitivities, the company strategy indicated that it is 'useful' to perform PD process maturity optimization.*"

3) *Answers interpretation*

If the answers on *step 1* and *2* both are '*true*', then the optimization process can continue with performing the PDPMA model's comprehensive Optimization Strategy Part (OSP).

The following paragraphs explain in detail how the steps work (*Figure 26*). *Step 1* can be performed by the MLC and MRC of the PDMO model designs and will not be discussed here in detail. *Step 2* requires a more comprehensive explanation.

Step 1

The first step can be fulfilled directly by the Maturity Landscape Component (MLC) and the Maturity Route Component (MRC) (*Figure 26*). By performing those (activity *1.a* and *1.b*), the answer to activity *1.c* can be found.

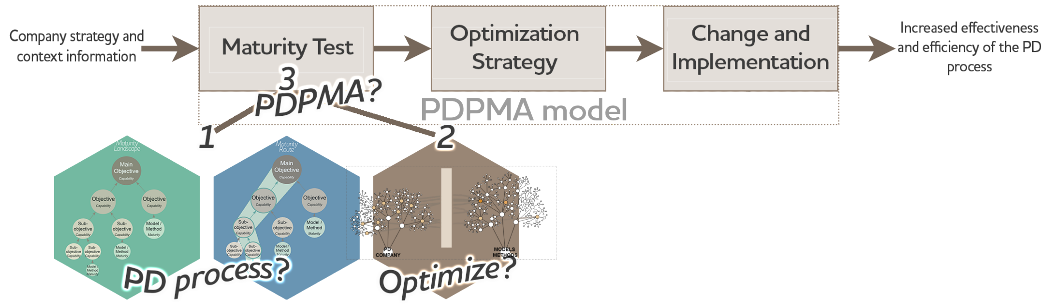

Figure 26 - Representation of the 2 steps in the Maturity Test Part (MTP): (1) validating the maturity dimension and (2) validating PD process opportunities

Step 2

The second step requires new design functionalities: to relate abstract company aspects to an indication for effective and efficient models and methods. For specific situations, the outcome of a model or method is not sensitive for the given context inputs. These situations are examples for when it is not required to perform the full PDPMA model, since only one solution is possible either way and the PD process structure is not changeable in the context. Solutions and insights can be achieved without the PDPMA model, based on intuition or simple model and method benchmarks. These situations result in a negative advice for PDPMA model execution (as answer to question *2.e*).

For relating the context with models and methods, a common ground between the two is required and found in 'overlapping functions'. Not many literature researches try to connect specific company contexts to effective and efficient models and methods. If that is done, best practices are used as common ground for relating them. However, this strategy has a limited theoretical base and is questioned by many researchers (*Chapter 1.3.2: Limitations of maturity audit models and methods*). The MTP is designed with use of a different common ground for relating contexts to models and methods: relations based on overlap in functions. This idea is explained only to a limited extend in this chapter, since the MTP works only towards an abstract and rough estimation of relations based on functions to provide an indication for changeability and opportunities. *Chapter 4.4: PDPMA model design: OSP* explains this concept in further detail.

The effectiveness and efficiency of PD processes are determined by the structure (with utilizing models and methods) in that context. If structuring models and methods provide all functions which the context needs (and only those), the effectiveness and efficiency of the process are high, resulting in "*doing the right things (effectively), the right way (efficiently)*". Models and methods applied are then suitable for the context. The design is based on

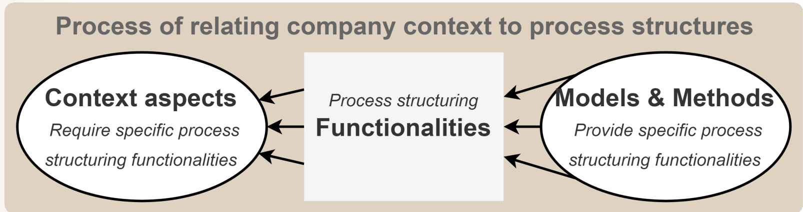

Figure 27 - Visualization of the concept for matching context aspects to models and methods

providing a rough analysis on how generic models and methods roughly fulfil functions required by the PD process context. The MTP evaluates the '*match*' in functionalities between certain generic models and methods at one side, and an indication of the company context on the other side. A representation of this relation is visualized in *Figure 27*.

For performing *step 2*, a tool for roughly analysing abstract contexts and relating them is required. Such analysis needs to show only a rough estimation of the model and method types suitable for the context, with influences of rough context aspects on that outcome. For such an (abstract) estimation, context aspects influencing suitability of PD models and methods need to be examined. *Nieberding (2009)* identifies these aspects and states four main categories of impact: Project, Product, Organization and Personnel *(Nieberding, 2009)*. These aspects consist of multiple sub-categories, such as Project Type, Project Size and Project constraints. A visualization of this topology is given in *Figure 28*. Beneath the sub-categories, supporting categories exist and this continues for multiple levels deeper. The author added Portfolio as extra main context aspect, since a valid indication for the existence of this fifth aspect has come up and flexibility of the content is an important requirement for sustainability of the MTP design. Therefore, adding or deleting context aspects as seen fit is possible to increase usability and reliability of the results.

Since only an indication for suitable process structures is asked for, only the main categories are used and related to generic model and method types in the MTP. For insights in the context categories of impact, they must be mapped or visualized before relation to functionalities is possible. Each context category has multiple sub-categories (an example is given in *Figure 28*), forming a tree-structure of company context aspects (*Figure 29* – the left tree, symbolically represents that idea) which influence the suitability of PD process structures as solutions. Models and methods often are based on a certain '*parent*' model or method forming the inspiration for development of a new model or method. By identifying the models and methods that form the origin for most developed models and methods, a tree visualization of them can be created as well (*Figure 29* – the right tree). Again, since only an indication is required, only the parent models and methods that form the origin need to be visualized and matched to the main context aspects. This results in two abstract

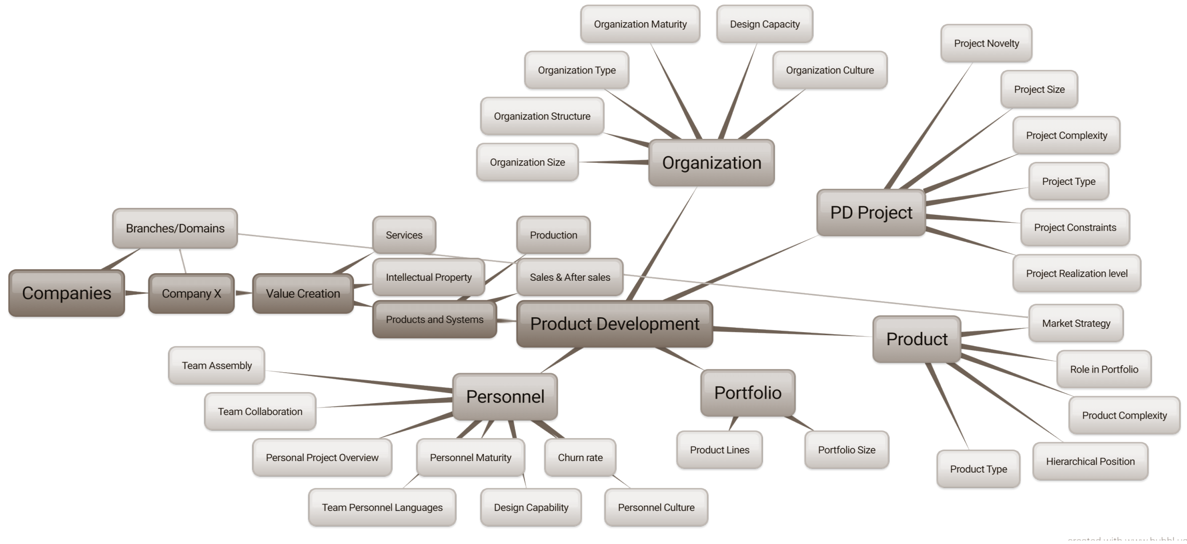

Figure 28 - Maturity Test context aspects in the design, based on Nieberding (2009)

and limited topologies. One of abstract context aspects and one of abstract models and methods. These two tree-shaped network topologies with relations through functions, are visualized in *Figure 29*.

Visualization of relations

The context is related through a network, with the overlapping functions as '*black-box*' in between. Digitalization allows other beneficial functionalities of the MTP tool. The elements in the tree-network of the context aspects are related via functions to the tree-elements of model and method types. The relation through functions provides insights in effectiveness and efficiency of structures in indicated contexts. Such networks are never complete and aspects can be complemented or deleted if proven necessary. Digitalization of the tool allows visual highlighting and information structuring after input is provided. For example, aspects with high sensitivity and uncertainty can light up with their relations to model and method types, functions can be grouped or often used aspect combinations can be used for scenario simulations. For the Maturity Test Part, the specific way of relating and matching through functions is not the focus and for now is seen as a '*black box*' with the functionality of roughly relating PD process context aspects to PD process model and method types. The exact functionalities and details of the 'black box' are designed and explained in *Chapter 4.4.2: OSP Design*.

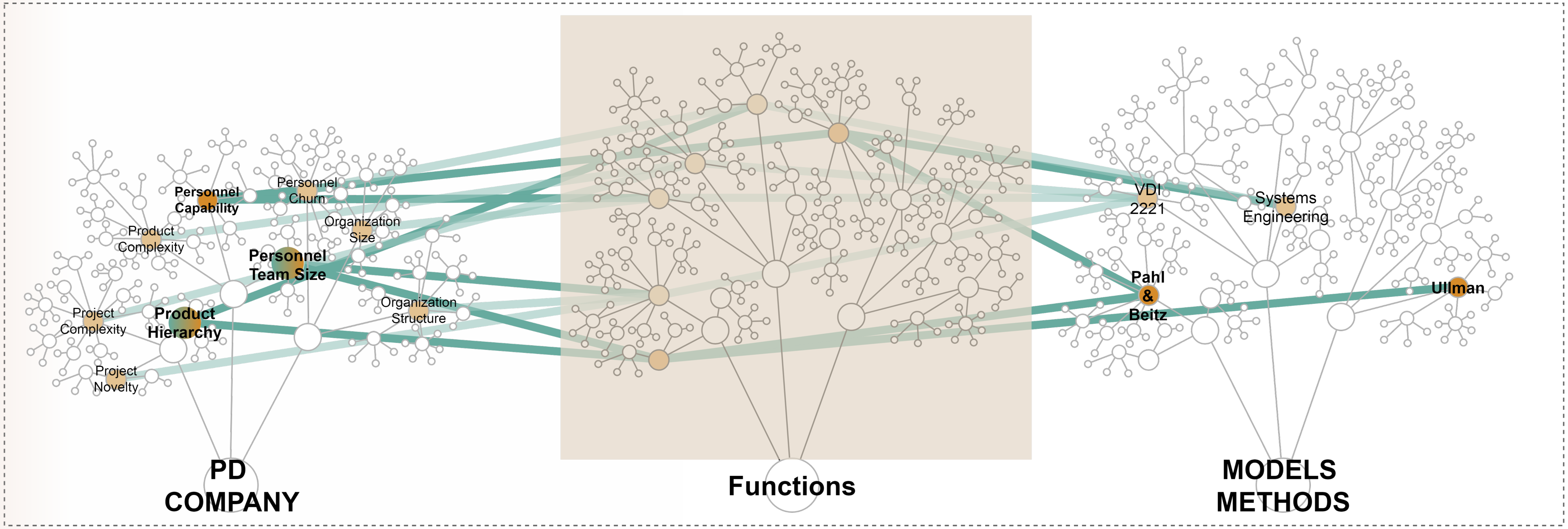

Figure 29 - Representation of the tree-shaped network topologies relating company context aspects to model and method types

Validating existence of optimization opportunities

High uncertainty combined with high sensitivity make it difficult to decide deliberately on PD process structuring when insights are limited. The next step in the MTP design is to validate the added value of insights in optimization for a context. For the PDPMA model to be valuable, the relation between the models and methods to context aspects must be difficult to oversee in a company, and cannot be achieved with use of logic sense only. This is the case when context aspects are uncertain, since the input for selecting a suitable process structure then is unknown, making it difficult for the decision maker to come to a result. If an uncertain aspect influences the selection of a solution, the sensitivity of that aspect is high as well. Consequently, for uncertain input aspects, the results are uncertain as well. With that in mind, the difficulty of decision making lies in contexts with the combination of a high uncertainty and a high sensitivity. The PDPMA model is most valuable in those situations where high uncertainty and high sensitivity occur, since it provides insights in the influences between (certain and uncertain) context aspects on the resulting effective and efficient process structures. Contexts which have only one PD process structuring option and no optimization opportunities, are filtered-out by the MTP design.

The result of the MTP is an overview of context aspects, which influence the outcome (resulting in related, possibly effective and efficient types of models and methods). Context aspects have a sensitivity on the outcome and an uncertainty of occurrence and accuracy. However, resulting model and method types are not the main focus for the question whether or not to proceed with the complete PDPMA model, but – as explained previously – the MTP focuses on searching for rough context aspects with the combination of high sensitivity and high uncertainty. The possible outcomes of this part of the MTP design – which relates contexts with model and method types – is visualized in *Figure 30*.

Analysing MTP results

Per context it may differ which of the first two steps is easier to answer. This depends on e.g. the availability of information and available stakeholders at time of the MTP execution. It is beneficial to start with the *step* (*1* or *2*) that is best or easiest answered within the company context. If one of the two steps result in a negative advice to continue with the PDPMA model, the model does not have to be performed further. If the step that is taken secondly provides negative advice, the first step is performed ineffectively and the MTP becomes less efficient in use.

Results of Step 1

The first step can be answered by analysing the Maturity Landscape and indicating a specific Maturity Dimension for optimization. If the outcome of the MRC is optimization of the PD process maturity dimension, the question of *1.c* is answered with '*true*'. Continuing with PDPMA model execution then only depends on the answer on the question of *2.e*. If the answer on *1.c* is '*false*', MTP *step 2* does not have to be performed, but focus must be shifted towards optimizing the indicated process from the MRC. When it is chosen to start with the second step, performing the first step is irrelevant after question *2.e* is answered with '*false*'. The other way around is possible as well. If validation of the PD process maturity as focus is very difficult in a context, the MTP can start with performing *step 2* first, if *2.e* is answered '*true*', then *step 1* can be performed afterwards.

Results of Step 2

This section illustrates the possible outcomes and the answers to the questions of *step 1.c* and *2.e*. Aspects with a low sensitivity (*Figure 30*, A and C) do not have a large influence on the outcome since both, certain *(A)* and uncertain *(C)* aspects, result in the same model or method type. These are therefore not interesting to know for the MTP. Aspects with a high certainty (*Figure 30*, A and B) (both, unsensitive *(A)* and sensitive *(B)* aspects) are known well beforehand and influences on the outcome can be predicted with a high certainty a full PDPMA model execution is therefore not necessary, a one time insights creation can be enough. The combination of high sensitivity and high certainty (*Figure 30*, D) is most interesting and provides means to fully perform the PDPMA model for optimization projects. The reason for this is discussed in further extend in *Chapter 4.3.3: MTP Validation*. MTP *step 2* can be analysed for its results for validating the PD process improvement opportunity in a context. Given that the answer on MTP *step 1.c* is '*true*', the answer of MTP *step 2.e* follows these three scenarios. An overview of these results, in combination with when to proceed with the PDPMA model, is given in *Table 6*.

4.3 PDPMA model design: MTP

Figure 30 - Abstract visualizations of the MTP relations (a, b, c and d) for a variety of illustrative context situations

- If there are no context aspects with high sensitivity and high or low uncertainty (*Figure 30*, A and C), the effectiveness and efficiency increasing advice can be created with logic sense only. There are no aspects influencing the choice for certain model and method types enough to make a difference for optimization or the PD process structure is not changeable for the context (*Table* 6, left column). The result is not to execute the rest of the PDPMA model.
- If there are aspects with high sensitivity and low uncertainty (*Figure 30*, B), it is possible to examine the results with logic sense as well, or with the resulting model and method types of the MTP (*Figure 29*). Since all variables are known, the influences on the effectiveness and efficiency are clear and optimization can be performed after a gap analysis and change and implementation strategy is developed. There is a high possibility that a good PD process is already in place in this scenario and a executing a full Optimization Strategy Part is inefficient (*Table* 6, right bottom cell).
- If there are multiple aspects present with high sensitivity in combination with high uncertainty (*Figure 30*, D), proceeding with the PDPMA model is valuable. The differences in results for the multiple parameters within the uncertainty can not be examined with logic sense only, since there are more variables to take into account and they are influencing the outcome. The multiple aspects with high sensitivity and high uncertainty, make it too complex to oversee all impacts on the effectiveness and efficiency of model and method types, and optima are difficult to find without additional insights (*Table* 6, right upper cell).

Required practical input information and uncertainty

The input information for performing step one is described previously, in the PDMO model chapters. Input information for the design of *step 2* consists of identified company context aspects, uncertainties of those aspects and sensitivity identification per aspect. The model provides an indication of suitable model and method types as output and relates them with use of comparable functions (as explained previously). For acquiring the input information, practical knowledge from the company is required. This can be captured with use of a variation of methods such as questionnaires, workshops or interview sessions. An example of a tool for capturing the required information is visualized in *Figure 31*. The user fills in a sensitivity level and uncertainty level if known and relevant in the project context. After digitalization of the tool, autofill functions, quick selection tools and scenario based inputs can be allowed to quicken the MTP process if required.

Table 6 - Value of proceeding with the complete PDMA for levels of sensitivity and uncertainty

		Sensitivity	
		Low	High
Uncertainty	High	The change of aspect due to uncertainty does not or only slightly change the outcome. NO PDMA!	Lot of uncertain results and no insights in how to optimize Eff & Eff. DO FULL PDMA!
	Low	The influence of the aspect on the outcome is very predictable. NO PDMA!	With insights in the effect of the certain aspect, the outcome can be thought of logically. USE RESULTS MTP

Uncertainty is not only located in the PD process context, but has many locations, levels and natures. The specific uncertainty and sensitivity values for a context aspect are determined by the company, with extra uncertainty levels involved. Uncertainty can be described with use of uncertainty profiles[31], which are based on the project team's subjective estimates (with the company strategy as global directive) and indicates which uncertainty types are potentially most important *(Meyer, 2002)*. There are multiple variations of uncertainty: levels of uncertainty, locations of uncertainty and natures of uncertainty *(Walker, et al., 2003)*. Location and nature of uncertainty can be determined directly for all aspects, since they exist and either apply or do not apply in a specific context. If uncertainty exists and on what level, is dependent on the context and, as explained previously, may affect the outcome if the sensitivity of the aspect is high enough. Benchmarking different parameters for an uncertain aspect or comparing selected input among different stakeholders reduces the uncertainty of the company filling in levels of uncertainty for the context.

4.3.3 MTP Validation

The objective of the MTP is to Provide companies with information for deciding whether or not to continue with performing the PDPMA model for optimizing the PD process. The MTP concept is designed as a stepwise approach, guiding companies in achieving this objective. The answer is based on the value of PDPMA model execution for a company context and in parallel identifies when there is no added value in performing the full PDPMA model. PD process maturity dimension as optimization focus is evaluated in the first step of the MTP. In the second step, relations between relevant context aspects and model and method types are simulated, indicating process structuring solutions and changeability for given input parameters. Based on those outcomes, the ability of the PD process to be optimized is validated, and with previous steps, the MTP objective is achieved.

31 Uncertainty profile: "*a qualitative characterization of the degree to which each type of uncertainty may affect the project*" (Meyer, 2002).

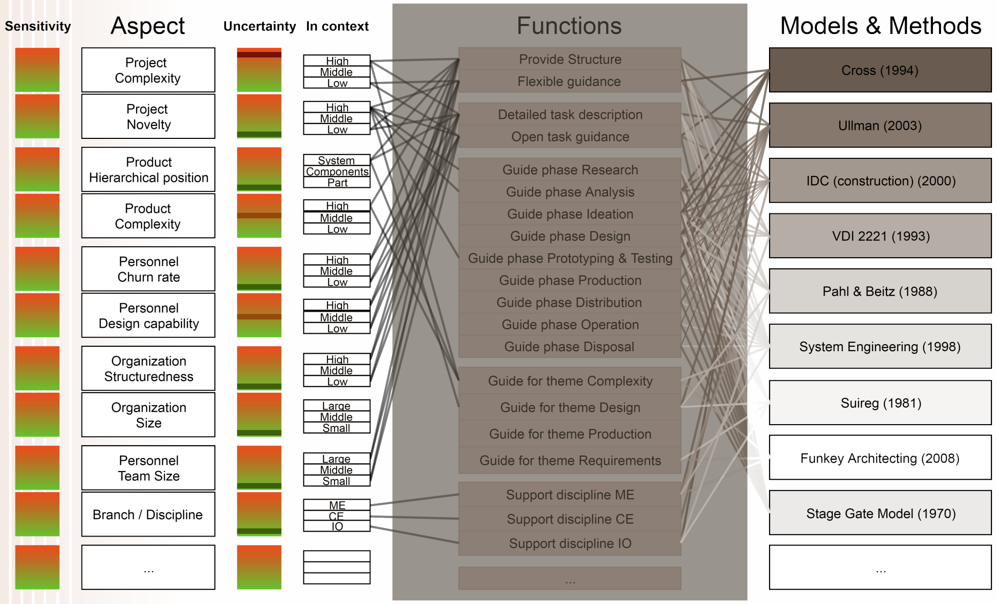

Figure 31 - Example of the MTP as an immature tool for performing the activities of step 2

Requirement validation

- '***Validates PDPMA model execution***': The design fulfils this requirement through the stepwise approach. It splits the question to validate the choice for PD process optimization in specific and the ability of the PD process to be optimized.
- '***Communicating insights***': The topology network tool for an uncertainty profile and the MLC with MRC designs help in answering the questions and communicate information paths behind results. Transparency of the tools ensure communication of the insights behind the results.
- '***Opportunities for a practical tool***': The stepwise activities enable development of a practical tool for the MTP. Applicability and feasible utilization are possible, but need to be validated during further development of the tool.
- '***Flexible information***': The tree-shape topology networks allow flexible communication and transparency of insights. Tree-shaped topologies using the network visualization method enable flexible adjustment of information, contributing to a future-proof design which enables complementing information for input, functions, outputs and relations between them after new information comes available.
- '***Applicable to the target group***': The input parameters are specifically determined for a target group of Product Developing companies, by using the context aspects as determined by *Nieberding (2009)*. However, if other aspects proof to be relevant, they can be implemented easily to ensure the fit to the target group.

Decision validation

The design of the MTP focuses on performing a global and more abstract analysis of aspects with high sensitivity and uncertainty. It will be time consuming to look into all specific context aspects for the impact on the model and method outcomes. That results in performing the complete PDPMA model, without the certainty that the results are useful to the specific company. Therefore, only a rough analysis of abstracted context aspects is performed in the MTP. The risk might be that a rough analysis results in a questionable '*yes*' or '*no*' answer for the decision makers to proceed with performing the PDPMA model and that detailed insights would better identify means for either one of them. However, since detailed information will be used in the later PDPMA model steps, and the MTP is transparent in created results, the questionable information will be evaluated in more detail if necessary then. Besides that, the efficiency of the PDPMA model is highly influenced by the amount of input information you need to deliver before valuable results are guaranteed. Therefore, for indicating a cost-benefit ratio, a rough '*go / no-go*' analysis will be sufficient without a very high level of depth.

A digital tool visualizes the three topology networks with relations between them, without focusing on detailed aspects, relations and functions. A digital tool is portable and available to a wide range of stakeholders. The network visualization method has been validated for the previous design components as well and allows flexibility and dynamic information structuring, which is beneficial for multiple stated MTP requirements. However, to develop such a comprehensive tool might be expensive, therefore a choice can be made to start with limited functionalities and data sets, resulting in an first immature version of the digital tool. Expansion of the input and output domain can be performed during use when required. The example tool visualized in *Figure 31*, uses a colour range to determine sensitivity and uncertainty levels of aspects. However, literature on levels of uncertainty is available and multiple solutions and ranges are identified. For example, the four levels of uncertainty identified by *Walker et al. (2003)* could be used as well. The effect of using a certain visualization method for levels of uncertainty and sensitivity can be evaluated and adapted if necessary, without changing the tool or concept to a major extend.

A sensitivity and uncertainty filter lead identification of relevant context aspects. Sensitivity is used as indicator for the value of the PDPMA model execution for a specific context. Other indicators for value might be thought of, but for this immature idea, filtering context aspects based on sensitivity is sensible. All low sensitivity aspects are per definition not interesting for the Optimization Strategy Part, since they will not influence the outcome. Therefore, the MTP filters these aspects to ask only the context specifications for the high sensitivity aspects. A risk of this approach is that determining the sensitivity of company aspects on process structuring results requires a broad range of practical and theoretical knowledge. It is unrealistic to expect the company to perform that step on their own, making professional specialized guidance a requisite and the costs of performing the MTP higher. However, not filtering the context aspects would result in a highly ineffective and inefficient process, since it may result in performing the complete comprehensive Optimization Strategy part (OSP) without guaranteeing valuable results.

Uncertainty of context aspects results in unstable inputs, what may result in variating or unstable outcomes for advice. That is undesirably, since the outcome then is unreliable. In reality, context aspects are never known with a hundred percent certainty, even (or perhaps especially) not by the company itself. With full certainty of context aspects, the outcomes can be found with logic sense since all input aspects are fixed. For less certainty, it is valuable to simulate the impacts and effects of variating inputs on the outputs, since it is too complex to see all influences with logic sense only. This is added value that the PDPMA model provides, but providing uncertain or unstable input information without knowing that it is uncertain might result in a false MTP outcome. Therefore, guiding the process of identifying and defining uncertainty levels for context aspects by professional specialists is preferred. This again increases the costs of performing the MTP, but increases the effectiveness and efficiency of the process, resulting in a decrease in cost. Balancing costs compared to effectiveness and efficiency is required. Both execution options are possible, and further research on total MTP process costs compared to effectiveness and efficiency gains is required to make a final decision on this topic.

4.4 PDPMA model design: OSP

4.4.1 OSP Directive

With a positive outcome of the MTP, the detailed influence of context aspects on parts of models and methods (and vice versa) must be determined to create insights for decisions on process structuring. With that objective, the Optimization Strategy part (OSP) of the PDPMA model is designed. This design is a proof-of-concept for the OSP, limited to providing only an illustrative starting point in the broad landscape of possible solutions. The MTP determined whether it is beneficial to perform the PDPMA model comprehensively for insights in PD process structuring. Thereafter, the OSP determines and generate these PD process structures tailored to the context. Awareness of sensitivity of the solutions for uncertain aspects leads to better insights for decision making, since more consequences and effects of decisions can be identified, simulated and shaped to fit the company strategy. Consequently, optimization opportunities can be evaluated objectively.

OSP Objective

Develop a concept that provides detailed insights in the reconfiguration of existing models and methods as PD process structure, tailored for their context

OSP Requirements

- The vdesign of the Optimization Strategy part generates an effective and efficient process structuring solution (referred to as '*the OSP output*') for a specific contests (referred to as '*the OSP input*'). It uses contest aspects with uncertainty and sensitivity as parameters for adapting results to the company strategy.
- The design of the OSP proposes a solution which is detailed enough to validate the principle of the OSP concept with its solution generating function (e.g. by benchmarking different outputs for variating inputs).
- The design communicates insights behind why a specific solution is presented with the given input and forms an effective and efficient solution. It can be developed into a practical, feasible tool for utilization in industry.
- The information that is used for and by the OSP must be able to be complemented and adjusted to new literature, insights and contexts. Source limitations do not influence reliability and utility of results.
- The OSP design should meet these requirements for the selected scope as discussed in the introductory chapters (*Chapter 1.4.3: Scope and limitations*).

4.4.2 OSP Design

A relation profiling OSP design

Effectiveness and efficiency are sensible only in combination to a defined context. Structuring PD processes has proven to be a best practice for effective and efficient PD processes. However, effectiveness and efficiency are always connected to the environment the process is performed in. Therefore, the need exists for identifying the influences of PD process structuring on PD contexts and vice versa, with increased effectiveness and efficiency as aspired result. The OSP design performs this function of identifying influences between both sides. The main objective is to increase effectiveness and efficiency of processes. However, achievement of that aim cannot be assured before an optimization project starts, since the specific context at that point of time is required for stating something about effectiveness and efficiency levels. Therefore, the OSP does not guarantee increased effectiveness and efficiency, but proposes a structured approach for selecting a PD process structure for the PD context. This contributes to the aim of increasing effectiveness and efficiency.

Relating the company context aspects to model and method parts is subject to uncertainties caused by e.g. stakeholder perspectives and personal objectives. These are variables which may cause the output to differ for the same inputs, causing unstable results in combination with sensitivity (a representation is provided in *11* in the Maturity vision chapter, the left side). The optimized result should benefit the overall company strategy, not an individual perspective or context with a different vision. This leads to the importance of identifying and mapping those variables and the influences of choosing certain parameters on the PD strategy outcome. With insights in simulated outcomes for given inputs, the uncertainties with their influences on the output (sensitivities) can be evaluated objectively and outcomes can be chosen that benefit the company strategy best, independent of e.g. stakeholder biases (*Figure 11* in the Maturity vision chapter, the right side). As general perspective, the company strategy is interpreted as directive. Levels, locations and natures of uncertainty are identified and elaborated on with use of the sensitivities of those uncertainties. Specified, denuded and identified perspectives, uncertainties and sensitivities enable deliberate decision making. This represents the vision, as was visualized in *Figure 11* (*Chapter 2: Maturity vision*).

Consequently, there is a need to simulate the impact of contexts on solutions to make deliberate decisions. The structured approach for selecting PD process structures tailored to a PD context and including insights in perspectives, uncertainties and sensitivities, is supported by a network visualization method. It enables simulation of outcomes (PD process

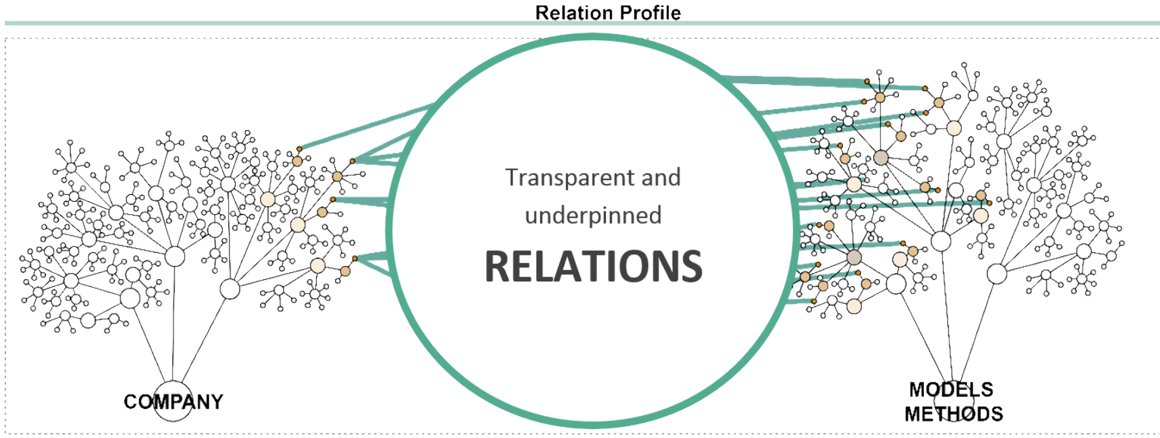

Figure 32 - Relating the context to (parts of) models and methods with use of functions

structures as solution) for certain inputs (specific context aspects). These are simulated with use of relation profiles, of which an example is provided in *Figure 32*. Development starts at identifying the context influences on PD structuring: the company context side (the left tree-visualization in *Figure 32*). These are related to detailed parts of existing models and methods, combined forming a reconfiguration as solution for the context.

The '*company context side*' of the relation profile

Input parameters as determined by *Nieberding (2009)* are used as input for the OSP. Project, product, organization and personnel are context aspects identified which influence the choice and selection of PD process structures. These form a starting point for the tree-network of company aspects, the company context side. The main aspects – with portfolio as extra included context aspect – contain more detailed aspects, as discussed in the design of the MTP. However, these may consist out of more detailed aspects or direct parameters that can be filled in with a company, which are needed for the OSP design. *Figure 33* shows a representation of such a '*PD context tree-network*' with the aspects of *Nieberding* and more detailed aspects, forming a tree-shape as represented in the left tree-visualization of *Figure 32*. Value creation from the company through product development practices forms the tree trunk, spreading out from the multiple PD context aspects to possible parameters for these aspects.

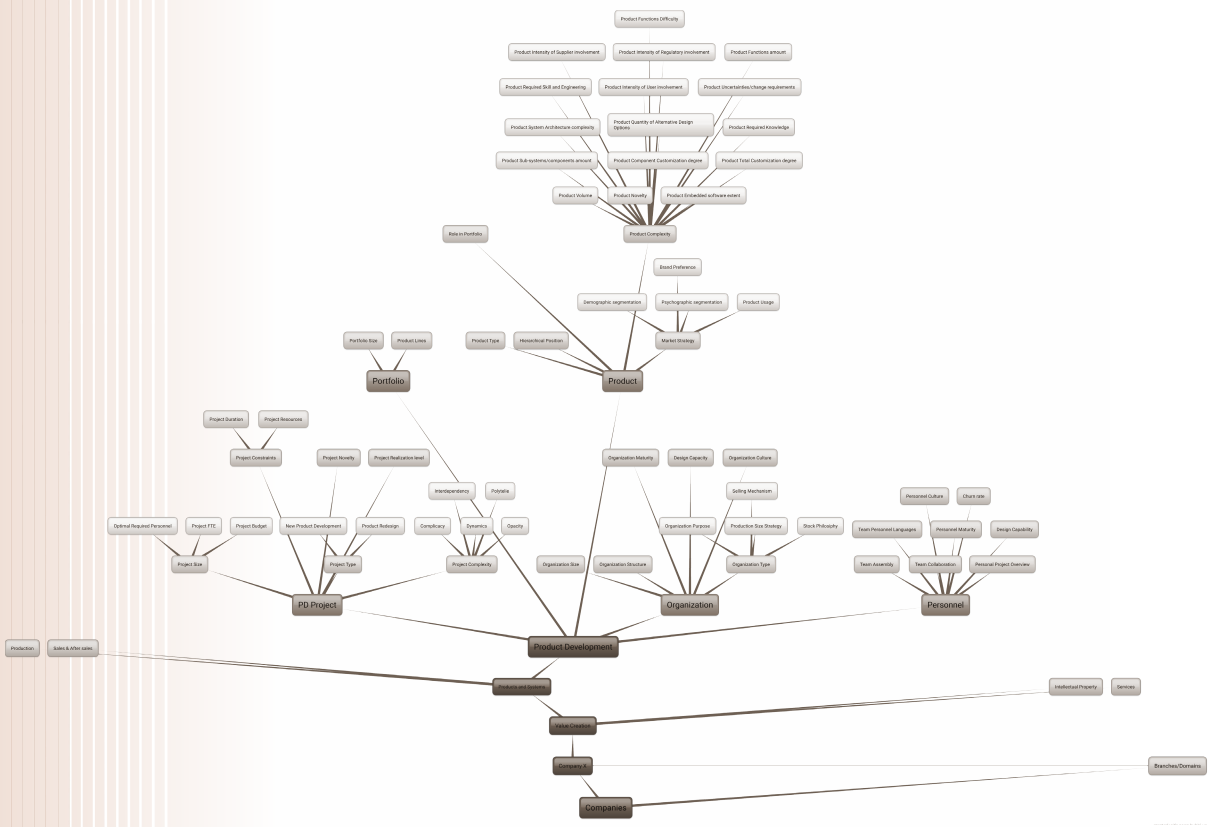

Figure 33 - Relating the context to (parts of) models and methods with use of functions

The '*PD process structuring side*' of the relation profile

For providing insights in the solution domain of PD process structures, benchmarking and comparison between model and method reconstructions is required. The OSP is designed to provide an unequivocal and underpinned topology of (parts of) models and methods to communicate differences between them to the stakeholders and enable objective comparison of them as solutions. Since developed models and methods for PD process structuring are often adaptations of older models and methods, indicates that they might be relatable and comparable. The OSP aims at creating such a topology with connections and relations between models and methods. Research exists on comparing models and methods with use of common characteristics. However, although for a large group of models and methods common characteristics may exist, others do not always fit in the created characterization rules. This aspect causes difficulties concerning requirement *4: providing the ability and flexibility to add and adjust (output) information.*

The OSP deals with comparing parts of models and methods through their '*reasons for existence*'. That is a more detailed and structured approach to enable benchmarking and comparison between models and methods. They often follow (some parts of) a logic process flow to go from product initiation to somewhere near product realization. Models and methods contain detailed elements (parts of models and methods) such as steps, blocks and lines between them, which exist for a certain reason the developer had for designing them. That reason for designing is the contribution of that model or method part to the logic PD process flow. Therefore, the reason for existence forms the function which the element fulfils within the model or method. Consequently, mapping the identified detailed parts and elements of models and methods with their overlapping reasons for existence, can form a topology shaped as a family tree with relations between different models and methods. By performing that, a '*model & method tree-network*' can be visualized.

Relating with use of functions

Relations must be more than a '*black box*' for the OSP objective. The next step is to relate the '*model & method tree-network*' (containing detailed parts of models and methods) with the '*PD context tree-network*' to identify impacts and influences between them. The steps occurring between that input and output are most important, since that information provides insights on 'why' the output is the result of the input. Therefore, the optimization strategy step cannot be seen as a 'black box' anymore – as done for the MTP development – but needs to be developed. This part of the OSP uses information from the MTP as input and creates information for the Change and Implementation Part (CIP) as output. It encapsulates the function of relating the specific company context with (parts of) existing models and methods, as described previously, and besides that, needs to show the information and choices behind the relations in order to provide insights for developing a change and implementation strategy based on the achieved insights.

Relations between context and structures need a step in between to split practical and theoretical knowledge and as common ground for relations. Creating relations between one side that is based on practical knowledge (concerning the specific PD process context) and the other side which is based on theoretical knowledge (concerning Design Science artefacts), sets high criteria on resources. This combination is difficult to procure. Therefore, one step in between is added to split the practical and theoretical required knowledge sides, for them to be filled in separately without influencing or requiring direct relations between them. The step in between can only consist of elements that both sides have in common, in order to connect them.

With that objective, the relations between context and structures are designed to focus on overlap in functions. However, multiple options for fulfilling that objective exist. The author identified three (3) elements on which relations can be determined. These are visualized in *Figure 34* and explained in further extend in *Appendix 8.3: Levels of relations.*

On a low level of detail with high uncertainty, relations can be created by finding best practices as common element. Company characteristics which are identified as 'best practices' are linked to models and methods used in that specific context. However, the source of best practices is limited and finding new best practices requires comprehensive research with a lot of uncertainties, variables and dependencies, since the resulting effectiveness and efficiency increases do not have to be resulting from the identified characteristics. This limits the reliability and availability of these relations. Furthermore, since there is no certain traceable link between them, the theoretical base to relate on this level is questioned (*Chapter 1.3.2: Limitations of maturity audit models and methods*). Therefore, it is preferred to relate on higher levels of detail in order to avoid uncertainty. The highest identified level of detail relates based on overlapping functions between company context and (parts of) models and methods. This level is identified by reasoning that the company context requires functionalities of structuring processes, and model and method parts provide functionalities for process structuring. These functionalities in the PD process context can consist of the same '*functionalities source*' or database. With previously stated, relating on this level is favourable to use for the OSP.

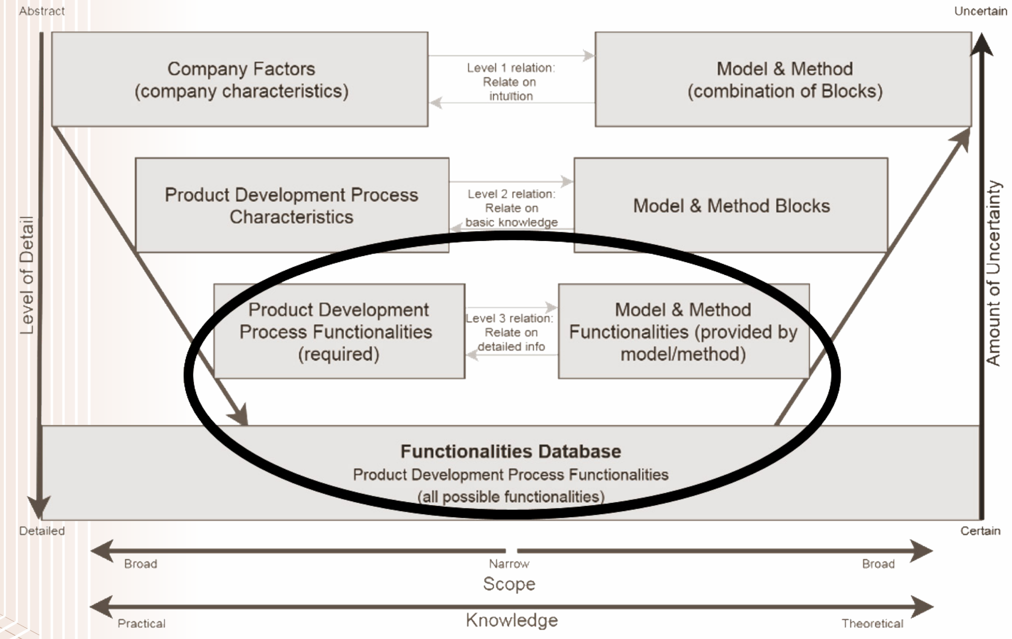

Figure 34 – V-shaped structure of the location and characteristics of relations between company context and models & methods

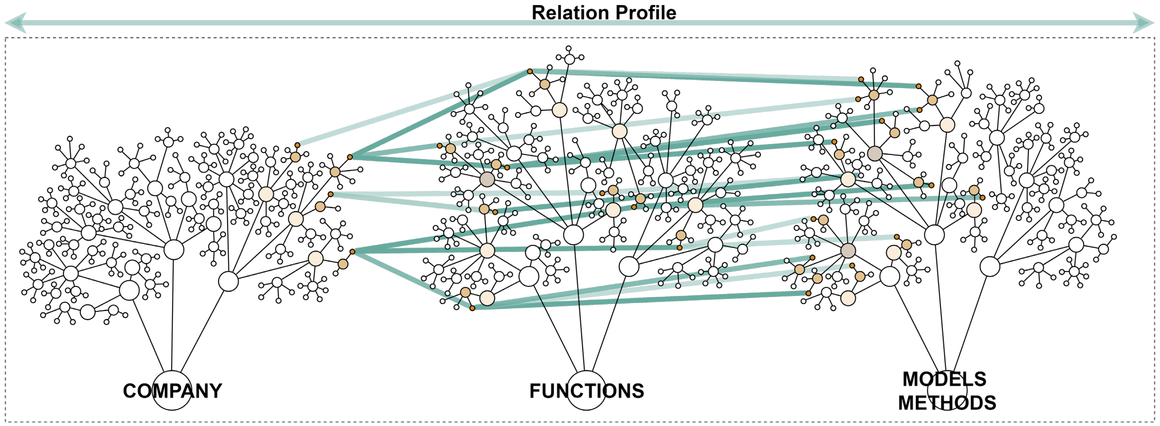

Figure 35 - Example of a visualized relation profile for a specific PD context (darker green lines represent uncertain relations)

Relation Profiles

After uncertainties and sensitivities are known, solutions can be tailored by using the company strategy to determine the appropriateness of the uncertainties selected and related to the solutions. With the functions between the PD context and PD structures, the visualized network looks as represented in *Figure 35*. Once a network is filled in with context information, a profile of the relations for that input can be created, since relations are known. These combinations of input information, relations and output information form a '*relation profile*'. Differences in input enable benchmarking between solutions. Simulating multiple solutions results in insights in sensitivities and impacts of uncertainties in the context.

Uncertainties and sensitivities do not automatically have an evenly distributed importance for a company or for stakeholders. Consequently, selecting and handling uncertainties and sensitivities in the relation profile for defining an optimized solution, is subject to perspectives and biases. For example, simulation (performed by the OSP design) may result in a selected range of related solutions (reconfigured model and method parts, reconfigured to form '*complete*' artefacts that suits the context). Imagunably, one solution may encourage exploration of new technologies, where a second solution allows extra managemental control during the project. Both solutions support the required functionalities, but uncertainties in e.g. *company size* after growth or influences of *higher organizations* allow these variations in solutions to exist. For deciding which solution to choose of the previous described example, stakeholders closely related to a R&D department in a company may favour the solution that actively promotes extra searches for innovative technologies before a concept is chosen for further development. On the other hand, stakeholders related to project management, would favour structures that enable close and detailed control and documentation of development activities. If these aspects seem conflicting and it is not effective and efficient to implement both – as the OSP does not propose that as solution – the company strategy is interpreted on the topics and a decision is based on that perspective. Continuing on the example, if the company strategy focuses on new product introductions to gain market shares in the coming years, this aspect may contribute to selecting the first structure as solution. If the company is subject to a higher organization which has as strategy to strictly measure and control process performances based on documentation, the second solution might me favourable. So, as perspective for filtering and prizing uncertainties and sensitivities, the interpreted company or organizational strategy is used as directive.

Structuring information for insights

Uncertainties and sensitivities are visualized and certain and uncertain results can be simulated for variating parameters for the uncertain aspects. An example of a resulting relation profile is visualized in *Figure 35*. This paragraph explores the information which can be achieved from such a visualized relation profile. At the left side, a start is made to fill in PD context aspects identified at the company. Uncertain context aspects can have darker green lines relating to the functions that one parameter (uncertain to say if this parameter represents the reality best or not) requires. An uncertain aspect with three possible parameters has all lines in a dark green colour from the parameters to the related functions, of which (an unknown) one represents the reality best. The related functions (uncertain or not) are related to model and method parts that provide a structure for fulfilling that function. Again, for darker lines it may not be certain if they are required in the real context, but they might be valid. Model and method parts that are related by '*certain*' lines (light green coloured), directly form effective (sub-)solutions for the related context aspects. Since it is certain what functions are required for the context, the model and method parts directly provide those functions, resulting in effective and efficient parts for the solution. However, model and method parts that have '*uncertain*' lines (dark green), need evaluation by stakeholders on effectiveness

and efficiency with use of the company strategy as perspective, as illustrated by the previous stated example. Possible solutions can be tried-out while simulating with changing one parameter of an uncertain context aspect. The outcomes can be benchmarked and context parameters used as input can be validated to match the company strategy and path to company success.

Objective mapping of PD context aspects as entity and PD process structures as entity, brings many additional advantages. The relation profiles of companies contain a large amount of information, resulting in the need for objective descriptions of contexts, functions and solutions. Firstly, the company context side enables an unequivocal description of PD context aspects and their uncertainties, objectively describing specific PD contexts. These can be benchmarked between companies, allowing for e.g. solution cross-checking as well. Set combinations of context aspects can form the basis for scenario creation, which enables more efficient input selection and scenario based simulation. Scenarios such as often used growth scenarios or new product development scenarios can be included for their impact on solutions. Secondly, the solution domains themselves – the models and methods with their characteristics, relations and parts – are identified and described objectively as well, based on the reason of existence. This aspect, as explained earlier in this chapter, allows (parts of) models and methods to be compared and benchmarked objectively. Finally, functions have commonalities as well. For example, functions related to communicating information can be specified by functions as '*provide a strict structure for documentation*', '*provide flexibility of languages used for communication in teams*' or '*provide management with (consumer) safety concerns during a project*'. These can be specified further, to a required level of detail that allows different outputs for differences in input of the OSP. This results in a '*functions*' tree-network, of which an example is provided in *Figure 36* for the more abstract function '*Minimizing total project costs*' that can be split in multiple other functions.

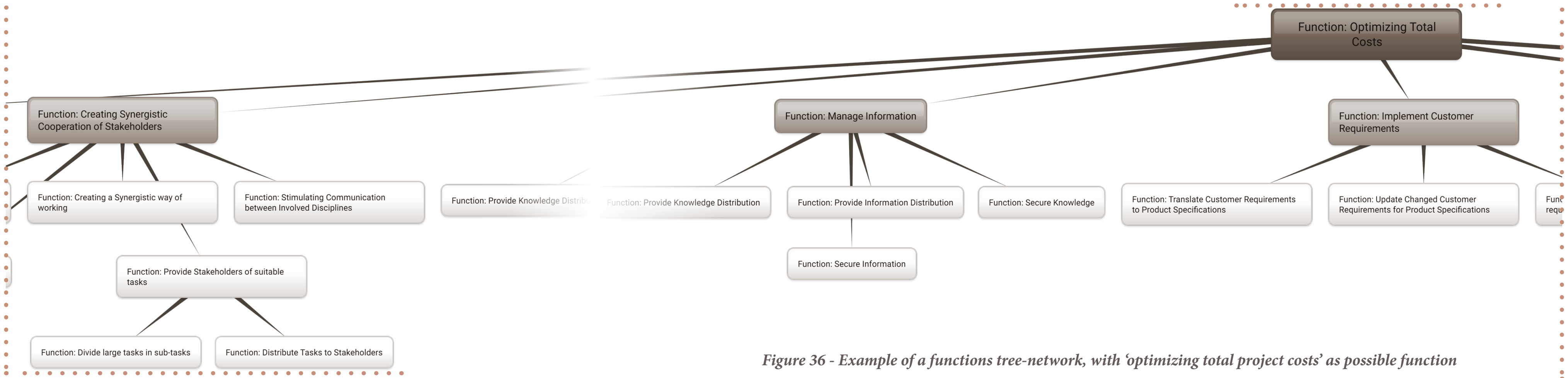

Figure 36 - Example of a functions tree-network, with 'optimizing total project costs' as possible function

This way of structuring functions enables and clarifies the three-shaped representation of functions in the relation profile as network visualization, *Figure 35*. Concluding, the ability to objectively describe contexts, functions and solutions provides advantages mainly for insights through benchmarking and classification or grouping of information.

Information visualization

For acquiring those benefits and functionalities, methods for visualization are required. This concept uses relation profiles to visualize and communicate influences between context aspects and process structuring solutions. The relation profiles can be seen as a combination of two networks related to each other through a (third) functions network. These are insightful due to inclusion of sensitivities and uncertainties, and due to the functionality of simulating, comparing and grouping information through classification. The strategy of the OSP to use one network for both, '*required functionalities*' and '*provided functionalities*', enables the search for effective and efficient reconfigurations of smaller parts of models and methods. Deliberate decisions on using a solution for the specific context can be based on insights created through comparisons / benchmarking, classifications and scenario simulations in relation profiles. However, this visualization needs to be performed first.

A network visualization method is used in the MTP design. As for the MTP visualization, for the OSP a digital dynamic network is proposed as tool for performing the activities leading to filled in relation profiles. The flexibility of adding new nodes in the three different network trees corresponds to the requirement of complementing and adjusting information when required. Besides the relation profiles providing visualized information, the benchmarking and comparisons of contexts, functions and structures allow for creating a big overview of separate entities as well. For example, the identified, objectively described and related structures can be placed in one big overview, to locate solutions and map Design Science practices. Since companies want to know beforehand what they can expect, such solution domain visualizations help them identify and communicate what solutions they can expect from the PDPMA model.

A mapped visual overview of the domain at one side of the relation profile – the '*context tree*' or '*structure tree*' – forms a sort of landscape as tool on which stakeholders can locate and map more specifically where they are and aim for, using optimization projects. Overlap and differences between context descriptions and model or method types can be shown through distances between them on the mapped landscape. Colour differences, sizes and labels help to structure the information in such a map, for example '*utilization in practice*' as parameter visualized. These maps ideally would be formed into a '*World map of PD Models and Methods*' tool or a '*World map of PD Contexts*' tool which in their turn can be used in industry and academy to communicate benchmarking results and focus of optimization projects in a uniform and visualized manner.

4.4 PDPMA model design: OSP

Required practical input information

As input information, context aspects, uncertainty, sensitivity and interpretations of the company strategy are required. For relating, the OSP requires practical information of the company context as input information. A broad range of possible detailed context aspects forms a comprehensive and flexible database of aspects – based on identified aspects by *Nieberding (2009)* as starting point – which can be adjusted or complemented. Within the company, experts of the practical process that is assessed need to identify the relevant PD context aspects for their company. Certain aspects can be selected by confirming the specific parameters of those aspects, directly related to functions. Uncertain aspects are taken into account as well in this process. By selecting a higher level aspect (to confirm existence in the specific context) with or without selecting multiple possible parameters of this aspect in parallel or after each other, show corresponding results in relation profiles. Previous steps can be performed with use of mainly practical knowledge. Interpreting the results for PD process structures as solution and translating differences in results into insights in sensitivities however, requires basic theoretical knowledge as well.

For selecting solutions, interpretations of the company strategy are required. After relation profiles are created and form a range of effective and efficient solutions, deliberate choices on them are required. This process requires more theoretical knowledge, since information from the company strategy must be evaluated and interpreted for concerned uncertain topics. The smaller decisions on detailed model or method parts need to be made by the company. For this, each identified solution needs to be clear for industrial stakeholders. A translation of theoretical information of solutions into practical information they understand, might be required. This results in decision makers knowing what solution corresponds to what uncertain parameter. Then they can interpret the company strategy's perspective on the specific parameter, to validate and indicate the value and reliability of that parameter. This process requires knowledge of the company's objectives and strategies, combined with detailed knowledge of the parameters of the context aspect. After translating theoretical models and methods for practical stakeholders to interpret the solutions, only practical knowledge remains that exists within companies and therefore increases its availability and realism for acquiring that knowledge.

4.4.3 OSP Validation

The objective of the OSP is to provide detailed insights in the relations between company context aspects at one side and (parts of) models and methods on the other side. This has been a complex requirement, since little attempts are performed in literature and the small amount of existing researches are based on best practices and have been criticized extensively for that. The OSP concept is designed with focussing on three different tree-networks for visualizing and structuring the elements '*PD context aspects*', '*required and provided functions*' and '*PD process structures*'. These are related with use of functions, since this has been identified as detailed common ground between the context and structures, resulting in relatively certain and clearly underpinned relations. The focus on required functions by the context, as well ensures effectiveness of proposed solutions for process structures, since only function providing model or method parts are used in the reconfigurations for solutions. Information structures in shape of the relation profiles with additional uncertainty, sensitivity and benchmarking functionalities allow deliberate decisions on structuring the specific process, supported by the company strategy.

Requirement validation

- '***Proposes suitable process structuring solutions***': The design fulfils this requirement with the use of relation profiles, tailoring solutions to the company context.
- '***Detailed solutions***': The tree-network visualization methods enable a high level of depth with still showing the 'roots' behind nodes in the network.
- '***Insights behind solutions, towards a practical tool***': Visualization of the context, the functions and the solutions with the relations between them, allows tracing solutions back to their origin. Digital visualization of the dynamic relation profile networks allows transparent utility and high applicability of the OSP. Splitting the theoretic and practical sides into two separately adjustable information sides, increases the practicability of the networks.
- '***Flexible information***': The OSP consists of three networks that can be adjusted, complemented and used separately as well. The dynamic network visualization method allows flexible adjustment of information, contributing to a sustainable OSP design. Content can be altered without consequences of damaging the general functionalities.
- '***Applicable to the target group***': The input parameters are flexible and for now based on applied ideas of Nieberding (2009). The flexibility of the design allows adaptation of visualization and presentation of inputs and outputs, to tailor it more to the needs of stakeholders.

Decision validation

Focus for creating relations is put on overlap in functions. It is stated that relations on function level are preferred above relations based on e.g. best practices. However, not all information for defining functions may be available, resulting in a gap in information. As option, a combination of relations can be used. Either way, a proven relation on a higher level of uncertainty initiates the existence of one or more relation(s) on lower levels of uncertainty. That is the case, since, if a certain model or method characteristic is proven to be value adding to a company (proven by best practices for instance), there must be a corresponding function (or set of functions) which add(s) that value. The insights to subtract the function may be a incomplete. Concluding, the theoretical base to proof the relation is best provided with relations on function level and extra attention is required if relations are identified with only using the higher levels.

Separated '*trees*' form tools for benchmarking and efficient data handling. An example to locate a company's situation or solution on and benchmark between closely related options is stated before, but imaginably other literature sources provide tools for that as well. However, since relations and descriptions of models and methods and specific contexts are often characteristic-based, this OSP adds value. The two opportunities for a '*context*' and '*models and methods*' topology (or '*World map of X*') are based on the actual functions they provide or require, which is different from the approach of earlier literature and researches where topologies are based on top-down characterization (where the topology is defined beforehand and aspects are made to fit), resulting in the possibility that contexts or solutions do not fit within the topologies. Instead, this research advocates a bottom-up classification method, where the topology is flexibly defined by the aspects in it.

The functions are visualized as nodes in a tree-network, instead of as lines / connections which can be an alternative. In the relation profile, the functions are represented in a tree-network of connected functions. The functions form the nodes in the tree and those nodes can be connected to the nodes of the '*context*' tree and '*structures*' tree. A different solution could be to not have the additional third '*functions*' tree. Then the functions can still be used, but as connecting elements, as line between a '*context*' node and '*structure*' node. This option is evaluated, but does not support the fact that one '*context*' or '*structure*' node might be connected trough multiple functions to same or other model and method parts. For visualizing all nodes together with optionally multiple lines as functions, would be disorganized. Furthermore, the structuring of function is levels and a topology would be more difficult if it concerns only lines, then it is as combination of nodes and lines (the tree-network). Therefore, this tree-network is evaluated as most suitable option to visualize and represent the functions as relations between contexts and structures.

A dynamic, digital tool for visualizing the relation profiles and network is chosen. The decision for using a digital tool for dynamically visualizing the relation profiles and networks is explained in the previous design chapter, as well as in *Chapter 4.3.3: MTP Validation*. The flexibility and dynamic information structuring functions are the main reason that this decision is made. An earlier mentioned downside could be the long development time for such a comprehensive simulation too. Other opportunities for visualization exist, but are not likely to meet all functionalities of flexible and dynamic visualization and simulation. In the future, they need to be analysed if the concept is designed in more detail or iterations are created.

4.5 PDPMA model design: CIP

4.5.1 CIP Directive

The Change and Implementation part (CIP) in this research is delivered as design brief for Industrial Engineering specialists. After performing the OSP, a defined aspired PD process structure for the specific context is the input for the CIP design. Now, the translation from theoretical and practical insights to implications for practice is required. The CIP design fulfils that role. However, the CIP design will not be developed in detail during this research, since focus is on the specialization of the author (which is in the PD process domain and optimization of its maturity). Therefore, the decision is made to direct and support future developers and specialists in developing change and implementation advices as results of the PDPMA model. By doing so, the change and implementation part is considered a design problem. Consequently, a design brief can be stated in which requirements are given. In other words, this research treats change and implementation as a '*black box*' with specified input, output, functions and requirements. The PDPMA model objective is to provide objective insights in optimizing PD processes in industry, in which change and implementation are the means, not the goal.

Contexts differ per company and require specified and tailored change and implementation approaches. Besides the specialization of the author and the change and implementation topic being the means and not the goal, the certain change determines the value of the optimization project for the company. That makes it a required topic to discuss in this research. Without change, no implemented insights and no realized optimization is achieved. However, the optimized envisioned situation differs per specific company context. Since the change and implementation elaborate on the results of the OSP, the specific change activities, implementation strategies and advice will differ per context as well. This advocates the need for a tailored change and implementation strategy with advice as deliverable for specific company contexts. Nevertheless, developing such deliverables for this research is out of scope, since no specific context is used. Consequently, this field of knowledge is not focused on and is represented to a minor extend in this research.

4.5.2 CIP Design brief

Summary

The Product Development Process Maturity Audit (PDPMA) model provides insights for companies in optimization of their Product Development (PD) processes. It consists of three steps that are performed in sequence. First, a Maturity Test Part (MTP) validates if performing the optimization project is worth the costs, resulting in a 'go/no-go' decision for further PDPMA model execution. Secondly, an Optimization Strategy Part (OSP) defines desired PD process structures tailored to the specific context. It provides insights that are required for selecting an effective and efficient structure for the specific context the PD process is performed in. With the output of this OSP – an aspired PD process structure – decisions on change and priorities are required. After that, the company needs and advice on how to implement these changes effectively and efficiently in their context. These last two functions are provided by the Change and Implementation Part (CIP). This design brief provides information for CIP development.

CIP Objective

Provides companies with insights in how to effectively and efficiently change PD processes towards the desired situation as identified by the OSP

CIP Requirements and wishes

The CIP supports operational change with prescriptive tools for practical use in the product developing industry for decision making on change. Three requirement sections are identified and first ideas are stated to contextualize the abstract vision on the solution domain for this design problem. Stated ideas for the three requirement sections are no fixed requirements, but form illustrations for solution domains.

Stakeholder requirements

- The CIP focuses on supporting '*operational change*' in PD contexts primarily – above strategic, cultural and political changes or other contexts – this can be expanded in the future if the PDPMA model is indicated as being useful for application on a larger scale
- The CIP uses tools that have a prescriptive nature, so steps are easily translated to, communicated to and repeated by the stakeholders
- The CIP provides information in an understandable language
- Provided insights by the CIP are available to and usable for all decision making stakeholders of PD process optimization, interested in the insights

Change and Implementation requirements

- The CIP contributes effectively and efficiently to the objective of the PDPMA model
- The CIP must focus on implementation of the OSP output (a process structuring solution) in the specific context of the product developing company
- The CIP creates its output from an input domain that entails all possible OSP outputs
- The CIP provides insights in the differences between the current process structuring situation and the aspired process structuring situation as presented by the OSP
- The CIP validates the possibility of changing context aspects in the future of a company
- The CIP provides insights in priorities for change to assure effective change
- The CIP provides insights in efficiency of specific change strategies for certain contexts
- The CIP provides a structured approach for developing the advice and creating the insights which can be performed efficiently and effectively in different PD contexts
- The CIP design is future-proof and information can be adapted or complemented as required in the future

Advice communication requirements

- The CIP provides a transparent and underpinned description of the current situation
- The CIP provides a transparent and underpinned description of the aspired situation as resulted from the OSP
- The CIP provides a transparent and underpinned description of the insights behind the designed aspired situation
- The CIP provides a transparent and underpinned description of the priorities for effective change in the specific context
- The CIP provides a transparent and underpinned description of identified required activities and tasks for the specific company to efficiently achieve the aspired situation

'Nice-to-haves' of the CIP design solution(s)

- The CIP provides the option to guide the implementation process in a specific company until the aspired situation is achieved
- The CIP offers different levels of end results which can be addressed dependent on the budget of the company
- The CIP provides a measurement tool that is able to indicate success levels of implemented changes
- The CIP provides a transparent and underpinned description of the Maturity vision

Indications for useful methods

Many existing methods can be useful for fulfilling these requirements and do not need to be fully developed from scratch. These form indications and illustrations of opportunities for the solution domain of the CIP and inclusion is no requirement.

- Methods for comparing current to aspired situations
  For example, by using gap analysis methods
- Methods for validating feasibility of changing contexts
  For example, by validating change feasibility of identified context aspects from Nieberding (2009)
- Methods for prioritizing change activities
  For example, through cost-benefit analysis or with Activity-Based-Costing methods
- Methods for separating levels of results
  For example, with use of selected Work Packages
- Methods for communicating insights
  For example, with visualization tools, management letters or cause-effect statements
- Methods for Capability-based planning
  For example, with use of the later stages of Capability Development Plans
- Methods for Implementation plan and Change Management Strategy development
  For example, by evaluating existing implementation plans and change management criteria
- Methods for building strategic plans
  For example, with use of Key Component Comparison or Barriers and Enablers Identification
- Methods for communicating advice to companies
  For example, with Management Letters or Task Specifications and Planning frameworks

Indications for useful CIP steps

Existing models for change execution can be used as inspiration for the steps performed within the CIP design(s). *R.T. By (2005)* evaluated three often used models for executing change (*Appendix 8.4: Change and implementation theory*). Herein he compares model parts to form a more complete list of required steps for effectively and efficiently executing change. Possibly, for specific context certain steps have are more valuable than others. Selecting steps to perform in a specific context must be done with effectiveness and efficiency of performing the CIP in mind. Provided steps can form an inspiration for the steps that the CIP design includes.

Notes for developing change activity plans

Decisions on prioritizing and selecting specific change activities need to be made in collaboration with practical experts in the context. The effectiveness and efficiency of a change and implementation strategy depend on the specific context it is applied to. Uncertainties and sensitivities make impacts of change on the real situation unpredictable. Furthermore, the company strategy provides an indication of the contribution of specific change activities for achieving the company objective. With that in mind, detailed decisions on budgeting and prioritizing activities for change require the practical insights of the stakeholders and interpretation of the company strategy. For doing so, visualization and communication of the small, selected change activities is required to include the stakeholder and company strategy in that decision making process. Priorities and activity sequences can be suggested for the company by experts, but need to be validated by stakeholders. This can be performed with use of a simple analogue tool of which a representation is provided by *Figure 37*. Filling this in allows stakeholders to provide the practical knowledge and validate suggested change activity plans.

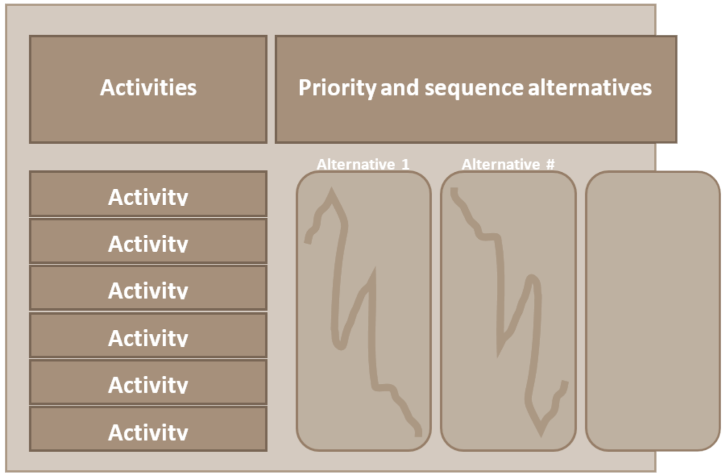

Figure 37 - Representation of a prioritizing and sequencing tool for change activities

5 Concepts summary

Chapter content

This far, the report used a top-down structure for explaining the designs. The resulting detail in the report is beneficial for the academical reasoning and allows inclusion of underlying theory and reasons behind the designs. However, providing the details can be detriment of the understanding of the main ideas. Therefore, this chapter shortly summarizes the designed PDMO model and PDPMA model oncepts to explain them from a more abstract perspective, rather than repeating previous detailed design explanations. The author includes this chapter with the intention to contribute to interpretation of the designs by the reader while guiding all detailed puzzle pieces into place to show the complete image before continuing with the future prospectives and concluding chapters.

5.1 The PDMO model

The Maturity Landscape component (MLC) identifies all maturity dimensions relevant in a company context. A topology of maturity dimensions is used in a visualized network, of which company success (company maturity) forms the core (the '*trunk*' of the maturity context '*tree*' in *Figure 38*). Supporting maturity dimensions contribute to achieving company success and maturity factors contribute to the maturity dimensions. Many levels and locations of maturity can be identified with the maturity topology network, representing the maturity context in a company. The MLC is represented in *Figure 38* as the green block, with the tree as illustration of the maturity topology network.

The Maturity Route component (MRC) supports the user in selecting a specific process for optimization. The highest objective is company success and the maturity dimensions related to the context are copied from the MLC. These form possible targets for optimization. However, success of a maturity factor is a required but insufficient condition for success of a maturity dimension. Therefore, deliberate decisions are required for selecting one dimension to focus on for optimization, effectively and efficiently leading to increased company success. This is achieved by comparing the maturity levels of maturity dimensions by using radar chart visualizations. With interpretations of the company strategy – which represents and describes company success – an aspired maturity level per maturity factor can be indicated objectively. Combined with the current maturity level of the factor, the gap indicates the need to improve that specific maturity factor. *Figure 38* represents the MRC in the blue block, with the stacked radar chart visualizations representing multiple locations and levels of maturity dimensions with their contributing factors.

Subsequently, the identified maturity factor requires optimization. This step is guided by the Maturity Optimization component (MOC). The function of optimizing a specific maturity factor can be fulfilled with any suitable maturity audit model, since that factor represents a specific process within the company. Many maturity audit models exist for optimizing processes, but they primarily target production (or manufacturing) processes and sustainability, software and Information Technology (IT) related processes. Maturity audit models that target PD process optimization effectively and efficiently are limited. After the maturity factor for optimization is identified, selection and execution of an appropriate maturity audit model is required and executed in the MOC. A representation of the MOC is provided in *Figure 38* by the brown block.

5.2 The PDPMA model

As first step, the PDPMA model guides an accreditation decision (*Figure 38*, the left side of the brown box). The Maturity Test part (MTP) is responsible for this step and evaluates the added value of performing PD process optimization. Two validations are performed within the MTP design: *(1)* it validates if PD process optimization is appropriate for effectively and efficiently achieving company success and *(2)* it validates if PD process optimization can be performed usefully in the context. The first validation is executed with use of the MLC and MRC designs and the second validation roughly relates the context to PD process structuring solutions, including uncertainty and sensitivity.

With a positive outcome of the accreditation decision based on the MTP, the Optimization Strategy part (OSP) is executed (*Figure 38*, the top side of the brown box). This step relates the detailed context aspects with parts of existing models and methods from the Design Science domain. Matching those sides based on functions, allows detailed and relatively certain relations between both. Furthermore, it allows the practical knowledge from the context side and the theoretical knowledge from the Design Science side to be adjusted and complemented separately and independently. The OSP results in a relation profile for a specific company context. The relation profile has detailed context parameters relevant for the context on one side, the related parts of models and methods on the other side and overlapping functions in between. The related parts of models and methods are reconfigurations of existing models and methods, forming the solution domain tailored to the context. Scenario simulation and benchmarking are among the opportunities after further development of this concept part.

The output of the OSP forms the input for the Change and Implementation part (CIP) of the PDPMA model (*Figure 38*, the right side of the brown box). The CIP translates the outcomes of the OSP into a transparent, underpinned and structured advice for change and implementation of the optimization solution. This is performed with respect to priorities of implementation activities in the company context and can be tailored to the needs of the company. Although the outline of the CIP is known and developed, change and implementation are fully dependent on the company context. Therefore, this research only provides a design brief comprehensively stating the objective, requirements, wishes and indications for solutions and change execution steps for the CIP. Per context, a suitable solution for the CIP is required and can be developed by the Industrial Engineering domain, enabling translation and communication of PD process maturity audit results.

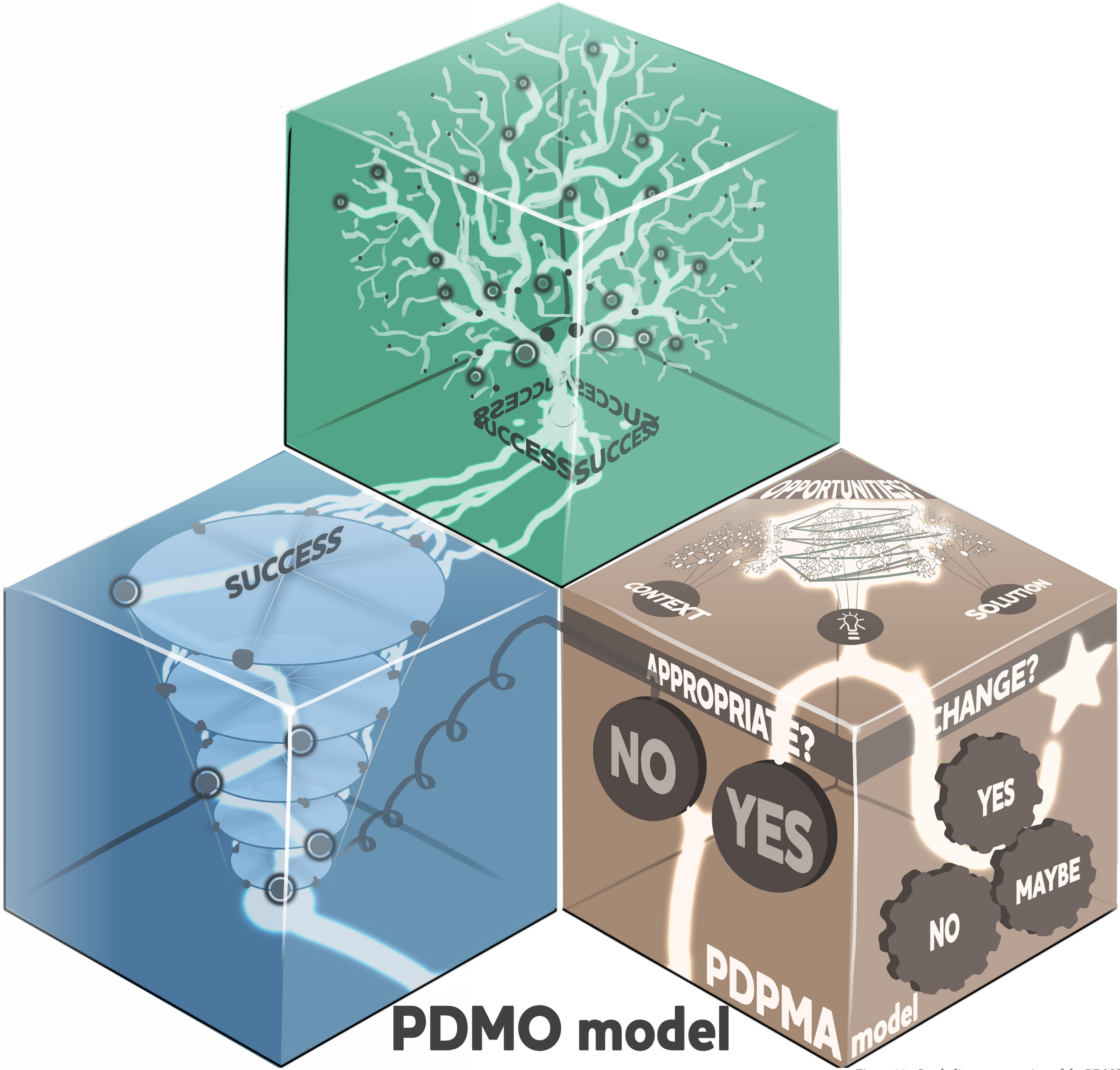

Figure 38 - Symbolic representation of the PDMO and PDPMA concept model

6

Future prospects

Chapter content

This chapter describes the required resources and steps for making these model concepts into practical tools. The concept models require resources and partnerships for development into practical tools. Costs for further development are estimated at €60.000,-, and yearly operation at €100.000,-. For the PDMO model, MLC needs further complementation and a connection to the MRC. A MOC database for selecting maturity audit models is required and all need to be developed into practical tools. For the PDPMA model, the MTP requires connection to the MLC and MRC tools. The MTP and OSP both require development of the network visualizations' content and relations. The CIP requires development per context, following the stated design brief. After development, the users can utilize the PDMO model if the dimension for improvement is uncertain, or the PDPMA model if PD process optimization is initiated. Work packages allow flexible audit step selection for the context and provide contextualization for communicating optimization projects. Marketing and communication activities lead to model operation where user needs and improvement potentials encourage model optimization. Self-learning functionalities and other beneficial opportunities can be implemented and execution and operation of the PDMO and PDPMA models are worth the costs compared to the created value.

6.1 Resources for development

This chapter assumes that the PDMO and PDPMA model concepts as presented in the design chapters are accepted and selected to develop into detailed designs and final tools for utilization in industry.

Concept models require resources and stakeholders (or partners) for development into a practical tool. Therefore, both concept models first needs acceptance, awareness and support from an external organization. They require specialistic stakeholders giving attention (and resources) for developing the PDPMA and PDMO model into practical tools for execution in industry. After that, the models require acceptance and awareness from the initiated target group to be utilized in such environments. *Table 7* provides a rough overview of estimated, segmented costs. Full development of both the models, roughly costs *€60.000*. The utilization costs per year mainly exist of labour costs for project execution, improvements and maintenance practices. Project and execution are performed at the facility of the customer, resulting in relatively low facility and overhead costs. These costs reflect the complete development and do not take into account that it is optional to start with utilizing the model in an earlier stage of development to spread start-up investment costs. However, since development costs are not exceeding yearly operating costs, assumed is that this strategic option is not necessary.

Table 7 - Cost specification for cost drivers

Segment	Major cost ownership	Estimated expenses	Explanation
Design	Indirect labour for external resources	€15.000	For external validation and case executions
1 time start-up costs	Direct labour for designing, validating, etc.	€20.000	€35.000 * FTE / year, for 1000 hours
	Tool development costs	€25.000	Complex software tool
	Total start-up costs: €60.000,-		
Facility	Facility costs and overhead	€10.000	10% of total operating costs / year
Operations	Design expertise for improvements	€17.000	€34.000 * FTE / year, 0,5 FTE
Continuous costs	Maintenance expertise for ensuring sustainability and availability	€13.000	€26.000 * FTE / year, 0,5 FTE
	Human resources, marketing and optimization project execution	€60.000	€30.000 * FTE / year, 2 FTE
	Total operating costs per year: €100.000 for PDPMA model utilization		

6.2 Models as tools

6.2.1 The PDMO model as tool in industry

The content of the MLC needs to be defined and complemented. The Maturity Topology network is used in the MLC as database to select applicable and suitable maturity dimensions of and structure them as seen fit for representing the specific company context. This database needs to be complemented with all possible maturity dimensions representing current knowledge on the topic.

The MRC needs to be connected to the output of the MLC. The Maturity Profile of the MRC needs to receive the MLC information as selected and structured by the company and uses that as input for the Maturity Profile. For every maturity location, the tool must enable setting a maturity level for the current situation and an aspired maturity level with the certainty of it. Overviews of the radar chart and structuring options are required for providing insights for maturity routing, the functionality of the MRC. Then the user – the target group in collaboration with an external company – can select a maturity factor as focus for optimization.

Since the MOC can be any existing maturity audit model or method for specific maturity dimensions, a MOC database needs to be developed storing these. The users must be able to filter and select suitable audit models for a specific maturity factor from a selection of validated, verified and optionally suitable audit models. For structuring this database, the same structuring strategy as used for structuring models and methods in the PDPMA model can be used. This is focused on taking the steps within the model or method and use the '*reason for existence*' to find the function of such a part. Classification of these functions can result in an underpinned and insightful structure of maturity audit models in the MOC.

All need to be developed into tools. A suitable software solution for the Maturity Profile needs to be found and the Maturity Topology network must be integrated as input of this Maturity Profile. Visualization methods (highlighting, colour and size coding, etc.) for structuring information (uncertainties, aspired maturity levels, current maturity levels, selected maturity dimensions, etc.) need to be developed and implemented in the software. After the MOC is developed, it must be integrated in the software solution as well where outputs of the Maturity Profile can be linked to relevant maturity audit model functionalities from the MOC database.

Work packages[32] allow flexible audit step selection for the context and decrease complexity of the PDMO model understanding. As for the PDPMA model, the PDMO model would benefit of dividing the activities in work packages . The customer can select appropriate packages for their context and suggestions for activities by the external organization can be explained and communicated in an unequivocal way.

6.2.2 The PDPMA model as tool in industry

The tree-networks' contents need to be developed and related, representing the current knowledge on the topic. For the PDPMA model to be developed for utility, the '*context*' and the '*PD process structure*' tree-networks must be supplemented and updated to achieve and preserve the quality level representing current knowledge on the topic. Both networks need to be connected properly through a '*functions*' tree-network, providing realistic relations on function level if possible and on characteristic level if necessary.

The Maturity Landscape component (MLC) and Maturity Route component (MRC) need to be developed for using their outputs in the MTP. The CIP needs to be designed to fit the design brief and other PDPMA model parts and objectives. After a validation, the developed PDPMA model tool(s) need(s) to support required CIP functionalities as well.

A suitable software solution for the relation profile tool needs to be found and the tree-networks with visualization methods (highlighting, colour and size coding, etc.) for structuring information (uncertainties, relations, changeability, etc.) need to be developed and implemented in the software. After the CIP is developed, it must be integrated in the software solution as well where outputs of the OSP are usable for the CIP functionalities.

After these developments, the target group can use the PDMO model (in the optimization strategy order of MLC, MRC and MOC) if the dimension for improvement is unsure, or the PDPMA model can be executed (with the test strategy – MRC to MLC steps – of the PDMO model built in the MTP) if PD process optimization is initiated. However, not all potential users would need all steps as comprehensively executed and some may be able to perform parts of the model steps themselves. Furthermore, these models can come across as being complex to look at as a whole. For both reasons, development of Work Packages can be valuable to make sub-divisions of more detailed activities. An example of such work package structure for the PDPMA model is shown in *Appendix 8.5: Work packages example.*

32 Work package: "*unit of work or job that is (1) clearly distinguishable from other such work packages, (2) has scheduled start and completion dates with interim milestones as applicable, (3) has a relatively short time span subdivided to facilitate measurement of work performed, (4) has an assigned budget, and (is integrated with the schedules of related work packages*" (BusinessDictionary, 2019).

6.3 Model operation

Marketing and communication activities for attracting the target group are required. After development, awareness and communication to potential users is necessary. Many maturity audit models exist and – although this maturity audit model is the first to be fully focused on the PD process and includes many unique and valuable extra steps – companies will not automatically know of its existence. Therefore, marketing and communication are required.

Operation of the PDMO and PDPMA models depend on the customer needs. The main operation of the PDPMA model starts, when customers are reached and an improvement project is initiated by them in cooperation with the external organization executing the PDPMA model. Such improvement project can be identified and validated for the context by the PDMO model (MLC, MRC then MOC), or the PDPMA model (MTP, OSP then CIP) can be executed if PD process is the initiated dimension to optimize.

The customer needs and improvement potentials are tracked during use for sustainability and improvement of the models. During use, improvement potentials and changing target group requirements need to be tracked and criticized for added value and implementation in the PDMO and PDPMA models. This ensures sustainability of the models and continuous appropriateness and value for the target group.

After use, self-learning functionalities can be developed in the tool that allow auto-suggesting changes and updates. Since this designed concept is only an illustrative starting point of a possible model and relations and dimensions are based on a limited source of existing literature for PD influences, they need to be updated and supplemented for fulfilling the requirements. Dynamic networking provides insights in the amount of uses per dimension and in the future may automatically '*think*' about the use of a node or relation, suggesting to delete not used ones or actively suggesting often used relations. This characteristic of networks allows for a self-learning capability of the network in the far future after developing the model further and applying it to multiple contexts.

A rough estimation for the value creation of model operation can be made. After development of the PDMO and PDPMA model, they are executed. Model operation results in value creation, measured for example in the shape of money. An estimation of the gains allows comparison with the costs for resources for development and execution. Income from model execution is often expressed in measures of time. However, the time required per optimization project can not be stated previously, since tasks and activities are tailored to fit user's needs. Consequently, one quantification for income per optimization project can not be given.

6.3 Model operation

Therefore, an assumption is made that model operation – the value creating process – is reasonable to provide one full-time function (*1 FTE*[33]) in total. This can be divided over the level of specialization and working hours of employees. For example, one full-time (*1 FTE*) model execution specialist costs the same as two part-time (*0.5 FTE*) specialists. Standard income – gross wage – from a maturity audit specialist is estimated at *€125,-* per hour (costs for the client) and one full-time position acts for *2040* hours. The multiplications result in a gross income of around *€250.000* per year of full-time model operation with the given assumptions on wages. Taxes (or *VAT*) are variable per year, location of the executing company and client, which needs to be taken into account for determining more detailed quantifies for operational value creation after the decision is made to examine operation in more detail. However, this short abstraction of numbers implies that PDMO and PDPMA model execution is worth the development costs of *€60.000* and one year's operational costs of *€100.000* combined. A large buffer of approximately *€100.000* exists if estimations for the first year are inaccurate. In conclusion, executing and operating the PDMO and PDPMA models are worth the costs compared to the created value.

33 Fulltime-equivalent (FTE): "*the ratio of the total number of paid hours during a period (part time, full time, contracted) by the number of working hours in that period Mondays through Fridays*" (BusinessDictionary, 2019).

7 Concluding remarks

Chapter content

This chapter contains the sub-chapters that state the validation, discussion, recommendations and conclusion of this research. The validation globally validates the validity of the research results – the designed concept models – and the research process. First, standards for validation techniques are explored and applied to the maturity vision, the PDMO concept model and the PDPMA concept model. Thereafter, the development process executed for this research is evaluated. The proof-of-concept models form the research results. These are discussed for their value and sensitivity to assumptions and limitations. It discusses the research on a higher level of abstraction than previous chapters, moving towards an answer on the research question. This research encourages future research, as stated in the recommendations. All previous report content is concluded, moving briefly from the initial knowledge towards and overview of most important findings.

7.1 General validation and evaluation

This chapter globally validates how valid the designed concept models are, how capable they are of fulfilling their objectives and how effective and efficient the development process is in this research' context. It starts with discussing a standard validation approach with a selection of validation techniques and applies them to the three top levels in the design hierarchy. First the maturity vision is validated, followed by the PDMO model validation and the PDPMA model validation. Thereafter, the development process is evaluated.

7.1.1 Specifying the basic design validation approach and selected set of techniques

For encapsulating the validities of the designs, the '*Evaluation Table*' of *Sargent (2010)* is filled in to form an overview of findings and used validation techniques. *Table 8* explains the selection of validation techniques, elaborated on further in next paragraphs. Underpinning of results through rationalism and comparisons to other literature are in the centre of this validation chapter, contributing best to validation of the theoretical backbone throughout this research.

Table 8 - Evaluation table for validity and verification, applied from the defined standard of Sargent (2010)

Item	Validation Techniques	Justification of techniques
PDPMA & PDMO model validation	**Face Validity**	Suitable for validating if clear results are assessed as being reasonable and logic sense by internal process experts
	Rationalism	Suitable for validating if steps within the model are clearly stated and underpinned based on logic sense
	Traces	Suitable for validating if steps within the model follow logic sense and do not show gaps
	Comparison to other Models	*For the PDPMA model:* Suitable for validating if approach is sensible compared to Maturity Audit models for other maturity dimensions *For the PDMO model:* Suitable for validating if maturity dimensions in topologies are comparable to those identified by other researches
Maturity Vision validation	**Rationalism**	Suitable for validating if statements and objectives in the vision are clearly stated and underpinned based on logic sense
	Comparison to other *Literature*	Suitable for validating if other experts on maturity optimization support the statements and objectives in the vision

7.1.2 Validating the maturity vision

Relevant validation techniques

With appropriate validation techniques, the design results, statements and design entities are validated. This chapter discusses the validation techniques as identified by *R.G. Sargent (2010)*, which are appropriate for validating the maturity vision. Thereafter, design results and statements are seen as design entities, validated for fulfilling the main objective.

Validated entity: Company Strategy as directive

As main statement, the maturity vision determines that the company strategy is the perspective from which decisions for optimization need to be made. Due to uncertainties in the company context and their sensitivities on decision results, perspectives and biases have their chance to influence the decision making process. As *D.K. Pace (2004)* states to the point:

"Sometimes the 'best' results are too costly, would take too long to obtain, or have some other impediment, so 'appropriate' results that have adequate fidelity for the intended use of the model or simulation serve as the referent".

Decision making on what is appropriate for the intended use of the model or simulation in a specific context is required and involves many stakeholders, perspectives and biases. The maturity vision is designed as vision above the stakeholders' individual objectives and biases and puts focus on decisions contributing to company success. For that, the company strategy defines what '*company success*' entails and determines the level of '*best*' which is appropriate to the context. This sounds as a reasonable vision.

Results of the research by *Xiaoying, Qianqian & Dezhi (2008)* support the maturity vision. A suitable validation technique is comparison to other models. The vision is compared to the ideas behind a model for describing relationships between business performance, business strategy, information system strategy and information system performance (*Xiaoying, Qianqian, & Dezhi, 2008*). They describe these relationships through a conceptual model. They conclude that achieving improved business performance cannot be guaranteed with improving a single one of the supportive dimensions – there are no factors impacting business performance solely – and that alignment of strategies may contribute to increase business performance in some contexts. So, not one single dimension is responsible for business performance and the amount of contribution after optimization depends on the context. These findings fully support and recognize the value of the developed maturity vision which states that it might be sensible to identify other dimensions – beyond business strategy, information system strategy and information system performance – which combined contribute to the business performance dimension (labelled as company '*success*' or '*maturity*' in this research) and indicate their contribution to success. This would create a more complete image on impacts of dimensions in specific contexts on company success, enabling indication and identification of best dimensions to target for optimization.

Validated entity: Maturity factors, required but not sufficient for success

An often mentioned statement in this research is the role of maturity factors and their contribution to higher level success. The vision builds on a set of maturity factors contributing in their way to the higher maturity dimension, with company success or company maturity as highest dimension. As shown in the previous paragraph, the research of *Xiaoying, Qianqian & Dezhi (2008)* supports this vision.

Only serendipity[34] is an exception of this statement, but this does not comply the research scope. Besides the comparison to other models as validation technique, rationalization is a suitable in this situation as well. For the assumption of PD process maturity being a required but not a sufficient condition for PD success, its contrary has been proven in industry as well. For example, if the Swiss inventor George de Mestral would not have walked through the Alpine where '*burdock*' plant seeds stuck to his clothes and dog's fur and if he did not have been annoyed by stuck zippers in his life, he did not have the inspiration and design idea to develop the successful Velcro product (*VELCRO, 2019*). Considering that some successful products are developed without intended, structured and organized processes, accidental discoveries can lead to a product development success. These developments based on chance encounters, are labelled as serendipity. But, such successes based on chance appear incidentally. As this research scope and the research of *Xiaoying, Qianqian & Dezhi (2008)* focus on company or business success as leading, no product development company would ever agree on the risks of that, and steer on coincidences, chance or beneficial incidences. Therefore, the assumption that PD process success is a required but not sufficient condition for PD success automatically applies for this research' context and scope.

34 Serendipity: the fact of something interesting or pleasant happening by chance (Oxford Learner's Dictionaries, 2019).

Validated entity: Bottom-up optimization processes

Optimization is performed from process to higher dimensions' success (a bottom-up approach), where selection for optimization uses a top-down approach. The vision states that company maturity is the highest maturity dimension in this maturity vision and that supportive maturity factors can be identified. More levels under that can be identified afterwards, repeatedly until the process level is identified. Therefore, this process of identifying and mapping maturity dimensions often follows a top-down strategy (not always – e.g. if looked from existing processes and worked towards maturities – but imaginably, most times). Besides that, the maturity vision states that maturity factors need to be focused on for optimization, not maturity dimensions. This means that maturity optimization occurs specifically in a bottom-up process. No literature reference is found that states directly the same difference between the two processes, however, with use of rationalization both options can be sketched and clarified further for validation.

Changing higher locations directly is too abstract where context influences are unknown, therefore a bottom-up approach is preferred with company strategy as directive for decisions. As indicated in the model of Xiaoying, Qianqian & Dezhi (2008), there are no insights in dimensions that directly influence company success. If someone would ask a person to build a bridge over a canal, it is unlikely for the person to start the first meter by building a six-car wide tarmac bridge. Most people would start with a light beam framework that reaches completely across the canal to see if the concept is right, and then stepwise increase the functionalities and quality to meet expectations. For optimization projects, one would expect an equivalent approach. For improving the higher dimension directly, it is often not known beforehand what maturity factors are influencing, where the optimization would end in and how uncertain and detailed context aspects influence the results. Since the context has high influence on the effectiveness, efficiency, capability and maturity, higher level optimization without taking the detailed context and higher company strategy influences into account, is certainly ineffective if aimed for continuous company success. Therefore, in order to optimize (change) on a certain organizational level, it is preferred to change lower levels towards higher levels instead of changing top-down. However, the risk of this approach is that changing lower locations without focus on the company strategy is not effective as well, since it is not guaranteed that the implementations will contribute to those higher objectives. A gap in modern maturity assessments and audits is that company strategy or higher objectives are not always taken into account as leading for the optimization project, resulting in limited improvement of the higher maturity dimensions. Consequently, the vision dictates to preferably optimize with a bottom-up approach, taking into account the higher maturity dimensions as higher objectives and directives for optimization decisions.

7.1.3 PDMO model design validation

The maturity vision leads to PDMO model design, which is validated in these paragraphs.

Validated entity: PDMO model results

Sensitivity cannot be tested in detail in the concept models. A balance between information depth while remaining an efficient and effective process is required. The PDMO model can not yet be tested in detail for the sensitivity of input on output, due to the conceptual level of the model design. In future developments, input and output information is required and the balance between the sensitivity and the level of detail for input information needs to be tuned. After that, differences in input information must be reflected in the output (requires detailed input, steps and output) with remaining efficient in performing the optimization project (only influencing information is gathered during the project).

A mentioned gap in model and method validation states that other organizational aspects which do have influence on optimization projects are not included in the project and decision making processes within the project. The PDMO model is very unique in handling other aspects and includes a comprehensive step for identifying other maturity dimensions and their influence on company success and other higher objectives. This is a unique selling point of the model and vision behind it.

The flexibility in depth of the results provided by the model as well is unique. The PDMO model empowers and includes the company strategy to determine the appropriate level of depth as required for adding value to that specific context. Rough analyses as well as comprehensive assessments are possible based on the same steps and both offer valuable results, tailored to the specific company context.

An often questioned aspect during model development is the theoretical base. This development is build with including many maturity audit and validation and verification standards as inspiration, but contributes with adding new functionalities that include higher maturity dimensions and a well underpinned decision making base for selecting a process for optimization. These contributions are designed in a development process including comprehensive theoretical research throughout the entire process. During this process, the substantiation of design decisions forms the proof for existence, ensuring focus is on underpinning designs and steps. Standards for model development processes are used, filtered for value and contribution to this specific development project.

7.1 General validation and evaluation

Besides the created advice – which is an often used deliverable for maturity assessment projects – insights behind the results is provided as well, contributing to creating '*know-how*' knowledge for industry. Furthermore, transparency in creating the results stimulates correct interpretation of results by industry and model development and assessment practitioners. This makes model functionalities visible and available. Open discussions about and validation of the functionalities and designs is enabled, contributing to improvements and development of iterations.

Validated entity: Practicability of required input information

Components rely on practical knowledge sources, which must be available and qualitatively high for project execution. The required input information for the PDMO model (*Figure 39*) consists of: *(1)* maturity dimensions within the context, *(2)* maturity levels within the context, *(3)* aspired maturity levels, *(4)* interpretations of the company strategy and information about *(5)* the specific process and its environment, dependent on the type and requirements of the selected maturity audit model (from the MOC). Within the company, management for goal and strategy input and production / operations management for technical and process input must be available to retrieve the required information. Since the components highly rely on those practical knowledge sources, availability, attention and endeavour is required for project success.

It is reasonable to expect availability and pro-active participation from the company, since such an optimization project is likely to be initiated and financed by the company and management themselves. Since they can benefit from the results, retrieving the required information for performing the PDPMA model steps is likely. A cooperation between the assessment / optimization project team and the stakeholders for input is mutual beneficial. However, not all industrial stakeholders may agree with the decision to perform the PDMO and / or PDPMA model for optimization. Therefore, required endeavour from both sides can be communicated or assured through stating '*criteria for success*' or by including these requirements in a project contract. Such adjustments need further research for their effectiveness, but are often applied in optimization projects.

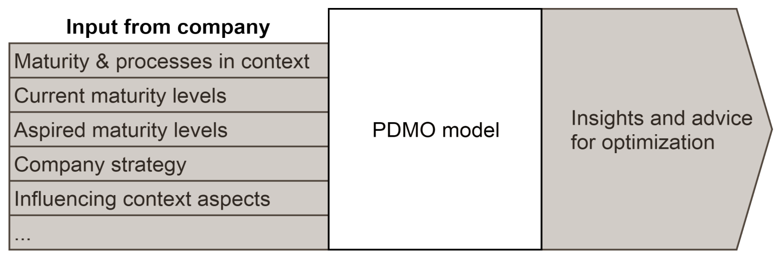

Figure 39 - Input and output information of the PDMO model

Validated entity: Cohesion of steps within the model

The size of the steps can be slightly unbalanced, e.g. the MLC could take less time than the MRC for indicating maturity levels for specific contexts and vice versa. This is not a problem for optimization projects, since in the start project planning and management activities often include indicating the required time for steps in that specific context, which can be done for the PDMO model as well. The information flow through the PDMO model steps is cohesive (*Figure 40*). The MLC requires information for identifying maturity dimensions in the context and has a maturity dimension topology as output. The MRC starts with that topology and requires information of specific maturity levels on those dimensions for indicating a focus for optimization. That output is used in the MOC to find a suitable maturity assessment model for that specific focus dimension, with tailored, underpinned and structured advice for optimization as output.

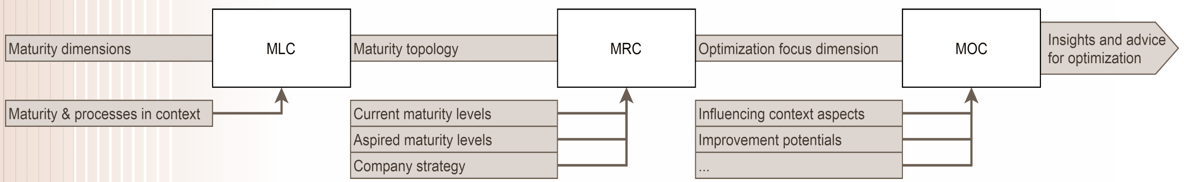

Figure 40 - Information flow in the PDMO model from input of MLC to output of MOC

The cohesive information flow can be sensitive for erroneous information, output evaluation as extra step before using information as input can be beneficial. With the outputs of former steps in line with the input for following steps, cohesion is validated. A risk of having such interfaces between the steps, is the possible flow of incorrect information through all steps once it is there. Consequently, results may be build on erroneous information. This emphasizes the need for management and process experts from the company as resources for input, so information can be acquired on a qualitatively high level. In the future, it can be sensible to measure given input information for an indication of quality. However, this design is only in the concept phase. Detailed steps – such as evaluating a specific output before it is used as input – can be added and do not form difficulties for future development.

Validated entity: Sustainable content, structure and data visualization

For the MLC and MRC, data visualization methods are proposed. They consist respectively of: a maturity topology network (*Figure 17*) and a maturity profile (*Figure 20*) for a company. The MOC can be any suitable maturity optimization model with own validated visualization methods. In the MLC, the maturity topology network uses a network visualization method to assure flexibility of content – which can be complemented and adjusted, e.g. if new

information comes available – transparency of steps and availability of the information with digitalization as opportunity. The topology enables structuring of information, which is a well-known and often applied method for such functionalities. The maturity profile uses the maturity topology as well, but additionally represents maturity levels for every maturity dimension in the identified topology (one current maturity level and one aspired maturity level per maturity dimension). As solution for visualization, a radar chart visualization method is used and proven capable of visualizing the required information. Stacking them into a maturity profile for the company (*Figure 20*), allows visualization of the maturity route, which provides insights for selecting one dimension as focus for optimization.

For these concepts, design ideas for information structuring and visualization are validated locally and assessed as being capable of fulfilling their functions. How capable they are for fulfilling those, compared to other methods for data visualization, is not assessed yet. First, detailed information for visualization needs to be developed further, on which comparison and selection of visualization methods can be based. Future development steps may search for variations of visualization methods to use for fulfilling the requirements, to design iterations of the PDMO model.

Validated entity: Practicability of required knowledge for execution

Execution of the models requires a relatively low amount of knowledge, but input quality needs to be high, advocating expert guidance. The PDMO model is more or less a passive model that uses visualization tools for the stakeholders to identify and structure information for creating insights for decision making. It guides with those methods, but does not generate solutions itself. Since the model is very transparent in use and functionalities, a relatively low amount of knowledge is required for execution, but the information needs to be of high quality (as explained in earlier in the paragraph about cohesion of steps). Therefore, the model is not complex in use. However, since input is sensitive and jargon might be difficult for some process or management experts, guidance through the process by external specialists is preferred.

Validated entity: Appropriation to selected target groups

The PDMO model has two target groups: the selected industry (as defined in *Chapter 1.4.3: Scope and limitations*) and the academy (mainly concerning Design Science practices). The use of a model as artefact to perform the maturity assessment, is a well-underpinned decision. In industry, application of theoretical knowledge is often performed through utilizing maturity assessment models, making that a recognized and valued source of information for the selected industrial target group. For academy, maturity model development and validation standards exist, making the transparent and underpinned design, testable and usable for the academical target group. Adaptation of jargon for the specific target groups contributes to appropriation of the vision and designs to the selected target groups and encourages utility of the designs by both.

Summarizing the validity of the PDMO model

The PDMO model fulfils its objective with three components: the Maturity Landscape component (MLC), Maturity Route component (MRC) and Maturity Optimization component (MOC). Local validations of the components are performed and described within the design chapters of those components (*Chapter 3: The PDMO concept model*). The validation results are summed beneath, representing the strengths and considerable points.

PDMO model strengths

- The design is validated with use of a selection of appropriate validation techniques from set standards
- The information flow in the model is cohesive and model execution and time budgeting are appropriated to the context
- The design includes other organizational aspects and influences as maturity dimensions, which is unique for maturity models
- Flexibility in the depth of results empowers the company strategy in decision making, enabling 'appropriate' depth of results tailored to the context
- Model development and validation standards are used during design and decisions are substantiated to ensure a firm theoretical base
- Insights behind created tailored results ensure openness of the PDMO model for improving it and sharing its insights
- The visualization methods (maturity topology network and profile) fulfil their intended functions effectively
- The jargon, maturity audit model shape and substantiation of design decisions advocate PDMO model utility by stakeholders

PDMO model points to consider

- Components rely on practical knowledge sources, they must be available and reliable during the project.
- Beneficial cooperation and communicating / contracting pro-active participation are necessary to acquiring the required input.
- The cohesive information flow can be sensitive for erroneous information, output evaluation might be required as extra step before using output information as input for a next step.
- Sensitivity can not be tested in detail yet, the depth of information must be determined to balance effectiveness and efficiency of the process while keeping an eye on sensitivities.
- Additional visualization solutions need to be explored to develop iterations of these concepts and ensure efficiency of data visualization and structuring methods.
- Execution requires a relatively low amount of knowledge, but input quality needs to be high, advocating expert guidance.

7.1.4 PDPMA model design validation

The PDPMA model design forms a selective part of the solution domain of the PDMO model. The general PDPMA model design is validated in these paragraphs.

Validated entity: PDPMA model results

The PDPMA model design requires balancing of the efficiency, sensitivity and the level of detail for input information (as described in *Chapter 7.1.3: PDMO model design validation*). The company strategy – as with the PDMO model – determines the 'appropriate' solution and level of depth of model execution. This is unique in the maturity audit sector, which often uses weighting factors and decision criteria from the perspectives of a selective group of stakeholders. Using the company strategy ensures long term focus on company success, instead of short term or individual benefits. This makes the PDPMA model less sensitive to subjective opinions and biases in input information.

For the PDPMA model, other maturity dimensions, organizational aspects and influences are taken into account, which is a unique selling point compared to other maturity audit models. The cooperation between the PDMO model its MLC and MRC, and the PDPMA model as MOC possibility, creates the opportunity to use input information throughout multiple tools for different levels and purposes. This increases the efficiency of PDPMA and PDMO model execution.

Transparency of the designed steps and information flows ensure focus on substantiation and underpinning of decisions and designs. The design is developed with use of a maturity audit model development standard and is objectively validated on all levels of design. The '*know-how*' / insights behind results are valuable for industry and the availability of design ideas, reasoning and the vision is valuable for academy as well. Open discussion and validation of the design is possible and encourages further iterations and adaptations.

Validated entity: Practicability of required input information

The parts rely on practical knowledge sources, which must be available and reliably during the project. The required input information for the PDPMA model (*Figure 41*) consists of: *(1)* relevant main context aspects, *(2)* insights in changeability of context aspects, *(3)* the MRC output, *(4)* relevant context parameters, *(5)* uncertainties of those parameters, *(6)* the company strategy for making deliberate decisions with uncertainties and *(7)* information required for the CIP design as stated in its design brief and determined after further development of the CIP for a context.

This information consists of practical knowledge in the organizational and process domains. Consequently, for acquiring this input, a management group together with process experts / operations management stakeholders are required. Availability of such a group is reasonable to expect, since performing the PDPMA model it is beneficial for all to pro-actively participate. Communicating '*criteria for success*' or stating this requirement in a project contract are two possibilities to ensure certainty of cooperation, these solutions for the PDMO model and PDPMA model execution require future research.

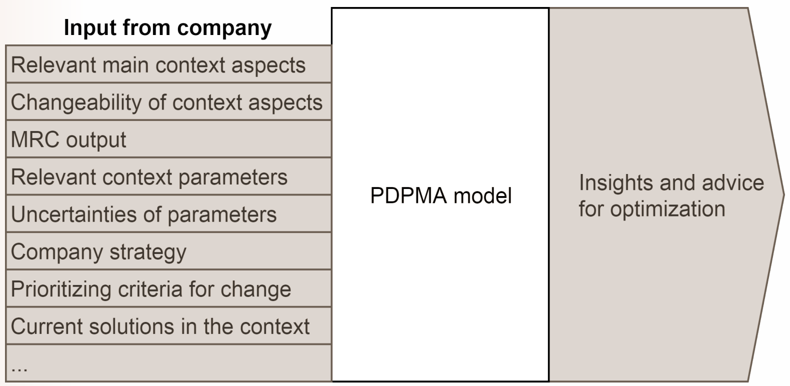

Figure 41 - Input information and output of the PDPMA model

7.1 General validation and evaluation

Validated entity: Cohesion of steps within the model

The maturity audit model for PD process optimization is a stepwise guiding model that starts with the MTP, which guides an accreditation decision for executing the full PDPMA model in a comprehensive way. Changeability of context aspects for the specific company needs to be validated and the MLC and MRC are filled in, after which the MRC validates if the PD process (structure) factor is the right maturity factor to optimize, contributing to PD and company success. The accreditation decision ('*yes*' / '*no*') is given and the OSP is performed. This step copies the changeability and rough context aspects that are filled in in the MTP. Relevant context parameters are selected and uncertainties for those are set. Solutions are created and the perspective of the company strategy is interpreted to compare and select relevant scenarios and relation profiles for the context. The resulting relevant relation profile – tailored to the specific context – is the output of the OSP. The CIP needs to be designed in further extend by change and implantation experts, therefore only main required information is described here. The CIP receives the relation profile. It requires information about the current situation of the context and what solutions are in place. The relation profile is translated into activities for change and criteria for change and implementation are interpreted from the company strategy's perspective. Activities are sequenced and budgeted for priorities and planning creation. An advice document states all prior discussed information. Other information for the CIP design might be necessary as well, validation of the required information for the CIP design is required after designing it.

This cohesive information flow can be sensitive for erroneous information. The information from the MTP is used in the OSP and complemented. This information is used by the CIP and complemented with mainly information about the current situation and priorities. This flow of information may result in a sensitivity of the design for erroneous information, as was the case with the PDMO model information flow. The outputs of former steps line up well with the input for following steps, validating the cohesion between them. The steps are balanced for their required activities, although that may differ slightly dependent on the context the model is applied in. A risk from the interfaces between the steps not validating information in between exists, which can be counter-acted in the future by a adding small quality measuring steps before stating information as output.

Validated entity: Sustainable content, structure and data visualization

The MTP and OSP use data visualization methods to communicate and structure information. Both work from the same relation profiling 'tool' which visualizes a network of company aspects with '*organization*', '*product*', '*project*', '*personnel*' and '*portfolio*' forming the '*trunk*' of the context's tree-network topology. The MTP makes use of the smaller context

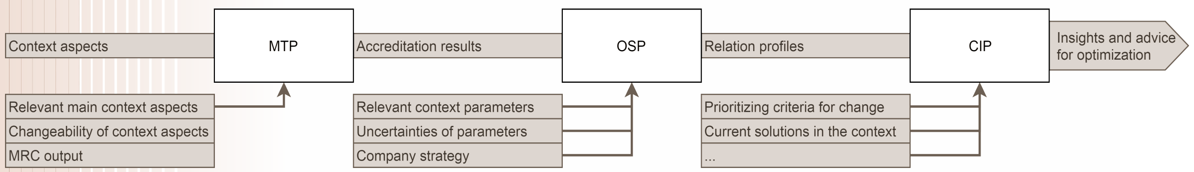

Figure 42 - Information flow in the PDPMA model from input of MTP to output of CIP

aspects that are emerged from the main context aspects, such as '*... size*', '*... capacity*', '*... type*', '*... structure*', etc. The MTP visualizes an indication of related models and methods as structuring solutions – for the filled in main context aspects with their uncertainty and changeability within the context – but related functions in between remain superficial.

Using the same visualization tool as the MTP allows the OSP to use the filled-in smaller context aspects from the MTP, on which the company can specify and adjust detailed context aspects with parameters, such as '*organization size = between 201 and 300 employees*', '*product complexity = average difficult product functions*', '*project complexity = high supplier involvement*', '*project complexity = many suppliers involved*', etc. The context network is connected to the specific and detailed functions, only visible in the OSP. These functions are again related to existing solutions, however, now in so much detail that they relate the parameters of the context to small, effective parts of models and methods.

The development of the models into (digital) tools is complex. All content combined into a dynamic network structure – consisting of three smaller tree-networks – allows adjustment and complementing data, contributing to a future-proof and sustainable model. A limitation is, that it makes the technical specifications required by the model more complex. However, comprehensive networking software exists and IT, software, network and topology specialists still develop and expand existing network capabilities. Therefore, realizing the visualizations into digital, dynamic tools for PDPMA model execution is assessed as not unreasonable.

Reusing information results in increased efficiency of the PDPMA model. The visualization methods in the PDPMA model reuse information and visualizations when possible. The MLC and MRC visualizations and information and the relation profile visualization and information are reused, resulting in an efficient input creation process for PD process (structure) optimization projects. This way, the designed visualization methods contribute to the efficiency of the PDPMA model.

Using the individual tree-networks in the relation profiles, enables visualization of information in other structures as well and enables a quick process for finding and adjusting specific data and comparing scenarios or situations for a specific type of information.

The content of the '*context*' and '*process structuring*' tree-networks only provide and illustration of network content. The network shape allows alteration and completion of content as seen fit. Since this research only provides a starting point, it is necessary to complement and validate the content in the PDPMA model. Other content and visualization techniques are not taken into account in this research.

The visualization methods for the CIP are not yet designed and need validation after they are developed for the specific contexts.

Validated entity: Practicability of required knowledge for execution

Since the PDPMA model proposes a given data set of possible input information, the use is not complex. Uncertainty and changeability of context aspects and parameters are indications and do not require exact quantifiable data, contributing to practicability of the model in the context. Since the model is very transparent in use and functionalities, proper execution is reasonable to expect with the available knowledge within the company. The CIP however, requires translation from results to change and implementation advice, which is a more specialized domain and requires comprehensive insights in change strategies, prioritization, implementation criteria and implementation planning. Therefore, the PDPMA model execution needs guidance and CIP execution by external specialists.

Validated entity: Appropriation to selected target groups

The jargon is based on the engineering and management disciplines and added value is validated in the MTP design. Academical stakeholders are aware of the processes and used jargon, since it is based on standards for maturity audit models. The time for performing the PDPMA model is extensive, the company needs to invest in it and planning cannot be taken lightly. However, for securing optimization project budgets and ensuring changes are high that results are valuable for the context, the PDPMA model design concept uses a designed MTP to validate accreditation. The model is focused on engineering and management disciplines and uses jargon of both. Possibly, some jargon may be unfamiliar for stakeholders from industry – engineering stakeholders might be unaware of management terminology and management stakeholders of engineering terminology – but majority of the terms can be defined easily if required.

A risk of the selected industrial target group is that they need to accept and be open for advice from external organizations. This is not a given fact. For making the PDPMA model utilized by industry successfully, marketing of the unique selling points by the external organizations performing the optimization project guided by the PDPMA model is required. This makes industry aware of the potential benefits for their context and broadens the solution domain they search in for improvement projects. If the cooperation between both is mutual beneficial, changes are high enough that companies are open for sharing information and consider accepting advice.

Validated entity: PDPMA model objective

The objective of the PDPMA model is to provide companies with objective and detailed insights for improving their product development process maturity. The PDPMA model consists of three parts for fulfilling this function: the Maturity Test part (MTP), the Optimisation Strategy part (OSP) and the Change and Implementation part (CIP). Local validations of the components are performed within their respective design chapters (*Chapter 4: The PDPMA concept model*). The global validation used a selected set of validation techniques and the results are listed beneath.

The design of the PDPMA model does not completely achieve the objective as stated above. It automatically assumes that structuring the PD process results in PD process success, which in many contexts will be the factor contributing most to PD process improvement. However, not in all contexts this automatically applies. It is a difficult and complex assumption to proof, since the author at time of writing this report did not find any literature stating other aspects in the PD process maturity dimension influencing this dimension much. In the next section, an attempt is made to perform and explain if a deliberately selected PD process structure can be seen as an effective and efficient PD process – as the resulting OSP design indicates. This validation results in a need for the Maturity Test Part (MTP) to be slightly adjusted in future iterations to fit to the OSP and PDPMA model objective better.

PD process is compared to PD process structure through definitions, to find gaps in the theory behind the PDPMA concept model. A note that has to be kept in mind, is that '*process structuring*' is not the same as '*formal processes*' in this research. Logically, appropriateness of the level of formality in process structures may vary per context, and process formality is only one aspect of the many that can be tailored to fit the context. The PDPMA model is very capable of guiding the selection process to find an appropriate level of formality of structures for a context. This paragraph refers to '*process structuring*' in general. For testing if the PDPMA model fulfils its objective, 'PD process' needs to be compared with 'PD process structure', to identify possible gaps between those in relation to '*effectiveness*' and '*efficiency*'. After that, the following assumption can be tested: *"improving PD process structures in specific contexts directly contributes to effective and efficient PD processes"*. All

definitions as stated in this paragraph are provided by the Oxford Learner's Dictionaries (2019).
'*Process*' in this research is defined as:

"A series of things that are done in order to achieve a particular result".

'*Effective*' is defined as:

"Producing the result that is wanted or intended; producing a successful result";

'*Efficient*' is defined as:

"Doing something well and thoroughly with no waste of time, money or energy".

Combined,
'*Effective and efficient process*' entails:

"An effective series of things, performed efficiently, with a particular result as outcome".

'*Structured*' however, is defined as:

"The state of being well organized or planned with all the parts linked together; a careful plan".

With those definitions,
A '*structured process*' would be:

"A process that is in the state of being well organized and planned in order to achieve a particular result as outcome".

'*Effective*' is achieving that particular result, where '*efficient*' related to structure is the planning and organization to perform it without waste of time, money or energy. So far, process structure and process are interchangeable if, '*well organized and planned*' is defined comparable to '*effectively and efficiently*'. '*Organized*' is defined as being:

"able to plan your work, life, etc. well and in an efficient way".

'*Efficiency*' is in the direct word used in the noun '*organized*', which is half of the definition of the noun '*structured*'. Then the other half of '*structured*' must cover '*effectiveness*', which is '*planned*':

"to make detailed arrangements for something you want to do in the future" or,
"to intend or expect to do something".

In the PDPMA model, PD Process related to effectiveness and efficiency results in:

'the achieved effectiveness and efficiency in the series of things done to achieve a particular result',

where PD Process structure related to effectiveness and efficiency is:

'the achieved effectiveness and efficiency in the series of things planned to achieve a particular result'.

The gap in between consists of that between '*done*' and '*planned*'. Therein, PD process structure capability represents '*planning*', and PD Process capability requires both. Therefore, with optimizing PD Process structures, the 'doing' side is not especially included and forms a gap in the PDPMA model design.

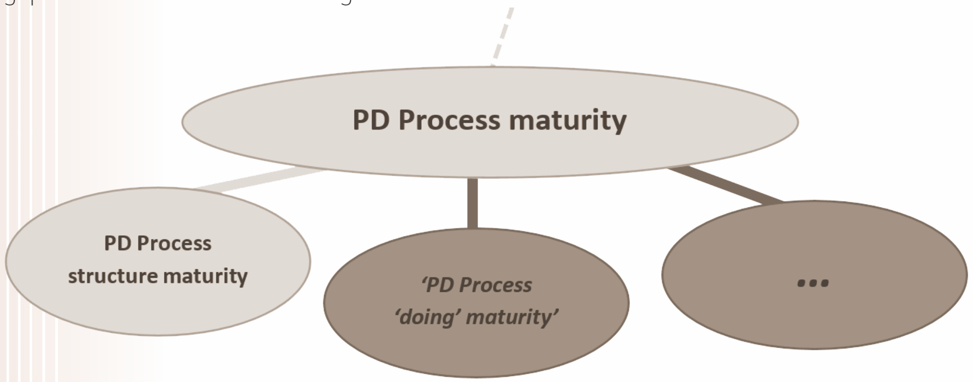

Figure 43 – Visualization of PD process structure maturity as one dimension of PD process maturity

However, for adjusting the PDPMA model design, the influence of the PD process structure dimension, the concept of the PDMO model can be applied to this PDPMA model context. The MLC can identify within a specific context what maturity factors influence PD process maturity (an example is given in *Figure 43*). After that, the MRC enables comparison of maturity levels to identify if PD process structure is the maturity dimension to optimize contributing most to increased PD process maturity. Consequently, the objective of the PDPMA model is not '*providing insights in PD process improvement*', but '*providing insights in PD process structure improvement*'. A different solution is to keep the objective as designed for, and adjust the first question in the MTP stepwise approach accordingly, to: '*validate if PD process structure (instead of PD process) is the maturity dimension to optimize for improved PD process success and PD success*'. For that question answering '*yes*', the PDPMA model stays the same and guides in achieving the intended objective.

Summarizing the validity of the PDPMA model

The validation results are listed beneath, representing the strengths and considerable points of the PDMO design.

PDPMA model strengths

- The PDPMA model designs are validated with use of a selection of appropriate validation techniques from set standards.
- The appropriateness of results and decisions is directed by objective interpretations of the company strategy.
- The design includes maturity dimension validation, organizational aspects and efficiency through combined tools, which is unique for maturity audit models.
- Model development and validation standards are used during design and decisions are substantiated for ensuring a firm theoretical base.
- Results are transparent and open to enable improvement and insights, valuable for industry and academy.
- Steps indicate an even time distribution between part execution, which can be adapted to suit the context.
- The steps follow a cohesive information flow from MTP trough MLC, MRC and OSP to CIP.
- Reusing information between MLC, MRC, MTP and OSP results in increased efficiency of PDPMA model execution.
- Individual tree-networks visualize different information structures beneficial for comparison, data searching and other functionalities.
- Execution of the MTP and OSP is realistic and practical for industry.
- The costs-benefits in terms of time / budget and optimization value is validated up front by the MTP design.
- Identified gaps between PD process and PD process structure can be filled easily by adjusting the MTP slightly to fit the OSP and PDPMA model objective better.

PDPMA model points to consider

- Effectiveness of PDPMA model utility depends on the balance between efficiency and sensitivity for the level of detail of content information.
- Components rely on practical knowledge sources, they must be available during the project.
- Beneficial cooperation, communicating and contracting pro-active participation is necessary for acquiring required input information.

- The cohesive information flow between the MTP, OSP and CIP can be sensitive for erroneous information, output evaluation can be performed as extra step after creating output information.
- Development of required software is complex, but based on existing software and potentials, it is not unreasonable.
- Illustrative content of the model requires to be complemented and validated, other visualization methods are not explored.
- Visualization methods and practicability of the CIP are not yet designed and need to be validated after a concept is developed.
- Jargon is based on engineering and management disciplines specifically, requiring more build-in definitions or translations.
- Marketing of PDPMA model unique selling points is required and the cooperation needs to be mutual beneficial.
- The PDPMA model in its current shape does not achieve the stated PDPMA model objective, validation did state a gap between PD process structure success and PD process success, which can be solved with the proposed small adjustment of the MTP.

7.1.5 Research process evaluation

This paragraph compares the '*as-intended*' development process based on Cross' model for the product development with the '*as-was*' process. A comprehensive logging of development and research activities is performed, enabling ex-post evaluation of the process.

The '*as-was*' process

The '*as-was*' process started with PDPMA model development and the objective to provide insights in optimization of PD process maturity in industry. After exploring the theoretical background, a start with the Optimization Strategy part (OSP) is made, since it was expected that most challenging and value adding efforts in this research where related to the OSP design. Thereafter, the Maturity Test part (MTP) is evaluated as most value adding, with the CIP design as final design activity (with the detail of the design dependent on the remaining time for this research project).

During the PDPMA model development – during Maturity Test part (MTP) development in specific – indications emerged which advocated the need of a higher perspective on optimization process selection, resulting in the PDMO model directive. The PDPMA model development process was paused during the MTP development (after OSP development),

since the MTP required insights in the validity of the decision to optimize the PD process in specific. Those insights desired a more comprehensive look at the higher perspective, resulting in a concept design for the PDMO model and its collaboration with the PDPMA model towards PD maturity optimization as higher maturity dimension.

The concept for the PDMO model is designed, following the logical sequence from the MLC design, to MRC design and MOC design. During the latter, the relation between the MOC and the PDPMA model became clear, where the PDPMA model objective and design connected well with the solution domain of the MOC. Thereafter, the PDPMA model is developed further with remaining steps of MTP (relating to the MLC and MRC design) and CIP development.

'*As-intended*' compared to '*as-was*'

This sequence of design activities, can be viewed from the perspectives of multiple product development process models, such as the ones compared in *Chapter 1.4.4: Development methodology*. By evaluating the overlap between the '*as-was*' representation and the original models, the choice for the Cross' model can be evaluated. *Appendix 8.7: Research process evaluation* provides the '*as-intended*' models next to the '*as-was*' visualizations.

The comparison between Cross' model and the '*as-was*' process adapted to fit his structure, is visualized in *Figure 44*. Many additional arrows indicate the '*design thinking*' activities during the research, which are not stated or supported by Cross' model. This resulted extra steps in the development process for updating and revising the report and prior designs, leading to a less effective and efficient process that it could have been.

However, Suireg's product development model did provide the '*design thinking*' loop that guides the developer after '*Test and evaluation*' back to the multiple design steps. Therefore, the '*as-was*' process complies more to Suireg's model although intentionally Cross' model was selected. The cause for this misjudgement is mainly explained by the uncertainty of the project complexity as context aspect (in the introduction estimated as '*mediocre project complexity*', *Appendix 8.2: Model development standards*). Due to the extra – underestimated – complexity of validating if PDPMA model execution is valuable for a context (the MTP functionality), the PDMO model design through the '*design thinking*' loop was required.

Execution of the PDPMA model prior to this research project could have avoided misjudgement. The uncertainty of the complexity was a known unknown which was not taken into account in the PD process structure selection. Furthermore, insights on the effect of this uncertainty on the PD structure was unknown. By simulating the PD structure solutions for the research context that includes uncertainty of the complexity, the possible relevance of a '*design thinking*' loop could have been foreseen. The selection of the development process then could anticipate on the possibility for increased complexity, allowing a hybrid process structure that e.g. combines Cross' model with Suireg's model to fit the context best.

For this research, only three models where considered as possible PD process structures. Imaginably – with a network of many models and methods – an even better tailored solution can be created by utilizing the PDPMA model, resulting in a more effective and efficient product development process.

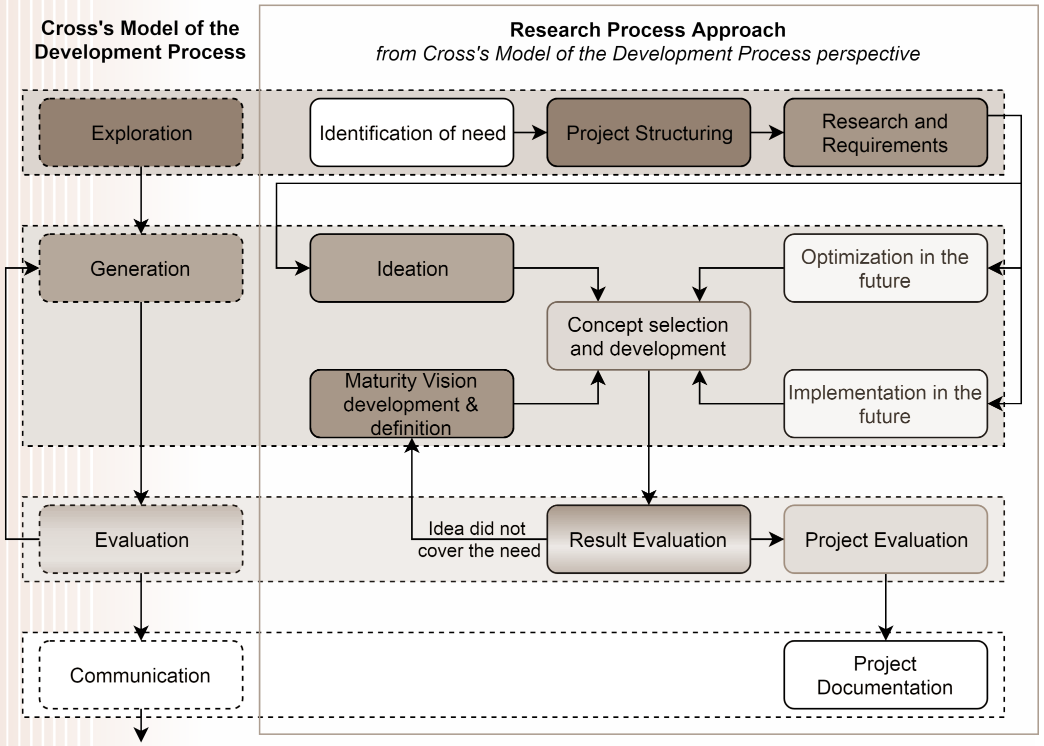

Figure 44 - Comparison between Cross' intended process structure and the 'as-was' process structure

7.2 Discussion

With the validated and evaluated proof-of-concept models as design results, this chapter discusses the research results by the value, assumptions, limitations and objectives. It starts with addressing a recap of the research results. It discusses the research on a higher level of abstraction than previous chapters, moving towards an answer on the research question. It addresses and highlights how this research reflects, differs from and extends current knowledge in product development optimization.

7.2.1 Summarizing the research results and key findings

This section provides a brief recap on the results, claims and statements. Assumptions and limitations are not included in this section, but are discussed in later paragraphs.

Recap of the research results

Companies strive for success and achieve that through improving efficiency and effectiveness of value creating processes. Those processes are targeted by maturity audit projects which aim at increasing capabilities of the company. Product Development (PD) is one of the value creating processes in the industry that can be targeted for optimization. However, maturity audit projects for PD processes in specific are not utilized effectively and efficiently in industry. Furthermore, knowledge on PD process optimization is limited.

A mix of theoretical and practical knowledge is required for optimizing PD processes, since effectiveness and efficiency are directly influenced by the context which brings uncertainties, sensitivities and stakeholder involvement. Consequently, finding the appropriate solution in an optimization project environment involves complex multi-criteria decisions with many dependencies. The highest objective is company success, which is theoretically underpinned in a developed vision on maturity.

For providing insights in the value of optimizing a certain process in a company context, a concept model (PDMO model) is designed. It provides insights in which processes within a context exist and identifies which process capability falls behind on expectations regarding an overall high maturity. The PDMO model results allow the company to deliberately select one process to focus upon for optimization, contributing effectively and efficiently to company success.

A specific maturity audit model is required which focuses on optimizing the PD process, if that process maturity is indicated as most valuable for optimization towards company success. For providing insights in PD process optimization, a concept for the PD process maturity audit (PDPMA) model is designed. It starts with assessing the company context on changeability and appropriateness of PD process optimization. Thereafter, a suitable and appropriate process structure is proposed by reconfiguring existing models and methods from the Design Science domain. The proposed structure is tailored to the company context and insights are translated into a change and implementation advice.

The PDMO and PDPMA concept models are a starting point of the future possibilities regarding PD maturity optimization in industry. The models are built on a theoretically underpinned vision contributing to the Design Science domain. First steps are made towards development of the concept models into practical tools, providing insights in improvement of industry's PD maturity.

Relevant claims

Appendix 8.7: Research claims, lists the key statements that this research uses for development of the concept models. These are discussed and explored in the chapters where they play a role, and substantiated if required. The list of claims provides more context for interpreting the research results. This chapter continues with discussing the research results in the light of the research question.

7.2.2 Considering findings in light of the research question

This section discusses the findings in relation to the research question. The highest objective, which the research contributes to and forms an illustrative starting point for, is stated as:

Provide companies with objective and detailed insights for improving their product development maturity.

This research contributes to this highest objective through the following research objective:

Develop a proof-of-concept model for providing industry with insights in PD maturity optimization

The objective is achieved through development of two concept models based on a theoretically sound maturity vision. The maturity vision answers the sub-question:

What influences and determines maturity in the PD context?

The PDMO concept model answers the sub-question:

How to validate if PD optimization is effective and efficient in a specific context?

The PDPMA concept model is developed to answer the sub-question:

How to assess and optimize PD process maturity in a specific context?

The maturity vision and the PDMO model achieve their sub-objectives, the PDPMA model requires a small adjustment, but is valuable for its design and future iterations. In *Chapter 7.1: Global validation and evaluation*, the developed results are assessed for their capability of answering these questions. The maturity vision and PDMO concept model answer their questions successfully. However, the PDPMA concept model addresses optimization of the PD process structure, which does not guarantee PD process success (as explained in *Chapter 7.1.4: PDPMA model design validation*). Furthermore, uncertainty and sensitivity are largely represented in the MTP, but a detailed step for validating changeability is mentioned but not represented sufficiently in the stepwise approach.

As discussed in the validation chapters, a gap between PD process success and PD process structure success exists. PD process success entails a combination between planning and performing, which can be interpreted as '*planning success*' and '*having success*'. The current MTP design only includes '*planning success*'. Since this research objective functions as illustrative starting point for further research on the PD maturity optimization topic, filling the gap between '*intending success*', '*implementing results derived from those intentions*' and '*having success*' is necessary in future iterations. This gap however, will not result in the PDPMA model being performed without valuable results, since the PDMO model and first step of the PDPMA model validate if focus on PD process (structure) optimization is appropriate. The insufficiently mentioned changeability in the MTP requires a minor change in the stepwise approach. With including that, the complete PDPMA model with the PDMO model make a valuable contribution to answering the research question and provide industry with insights in PD process optimization in their specific context.

7.2.3 Discussing the value to stakeholders

This section discusses value of the research results for the stakeholders. It highlights the value for industry and for the academy, in specific for the Design Science domain. The main contributions of this research are discussed and explained in more detail, other valuable results are shortly summarized without further detailed explanations.

The aim of this research is utility of the designed concept models, since utility represents the value of a model for users. The stakeholders of these concept models are *(1)* the industry as direct user of created advice and insights through the models, and *(2)* the academy as indirect user of the theory and reasoning behind the models. Opposing interests of both stakeholders form a challenge for defining the level of depth addressed by this research. Where industry wants specific and clearly stated advice, tailored to their context to make deliberate decisions for optimization, the academy wants generic, underpinned reasoning behind model designs, dependencies in (abstract and semantic[35]) ontologies and influences on the decision making process related to optimization projects. Due to research limitations, fully developing a model for PD maturity optimization is unrealistic and a only first steps towards serving both needs are performed.

Value for industry

This research contributes to the wish for industry to optimize PD practices by designing the *(1)* PDMO and *(2)* PDPMA concept models. They aim accordingly, for providing insights in *(1)* selecting appropriate processes for optimization and *(2)* optimizing PD processes in industry, tailored to specific contexts.

Value of the models for the company is explicitly created by the change and implementation insights, whether it is in the PDMO model or PDPMA model objectives. These result in prioritized activities for change towards effective and efficient PD process structures. The created PD process structure in the PDPMA model is a reconfiguration of existing models and methods, of which parts which perform specific functions (their reason for existence) are related to context parameters which require that same function. The PDMO model provides insights for indicating which process optimization contributes effectively and efficiently to company success. The solutions of both are created in a theoretically underpinned way and the resulting network ontologies allow finding appropriate solutions with respect to the differences in contexts and objectives of companies, aiming for increased company success.

35 Semantic ontology: "*definition of the elements and relations between these elements. It represents the conceptual graph, in which the information content is defined. It encompasses e.g. the definition of the notions … independent of specific instances.*" (Lutters, Brinke, Streppel, & Kals, 1999).

The models are versatile designs. In and before each optimization project, myriad decisions are made, influencing the company context and being influenced by the company context. The models relate entities through theoretically detailed functions and relations in a flexible network shape, forming versatile designs that allow analysis of reasoning and providing insights in decision consequences. For identifying and selecting appropriate processes for optimization and PD process structures for the specific context, influences of uncertainties, sensitivities and stakeholder perspectives require transparent representation. The visualization and information structuring methods used in the concept models offer this functionality, making information accessible and clear for creating insights by industrial stakeholders.

Information presented by network visualization methods, allow severally adapting content to needs and knowledge. Presenting the information in an ontology through network visualization methods allows and encourages evolution and flexibility of the content, contributing to sustainability of the models in favour of model utility. The entities *(1)* company context aspects (with parameters, sensitivities and uncertainties), *(2)* functions and *(3)* models and methods, form their own smaller ontologies in network shape as well. Consequently, benchmarking and severally adapting content according to user needs and available knowledge can occur. These functionalities enable practicability, reliability, sustainability and accessibility of information.

Opportunities for automated tool functionalities and '*what-if*' scenario simulation exist for the designs. Automated adaptation of information structures becomes possible by completing uncertainties to form '*what-if*' scenarios. By filling in often used parameter combinations and running multiple simulations for different uncertain aspects, the models can suggest content adjustment activities. Furthermore, questions such as "*what would the product development process look like, if the company doubles the amount of employees in the next two years*" or "…, *focusses on developing more complex products*" or "…, *optimizes production processes instead of product development processes*" can be answered based on the '*what-if*' simulations. By validating these scenarios from the interpreted perspective of the company strategy, an objective answer can be created with company success as highest objective.

Value for academy

This research performs steps towards a practical tool for utility in industry, but focuses mainly on underlying principles and theories for such a maturity optimization tool through maturity audit model development. This is reflected in the developed maturity vision which forms the basis for the concept designs. The concept models communicate information in a conceptual and practical way to present specified and tailored advice for industry. However, the theory located between the input and output of the designs – within the ontologies and information structures – is approached with a high level of detail and in a theoretically underpinned way. This separation between *(1)* the superficial information for transparent and underpinned communication and utilization in industry and *(2)* the in-depth theoretical base the ontologies and model content is developed with, avoids disproportionate abstraction of practical and theoretical information and stays closer to the reality of individual company contexts. This approach contributes and illustrates a solution that might close the gap between developed artefacts of the Design Science domain and utility of them.

Focus is put particularly on the underlying principles and theory that influence product development processes, decisions on optimization and – in specific – the structuring and underpinning of both. The models are developed up to the conceptual phases, but designs and theory are described and included with enough detail (which may seem undue for a design in the concept phase). This high level of detail underpins the logic of the designs, provides insights in influences on concept model results and hinges them on a firm theoretical base. The uniqueness of applying maturity audits specifically on the product development process and – it may be as cause or as consequence – the limited knowledge on tailoring processes to contexts, foster model transparency and theoretical substantiation. The models provide this transparency and allow open discussion and evaluation of the designs. Consequently, discussions and evaluations are the basis for future design of iterations and objective research result interpretations.

To that end, the PDMO model and the PDPMA model contribute in their unique way to objective decision making on process optimization selection and product development process optimizations. The triangle shape of the PDMO model indicates a unique characteristic of this model: within the maturity optimization context, strategy does not follow one top-down or bottom-up approach, but influences projects from both sides. With inclusion of other maturity audit models for process optimizations, the PDMO model enables comparison of many optimization projects on maturity dimensions for their contribution to higher level – in most cases concerning the company's – success. Furthermore, the PDPMA model uniquely provides a theoretically sound strategy of tailoring process structures to their specific context. Decisions on optimizing PD processes and optimization projects can be evaluated for sensitivity of perspectives and uncertainties, making them open for discussion and subject to verification.

The PDMO and PDPMA models both require ontologies of aspects such as the contexts, maturity domains and artefacts for process structuring. These are related by the concept models, and additionally provide a useful function of mapping aspects individually as well. In brief, models and methods can be structured and benchmarked for characteristics such as discipline, application and formality. The characteristics are identified, not with use of questionable and time consuming best practice researches, but based on the detailed functions – the reasons for existence – of all parts in the models and methods. Examining existing artefacts this way, results in a multi-functional ontology on which Design Science artefacts can be tracked and mapped.

Listed values of research results

This research provides value for the stakeholders, as discussed previously. A list of values is made to summarize the added value of this research for the industry and for the academy, concerning the Design Science domain in specific.

Value for industry

- The concept models provide insights for and behind practical changes and implementations leading to optimized processes which contribute to company success.
- The concept models provide insights for indicating effectiveness and efficiency – or maturity – of current PD practices and improvement opportunities specifically tailored to the company context with its sensitivities, uncertainties and stakeholder involvements.
- Insights for selecting processes for optimization and for optimizing PD processes in specific are provided with the concept models. The valuable combination of practical and theoretical knowledge made accessible to industry, enables companies to make deliberate decisions regarding optimization projects and PD process optimization.
- The visualization and information structuring methods form the concept models into versatile designs, allowing availability, flexibility and sustainability of content.
- Content in the concept models can be adapted to fit the needs and knowledge of the industrial stakeholder, which often change over time.
- The concept models can be developed further into automated tools with a wide range of additional functions such as '*what-if*' scenario comparison, automatic input suggestion and benchmarking between contexts.
- By utilizing parts of the PDMO and PDPMA model, selective work packages can be tailored to fit the company's interests and requirements.

Value for academy – the Design Science domain in specific

- The concept models are developed and evaluated with respect to the research guidelines for Design Science, based on standards for model development and model validation and verification. Therefore, the research results are substantiated from a firm theoretical backbone.
- The designs are developed as semantic ontologies, representing definitions, theories and relations independent of specific instances. Consequently, the research results are general results which can be utilized without specific contextual details in the content of the concept models.
- The PDPMA model focuses on a unique application of maturity audit models, specifically for optimizing the PD process.
- A framework for tailoring PD process structures to the company context is proposed as first of its kind, which relates both entities (the PD process context and PD process structures) based on overlapping functions.
- The PDMO model uses a unique vision where optimization decisions are based on the highest objective of a company, as represented in the company strategy. It provides guidance in selecting the appropriate process for optimization, contributing to achieving the highest objective. The maturity vision and proposed implementation of the vision through the PDMO model are unique in the Design Science domain and deserve attention in future maturity audit developments.
- After the ontologies are developed further, mapping and clustering of *(1)* existing artefacts, *(2)* utilization of artefacts and *(3)* knowledge on artefacts and their characteristics in a structured way is possible. A literature landscape of artefacts can be created, enabling the user to navigate through it based on disciplines, company contexts and other artefact or context characteristic.
- The created insights in current PD processes in industry – that can be tracked and mapped through the relation and maturity profiles – enable the academy to critically review existing PD practices and develop new solutions that support improvement of the capabilities.
- Closing the gap between developed artefacts in Design Science at one hand and utilization in industry on the other hand, advocates for the industry to see and recognize the value of artefacts for their context. This increases Design Science success, since artefacts will be utilized more and artefact utilization leads to artefact success.

7.2.4 Validity influenced by scope and limitations

These paragraphs discuss if limitations and the set scope influence the validity of the research results. Limitations are addressed separately based on the set limitations and scope in *Chapter 1.4.3: Scope and limitations.*

Limitations of the assignment

A full design of a model could be developed – as explained in the first paragraphs of Chapter 1.4.1: Research Directive – for the objective to increase the maturity of PD practices in companies.

This research contributes to this main aim within the realistic scope of the assignment, by fulfilling a research objective that functions as illustrative starting point contributing to achieving PD maturity optimization. This limitation prevents the research from developing and validating a full model with tangible model results. However, extra value for academy is provided with this limitation since an interesting range of opportunities for future research is identified.

Limitations of the industrial context for application

Industry overall is a very broad scope with many variations and context differences, forming an enormous landscape of possible focus target groups. A PD maturity model design would be applicable on only a very high and abstract level or requires many complex configuration steps in order to tailor it to specific context variations.

The designed concept models manage to balance required knowledge and specificness of the results while remaining applicable to a big target group. This limitation decreases the size of the target group, which may decrease utilization at first. However, it as well results in the balance between those aspects as unique selling point of the designs, substantiating utilization after further development.

Out-of-scope scenarios include companies that are restricted from choosing PD process structures due to regulations, costs, etc. Furthermore companies that do not develop tangible, technical products and do not generate value by developing products are excluded in this research. Finally, the company must – in some way – see value in optimizing the maturity of PD practices.

This limitation is seen as necessary to accredit and guarantee valuable results for the effort of performing the models. However, not filtering the in-scope and out-of-scope scenarios before performing the models is a major risk and therefore the designs themselves filter the out-of-scope situations with executing the PDMO model and first step of the PDPMA model. As a result – with or without this limitation – the validity of the research is not affected by it and inclusion of the accreditation decision strengthens the concept models compared to existing maturity assessment models.

Fulfilling the highest objective stated in this research can be valuable for any product development project, irrespective of size or industry and especially tailored to e.g. size and industry. The limitation to industrial target groups that create tangible, technical products to create value ensures that effectiveness and efficiency of the PD process has a direct influence on the value creation of the company and the company success as highest objective.

This research focuses on tailoring process structures and identifying effective and efficient optimization targets within the broad target group as stated in *Chapter 1.4.3: Scope and limitations*. This target group is specified in more detail as first target group of the concept models, but can be enlarged if proven valuable. The designs provide the flexibility to be complemented and expanded as seen fit, resulting in this limitation being a temporary one with little effect on the validity of the research results.

This research scope is limited to only industrial target groups that ensure that the efforts for increasing the maturity of PD practices are worth the benefits. Therefore, industries that include automotive, one—off or rusted up sectors are not initially included.

However, during the concept design, it proved difficult to limit that target group before performing a maturity assessment. Since some cost-benefit validation is required to select in-scope and out-of-scope target groups, insights for indicating added value in a specific context are required and cannot be achieved before the start of a maturity assessment project. The MTP of the PDPMA model facilitates this function and should filter this selection, although the scope is set. Initially, changeability is shortly mentioned during the scope of this report as important requirement for valuable optimization of PD processes. However, this filter can be included in the design as well. An appropriate location for assessing changeability exists at the start of the second step of the MTP's stepwise approach (*Chapter 4.3.2: MTP Design*). Before the stated sequence of '*2.a*' until '*2.e*', an extra *step* can be added stating: "*Indicate the changeability of relevant context aspects*". The MTP is designed for filtering on uncertainties, sensitivities and perspectives, but one requirement can be added in the future that includes filtering on changeability. It can be

filtered in the scope – as it initially was – but including changeability in the design enables approaching a larger target group initially – which is beneficial for marketing and utility purposes – and transparent and structured filtering of the target group through the design.

Limitations in included higher organizational influences

The focus of this research is exclusively on the company level in which the PD process is executed. Due to research time restrictions and avoidance of generality of solutions this limitation was necessary.

The designs deal with this limitation by including higher organizational decisions and perspectives only in the theoretical backbone of the designs, mainly reflected in the components of the PDMO model. Resulting concept models include and leave space for decisions and perspectives from higher objectives but do not address them in detail. Flexibility of including them in more detail in further design iterations is ensured, making the limitation not affect the validity of the research results.

Limitations in the solution domains

For the concept models being utilized, the PDPMA model must include a wide range of existing models and methods for PD process optimization as solution domain and the PDMO model for guiding and structuring maturity optimization projects. For providing a starting point and illustration of the solution domain, only examples and illustrations of (parts of) models and methods are given, limited to prescriptive engineering models and methods.

This limitation however, does not influence the validity of the research results due to the included and ensured flexibility of the content of the concept models. The used information structuring and visualization methods support complementing and adjusting information, counteracting the limitation of the included solution domains. A focus on prescriptive models remains valid since the unstructured characteristic of descriptive models restricts them from being useful in the context of this research. Since product development practices is mainly seen as an engineering practice, the focus on engineering models seems valid. However – as PD becomes more and more a multidisciplinary team effort – (parts of) models and methods from other disciplines can be implemented easily forming a valuable addition to the solution domain.

Limitations due to use of existing literature

Literature sources take their limitations with them in this research, causing a risk of subjectivity or imbalances in results. Included company context aspects, limited and focused objectives of maturity assessments and included maturity dimensions and factors can be limited compared to reality.

Initially, the context aspects as identified by *Nieberding (2009)* are used to illustrate possibilities for content of this ontology in the PDPMA model. However, the concept model takes into account and requires complementation of information and content. If aspects as identified by *Nieberding* prove to be insufficient or overdetermined, adjustments can be made easily. During development, process maturity is kept as focus of the solution domain since the concept models aim for process optimization. The models exclusively focus on optimizing the process maturity, but – since context aspects such as people capability and product maturity are included as well as context aspects – increase in people maturity and object maturity can be expected as well. The focus on optimizing process maturity must be predominating, as the names of the concept models indicate. Not much knowledge exists on identifying and structuring maturity dimensions, flexibility of the PDMO model allows and requires revision of that content as well. Sensitivity of the validity of results requires continuous evaluation and validation of content. Transparency, openness and flexibility in content of the designs counteract wrong interpretation of solutions and contributes to objectively discussing and evaluating if limitations affect the validity of the designs. It must be ensured that validation and evaluation of the content is performed regularly for sustainability and reliability of results. As a result, validity of the research results are not affected by these limitations.

Summarizing validity influenced by scope and limitations

Based on previous discussion of the scope and limitations and their influence on the research results, the abstract strengths, weaknesses and opportunities of the research results are stated. Further opportunities for future research and development are discussed in the next chapter (*Chapter 7.3: Recommendations*).

Strengths:

- The concept models encourage and enable flexible adjustment and complementation of content as seen fit for increased value to the stakeholders. Therefore, the limited target group and solution domains are only temporarily and do not influence validity of the research results.
- The models take into account higher organizational context aspects and higher objectives of the company, counteracting the set limitation of excluding higher organizational influences.
- The risk of invalid results was present concerning out-of-scope filtering based on expected added value before the concept models are performed. Therefore, the designs include this selection and filtering for an accreditation decision of model execution.

Opportunities:

- The research does not present fully developed results, but identifies and contextualizes interesting opportunities for future research.
- It does not include a solution for a complete target group, but balances depth and required knowledge to deliver valuable results to a first limited target group, enabling future developments for enlarging the target group.

Weaknesses:

- Validity of the research results are not affected by limitations of used literature, provided that regular evaluation and validation of content is executed for sustainability and reliability of results. If this is not performed, limitations of used literature might influence validity of the models' results.

7.2.5 Validity influenced by assumptions

This section discusses the influence on assumptions used in this research on the validity of research results. Only the major assumptions are included and assessed for their certainty of being true and their sensitivity on results.

Company strategy as objective directive

Chapter 2: Maturity Vision: The company strategy defines and supports the company's main objective and is present in the company context before optimization takes place. The highest level of maturity represents the highest objective as stated in the company strategy and is assumed as being defined within a company.

This assumption is used in creating the maturity vision. If this assumption is wrong, a different source for interpreting an objective perspective aiming at company success is required for PDMO model and PDPMA model execution. Alternative solutions could for example compare and examine model results of multiple independent stakeholders to find the common perspective which is independent from individual biases. However, this assumption can be accepted in the scope and practicability of this research. Since company strategy reflects and aims at company success and is well known business essential, absence or inadequate formulation of the company strategy would already suggest that the company first needs to focus on determining what company success entails in their context before focus can be put on effectively and efficiently optimizing PD practices in specific. '*Success*' is defined as "*the fact that something wanted or is tried to get is achieved*". Therefore, a statement which defins what is wanted is required, in business context addressed by the company strategy. For utilizing research results, this assumption needs to be true.

Company success as highest maturity dimension

Chapter 2: Maturity Vision: The capability of performing the highest objective of achieving company success is the highest location of maturity.

Having all decision makers understanding and seeing the broader maturity vision as basis for objective decision making is the next step after interpreting the company strategy, leading to performance of the PDMO model and the PDPMA model respectively if PD process maturity requires optimization based on the PDMO model results. If this assumption is not true, the named 'company strategy' might not reflect the aim of achieving success of a single company, but may be based on a higher organizational strategy, including objectives of that maturity dimension to work towards organizational success. The research results allow focus on higher organizational objectives, company success overall is used in the concept models with flexible interpretation of on what operational level – success of a single company within a big organization or success of the large organization – the company success dimension acts. It is flexible and open to choose the highest objective dependent on the context and intended results, as long as its perspective is interpreted and used as highest directive for optimization decisions during performing the concept models.

7.2 Discussion

Quantification is only appropriate in relation to a context

Chapter 1: Introduction: Maturity, capability, effectiveness and efficiency cannot be quantified or estimated without a close relation to the context.

Figuratively speaking, if one company aims to achieve a randomly chosen *7.3* grade out of *10* on efficiency, another company might aim for increasing efficiency from a *9.7325* to a *9.7330* out of *10*. The contexts of the companies determine everything for interpreting those numbers. For example, the bakery on the corner of the street wants some spare time to spend it on selling his goods on the marketplace, aiming for an increase of efficiency from *5* to *7.3* out of *10* which might be sufficient to achieve his objective. However, if an automobile parts developing company needs to increase efficiency to keep-up to requirements of high performing customers, *7.3* out of *10* will not even be close to performances of competitors, and minor improvements of the secondly mentioned efficiency increase determine who has competitive advantage. The added value of the research results relies in this assumption, since complex multi-criteria decisions would not be necessary if the context did not have influence on the effectiveness and efficiency of solutions. Since industry and academy both struggle with finding appropriate solutions per context and solutions that do not take into account the context are not utilized effectively and efficiently, this assumption can be accepted in this research' context.

Success on maturity dimensions and factors related

Chapter 2: Maturity vision and Chapter 3: PDMO model design: Success of a maturity factor is a necessary but not sufficient condition for success of a maturity dimension.

Consequently, PD process success is a necessary but not the only condition for PD success, which in its turn is a necessary but insufficient condition of company success. This assumption can be accepted, after it is reasoned by using logic sense. A maturity dimension is based on a – it may be an underdefined – set of maturity factors. The success of the dimension is not defined by summing the successes of the maturity factors, as the functioning of a '*system*' cannot be guaranteed with validated functioning of its '*parts*'. This provokes the use of the word '*insufficient*'. However, a dimension that contains a maturity factor which is ineffective or inefficient, can never be effective and efficient itself. Therefore, it is necessary to have high maturity on the maturity factors for success on the maturity dimension, proving validity of the word '*necessary*'. With this combination, the assumption can be accepted within the context of this research.

7.2 Discussion

Summarizing validity influenced by assumptions

Based on previous discussion of the assumptions, their influence on the research results are summarized. Assumptions are discussed for their certainty of being true and the sensitivity of the validity of research results. Assumptions with high certainty or low sensitivity are not threatening to the validity of results, assumptions with low certainty and high sensitivity are threatening and validation of the assumption is required in future research or future design iterations must target the designs' sensitivity for these assumptions.

Assumptions with high certainty or low sensitivity:

- The capability of performing the highest objective of achieving company success is the highest location of maturity.
- Maturity, capability, effectiveness and efficiency cannot be quantified or estimated without a close relation to the context.
- A high – or, success on a – maturity factor is a necessary but not sufficient condition for high – or, success on a – maturity dimension on a higher location.

Assumptions with low certainty and high sensitivity

- The company strategy defines and supports the company's main objective and is present in the company context before optimization takes place. The highest level of maturity represents the highest objective as stated in the company strategy and is assumed as being defined within a company.

  For utilizing the research results, *(1)* this assumption needs to be proven as being true or *(2)* the design needs to be adapted in future developments counteracting on the sensitivity for this assumption. Since a mature company strategy can be seen as a business essential, the author recommends for these situations to implement option one *(1)*, and advices to first define an appropriate and mature company strategy that reflects company success before optimizing other processes within the company. Doing otherwise may result figuratively in optimizing a road that leads into a ravine, since the end point is not known.

7.3 Recommendations

This section states recommendations for future research which are identified during this research. Research and development recommendations for the PDMO and PDPMA model designs are stated and additional validation steps are recommended that may lead to development of design iterations in the future. The transformation of the model in a practical software tool enables application in practice. However, before that is possible, future research and development steps are required.

Develop the models

The concept models are sensitive to the quality of the given input information. Therefore, it is recommended to investigate opportunities for a measurement step which validates given input as it travels through the models. Since this research' results present the designs from the concept phase, such details are not yet included.

The information visualization and structuring methods in the concept models are evaluated for their capability of fulfilling the stated requirements. However, how capable they are is not assessed in detail. Comparison and selection of other visualization methods as well is required to design iterations of the concept models, and assure mature information visualization and structuring methods. Additional literature research on data visualizations, taxonomies and ontologies can be useful for achieving that. Iterations for taxonomy visualizations such as stated in *Müller & Schumann (2003)* can form inspirations for future visualization methods, enabling deliberate comparison of static, dynamic, conventional and multivariate visualization methods for the intended functions.

The difficulty of relating contexts to process structures, is the required mix of practical and theoretical knowledge. This might be a reason why existing literature does not often state how to adapt developed artefacts to fit specific contexts. However, this functionality is required for the PDPMA model development. For developing the PDPMA model further, the context ontology needs to be connected to required functionalities. Most of them can be identified by PD specialists in industry or by logic sense, since it is a small step to get from such detailed company aspect parameters to connected functions. Best practices can support with identifying those relations, but are not preferred. In parallel, the model and method ontology needs to be complemented with a broad range of existing process structures. For this process – with theoretical knowledge from the Design Science domain – information on product development processes and their artefacts is required. It needs to be implemented in the database with taking them apart in small model and method parts, which can be evaluated for their reason for existence. The reason for existence is closely related to the function they perform. Therefore, relating them to corresponding functions is a realistic and doable step. The functions ontology quickly expands after filling in some elements, for that reason the explained classification of functions is useful and necessary while developing the ontologies in the future. Such classification methods are used often for comparing research. An example of such a process for mapping information through classification is provided in *Figure 45*.

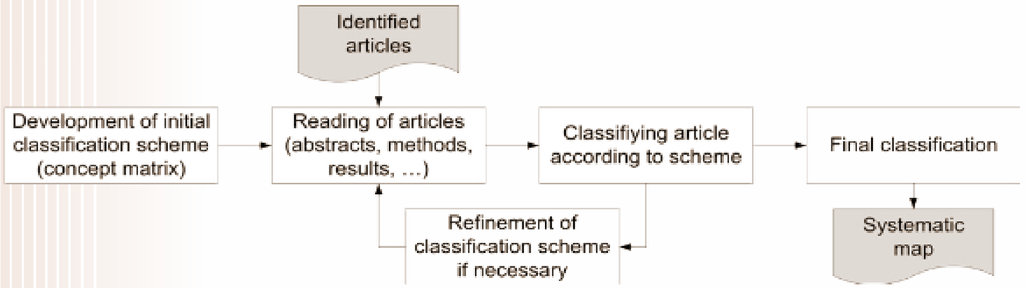

Figure 45 - Image retrieved from (Wendler, 2012), representation of a systematic classification process

The PDMO model mainly requires complementation of the maturity dimensions ontology as a database. Since the domain is complex and limited knowledge is available on maturity dimensions in a PD context, identification of more detailed maturity factors in industry is recommended. This provides an additional detailed layer to assist future developers in developing a tool for the inspirational maturity dimensions database, enabling a higher quality of input information and richer analyses of maturity profiles. Consequently, the maturity profiles can be presented in the accuracy that meets the user's requirements.

Since PD becomes more and more a multidisciplinary team effort, in the future it can be useful to include PD process structure solutions from other domains as well. Further research on implementation and suitability of such solutions in the PDPMA model and PDMO model designs must be performed.

For future iterations of the PDPMA model, the Maturity Test Part (MTP) needs to be adapted slightly to fit the Optimization Strategy Part (OSP) and PDPMA model objective better. This change is discussed and validated comprehensively in *Chapter 7.1.4: PDPMA model design validation*. Furthermore, during MTP design the required validation for changeability of the context is mentioned, but is not reflected properly in the concept with the stepwise approach. Both adjustments form the inducement for MTP improvement in future developments of PDPMA model iterations.

The CIP is only presented through a design brief, aiming for future development. The development of the CIP mainly corresponds to the Industrial Engineering domain. It is recommended to develop the CIP in parallel with further PDPMA model developments, to tune solutions and design decisions. Furthermore it is recommended to provide this report as addition to the design brief, for contextualizing the CIP objective, requirements and interface between the OSP and CIP.

This research does not include detailed examinations of data acquisition methods. Input information for the concept models' steps requires some data acquisition techniques in order to achieve the necessary information from the stakeholders. However, this research is limited to state what information is required and illustrate some possibilities for achieving that information. Additional research for effective and efficient data acquisition methods is therefore required.

Execute the models

In further developments of the concept models, extra attention must be given to communicating and assuring the required endeavour from both sides. First ideas include stating '*criteria for success*' or adding this requirement in a project contract. Other solutions need to be investigated as well to effectively and efficiently assure a cooperation which is mutual beneficial.

After previously stated further development is performed and initial operation has taken place, the designs benefit from further validations. *Sargent (2010)* stated other validation steps related to finished designs and simulation models which can be performed. Case testing and interviewing industrial stakeholders can be used to validate expected outcomes and evaluate the '*real*' added value of the models for the industry. Operational validity needs to be strived for to determine whether the models' output behaviours have the accuracy which is required by the users. *Sargent (2010)* discusses validation techniques applicable for this type of validation, but application is only sensible after further development. After further development is performed, stated *MOEs* for the PDMO model can be tested, for example with using the theory developed by *Sproles (2002). MOEs* for the PDPMA model can be stated as well. However, effectiveness cannot be measured in a concept phase and therefore needs validation after development. Other effectiveness and efficiency validation methods can be explored as well for application in this research' context.

7.3 Recommendations

Summarizing recommendations for future research and development

The previously discussed recommendations are briefly listed to form an overview of potentials for future research and development.

Recommendations for future development

- The research results would benefit from an additional examination of steps that measure the quality of input information.
- Assessment and validation of the capability of the visualization and structuring methods is recommended, combined with developing iterations based on other methods that fulfil visualization and information structuring requirements.
- Further research and development is required for completing and filling the ontologies.
- After further research and development, the designs must be developed into a practical software tool.
- The MTP requires a new iteration in which it closes the gap between the objective and the design.
- The CIP needs to be developed based on the design brief and information in this report.
- Research and development must be performed for data acquisition methods and their effectiveness and efficiency in the context of the concept models.
- Recommendations for models' operation
- The required endeavour or effort from both sides needs to be assured, additional research for suitable methods is required.
- Additional validity and verification tests must be performed after further development.

7.4 Conclusion

This chapter concludes the research from a high level of abstraction, moving briefly from the initial knowledge towards an overview of the most important findings.

Companies strive for success – or '*maturity*' as '*the capability to achieve success*' – and act towards that by optimizing their value creating processes. With the motive to optimize processes, maturity optimization projects are initiated. They are guided and structured by maturity audit models which assess the situation, identify potential improvements and change the process to make it more effective and efficient. Effectiveness represents '*doing the right things*', where efficiency is '*doing the tings right*'. The Design Science domain in the academical context aims at providing useful artefacts that guide and structure processes such as optimization, production and product development processes. Developed maturity audit models or process structuring models and methods are the result.

Product Development (PD) is a possible value creating process that can be optimized in the industry. Surprisingly, existing maturity audit models do not adequately target PD practices in specific for optimization. Furthermore, literature on PD process structuring and optimization do not sufficiently address tailoring the structures to the company contexts. However, since effectiveness and efficiency are directly influenced by the context, it is necessary to tailor process structures. That context brings uncertainties, sensitivities and stakeholder involvement, resulting in complex multi-criteria decisions concerning optimization projects and process structuring solutions.

For finding and interpreting the '*appropriate*' solution which optimizes a process, external companies are involved which perform maturity audits for processes in companies. However, due to '*utility*' as measure for model and method success – among others – external companies are biased in the proposed solutions and process structures. Furthermore, detailed insights in the maturity audit models used by the external organization are often concealed. In combination with the complexity of the decisions concerning optimization, the optimization projects are not performed objectively with company success as highest aim. Underpinned results are missing and decisions on the projects are too complex to openly discuss, compare and validate solutions. In conclusion, objective insights in PD maturity improvement in industry is limited and artefacts for maturity optimization and PD process structuring are not utilized effectively and efficiently.

For those reasons, this research aims at providing insights in improving industry's PD maturity. With those insights, the industry is capable of making deliberate decisions related to optimization projects and PD maturity in specific. This is a twofold research objective. To start with, optimizing a maturity dimension (a process with a certain level of maturity) does not automatically result in increased company success. Therefore, insight in the path from the optimization project to company success is required. Hence, the optimization project can be validated objectively for effectively and efficiently contributing to company success. Furthermore, if the PD process is identified as the 'appropriate' maturity dimension to optimize regarding to achieving company success, insight in the path from the current PD process into a more effective and efficient PD process is required. This research results in a vision on maturity and two concept models that combined achieve the twofold research objective. They form a starting point and illustrate what is possible in the future regarding PD maturity optimization in industry.

Based on the knowledge on product development processes, environments, process optimization and existing PD process structures (*Chapter 1: Introduction*) the need for a strong vision as directive for maturity optimization model development is identified. A maturity vision is developed (*Chapter 2: Maturity vision*), which states that higher objectives – as represented by the company strategy for company success as highest objective – form the directive for selecting processes for optimization. Success on a maturity factor (a process that contributes to higher objectives) is a required but not sufficient condition for success on a maturity dimension (the dimension that strives for achieving the higher objective). In other words, optimizing a process does not automatically lead to success on higher objectives. Therefore, identifying maturity dimensions for effective and efficient optimization uses a top-down approach, where the optimization acts bottom-up, from process optimization to company success.

For providing insights in the influences of maturity optimization on company success, based on the vision, the Product Development Maturity Optimization (PDMO) concept model is designed (*Chapter 3: The PDMO concept model*). It provides insights in maturity contexts advocating PD process Maturity optimization. This design contains three components (the MLC, MRC and MOC) to support decision makers for optimization projects in selecting an appropriate maturity factor to optimize, which contributes effectively and efficiently to company success as highest objective.

Specifically for PD processes, knowledge on maturity optimization is limited. For PD processes, no effective and efficient maturity audit models exist. Therefore, in this research a concept model is developed for optimizing PD process maturity (*Chapter 4: The PDPMA concept model*). The PDPMA model forms one possible solution within the solution domain of the PDMO model.

The PDPMA model starts with validating if accreditation of the complete model is valuable for the specific context (*Chapter 4.3: PDPMA model design: MTP*). After positive results, the PDPMA model relates specific context parameters to relevant model and method parts through corresponding functions, forming a relation profile (*Chapter 4.4: PDPMA model design: OSP*). The results from the relation profiles are the input for a change and implementation advice of which a design brief is stated in this research (*Chapter 4.5: PDPMA model design: CIP*).

The PDMO model is capable of providing insights in the value of optimizing a specific process in the company context, guiding decision makers to optimization process selection while aiming for company success. The PDPMA model is capable of proposing appropriate solutions for PD process structures, tailored to the company context. First ideas for iterations are stated, recommending *(1)* research for other maturity factors influencing PD process success (other than PD process structure) and *(2)* proactively including '*changeability*' of the company context as criterium for successful PDPMA model execution.

The valuable combination of practical and theoretical knowledge is made accessible to industry with developing the PDMO and PDPMA model into practical tools. Combined, they provide the industry with insights in improvement of their PD maturity. The designs enable stakeholders in optimization projects to make deliberate decisions regarding optimization projects and PD process optimization. The versatile designs that use network visualization and information structuring methods allow availability, flexibility and sustainability of the models' content. Optimization project execution with use of the PDMO model and / or PDPMA model allows tailoring focus and effort to the (often fluctuating) needs of industrial stakeholders, contributing to the industry's aim for company success.

This research contributes to the Design Science domain and builds on standards for model development and validation. Research results are presented as generic semantic ontologies – independent of specific instances – exploring maturity assessments for a new application: PD optimization. The PDMO and PDPMA model have three unique characteristics: the focus on Product Development practices, the use of company success and the strategy used for relating context with solutions based on overlapping functions. By providing the industry with insights in the potential value of them, utilization of developed artefacts by the academy is promoted, contributing to the success of the Design Science domain. This research does not present fully developed results, but identifies, illustrates and contextualizes interesting opportunities for PD maturity optimization in industry. It describes a proof-of-concept model development success, providing tailored insights in improvement of industry's PD maturity.

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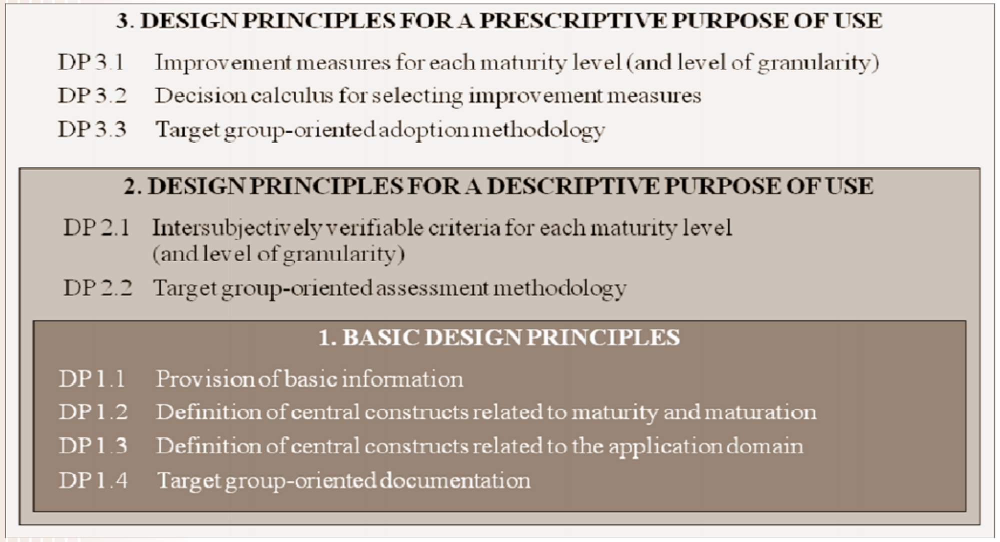
8 Appendices

Chapter content

8.1 Principles of maturity models

Referred to from Chapter 1.4.4: Development methodology, page 42

Röglinger, Pöppelbuß, & Bekcer (2012) provide a framework of general Design Principles (DPs) for maturity models. This Appendix compares the themes identified in the Introduction with the design principles to indicate the overlap between the research context and maturity models as solution domain.



Framework of general DPs for maturity models (retrieved from Pöppelbuß and Röglinger (2012))

DP 1.1 "Provision of basic information"

- Process structuring models and methods
- Effectiveness and efficiency
- Model and method (part) selection
- Change and implementation decisions
- Maturity definitions and assessments

DP 1.2 "Definition of central constructs related to maturity and maturation"

- Model and method design for structuring and guiding the maturity optimization project
- Universal language for maturity context with levels and locations

DP 1.3 "Definition of central constructs related to the application domain"

- Definition of required context inputs
- Definition of the solution domain
- Model and method design for implementation criteria determination for context

DP 1.4 "Target group-oriented documentation"

- Communication of information for transferring insights to the industrial target group

DP 3.1 "Improvement measures for each maturity level (and level of granularity)"

- Model and method design for insights in relations between context and models and methods
- Model and method design for comparison between the current and the optimized situation

DP 3.2 "Decision calculus for selecting improvement measures"

- Model and method design for optimization cost-benefit analysis for context

DP 3.3 "Target group-oriented adoption methodology"

- Models and methods designed for availability and understanding of the target group

8.2 Model development standards

Referred to from Chapter 1.4.4: Development methodology, page 43

Mettler (2011) defines decision parameters which guide the development of the model towards the initial intentions. As standard for maturity model development, the intentions for the PDMO model and PDPMA model are filled in at the start of the concept development phase. These decision parameters guide during development and help contextualizing and defining the models afterwards. Furthermore, the global PD context parameters as identified by Nieberding (2009) are filled in for the context of this research. Based on those, a suitable approach can be selected.

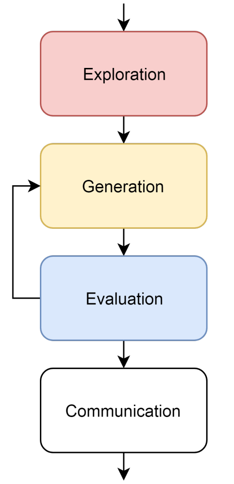
PDMO model
PDPMA model

Phase	*Decision parameter*	*Characteristic*			
Define scope	Focus/breadth	General issue		Specific issue	
	Level of analysis/depth	Group decision-making	Organisational considerations	Inter-org. considerations	Global and societal considerations
	Novelty	Emerging	Pacing	Disruptive	Mature
	Audience	Management-oriented	Technology-oriented		Both
	Dissemination	Open		Exclusive	
Design model	Maturity definition	Process-focussed	Object-focussed	People-focussed	Combination
	Goal function	One-dimensional		Multi-dimensional	
	Design process	Theory-driven	Practitioner-based		Combination
	Design product	Textual description of form	Textual description of form and functioning		Instantiation (assessment tool)
	Application method	Self-assessment	Third-party assisted		Certified professionals
	Respondents	Management	Staff	Business partners	Combination
Evaluate design	Subject of evaluation	Design process	Design product		Both
	Time-frame	Ex-ante	Ex-post		Both
	Evaluation method	Naturalistic		Artificial	
Reflect evolution	Subject of change	None	Form	Functioning	Form and functioning
	Frequency	Non-recurring		Continuous	
	Structure of change	External/open		Internal/exclusive	

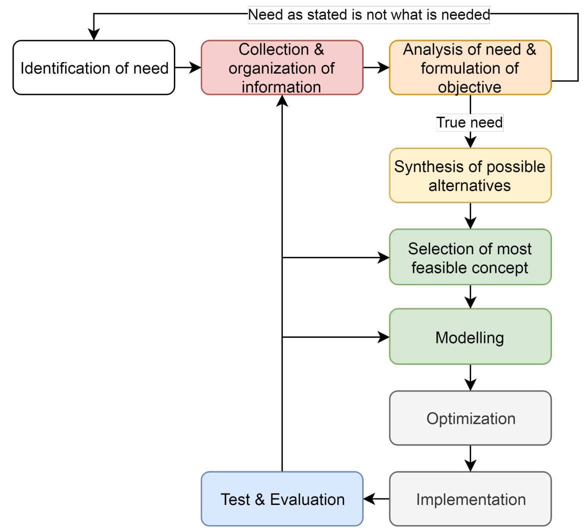
Filled in decision parameters for development of maturity assessment models, as stated by Mettler (2011)

Context aspects concerning this research project explained with use of identified context parameters by Nieberding (2009)

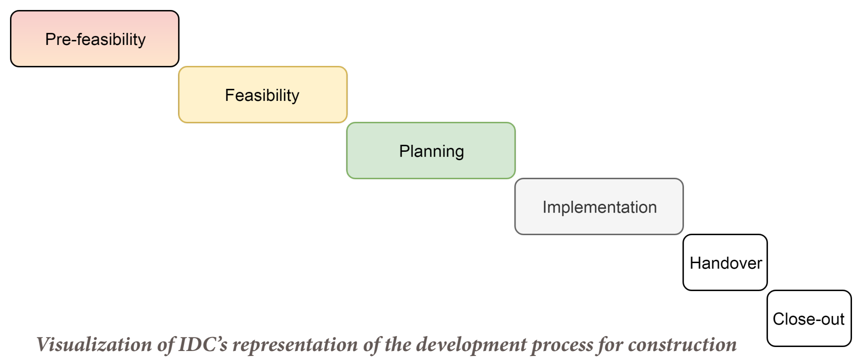
Context aspect	Description for the research project context
Project size	Limited to realistic for performing within 10 months fulltime, by one person
Project type	Between redesign and original design
Project constraints	Time (10 months), resources (1 person), other limitations as stated in the scope chapter
Project complexity	Mediocre complexity: mainly caused by complicacy, limited opacity and multiple objectives
Organization size	University of Twente, faculty DPM, limited to a master thesis student's resources
Organization type	Customized product development, with focus on innovativeness and theoretic foundations
Organizational maturity	Mature in its function of guiding, evaluating and assessing master assignment projects
Organization structure	A specialist is assigned as guide during the process, and evaluates and assesses the project
Organization design capacity	High, design resources are sufficient
Product complexity	*Mediocre complexity: mainly caused by complicacy, limited opacity and multiple objectives*
Product level in hierarchy	PDPMA model on component level and PDMO model on system level
Product type	Maturity Audit Model on two levels of abstraction (PDPMA model and PDMO model)
Personnel team size	1 person
Personnel level of maturity	Level of an Industrial Design Engineering master student
Personnel design capability	Level of an Industrial Design Engineering master student



Visualization of Cross' model for product development (Cross, 1994)



Visualization of Suireg's representation of the product development process (Suireg, 1981)



Visualization of IDC's representation of the development process for construction projects (Nieberding, 2009)

8.3 Levels of relations

Referred to from Chapter 4.4.2: OSP Design, page 112

Chapter 4.4.2: OSP Design introduced three levels on which relations between a specific company context and effective and efficient process structures can be identified. The three levels of relating are discussed, all with using terms as level of detail, level of uncertainty and required knowledge depth.

Relations based on abstract characteristics

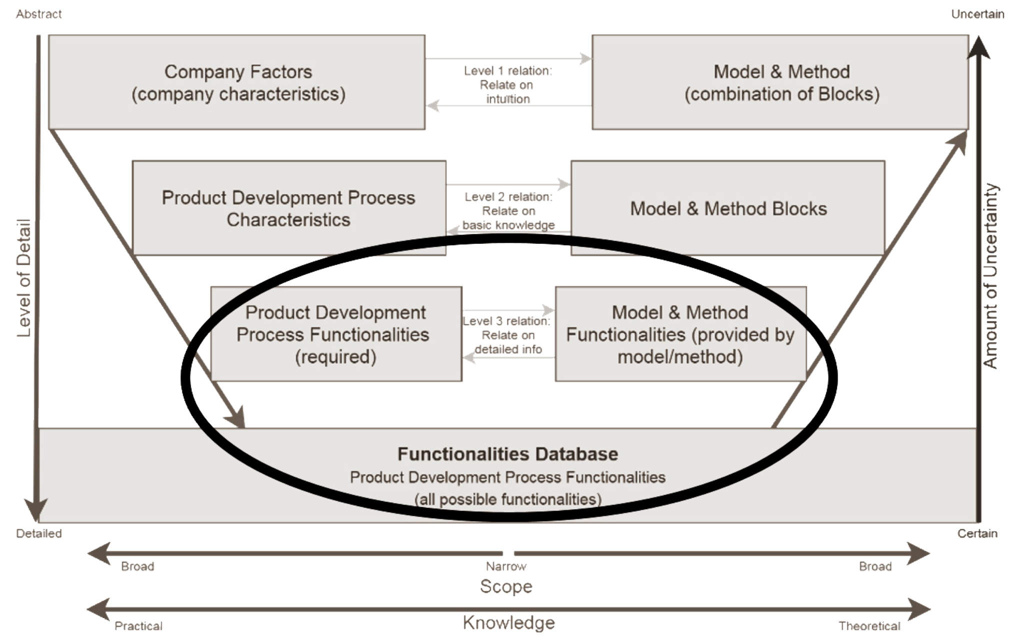
The majority of maturity assessing literature uses this level of relating. They examine the best practices for model and method use in certain branches of the industry and their success. They identify practical, broad, organization-wide context characteristics and relate them to theoretical and abstract characteristics of models and methods. The relation is based on e.g. observations and intuition, after the project (in its context) has taken place. These relations, based on characteristics of both abstract sides (context and structures), have a low level of detail and a broad scope. They can only partly be extrapolated to other companies in the future for PD process improvement projects, since they provide only limited insights in context differences and influences of that on the best practices. Therefore, lack of structure and detailed relations of this approach, result in a high level of uncertainty.

Relations based on detailed characteristics

By specifying the context to only the PD process context within the company on one side and the specific steps described within models and methods on the other side, slightly more detail is added in relating both. More detailed relations can be identified and justified in a more structured way. Only the influencing characteristics are taken into account, which narrows the scope slightly and decreases the uncertainty, since focus is on more detailed relations and detailed theory behind those relations. More detailed knowledge is required on what the PD context within the company looks like and what steps models and methods consist of. Characteristics from those are determined and related based on logic sense and an abstracted mix of practical and theoretical knowledge.

Relations based on detailed functions

The previous options for relating have the disadvantage that all characteristics of both sides are linked to each other, without validating the added value and the 'reason for existence' of those characteristics and (process) steps. By looking at the 'reason for existence', a filter is placed on the relations which only allows value adding relations to exist. The 'reason for existence' closely interacts with the 'function' of an aspect. For the PD process, all functionalities the PD process requires are searched for. For the models and methods, all the provided functionalities of the single detailed aspects within the models and methods are searched for. This enables relating the required functions by the company with the provided functions by the (parts of) models and methods, resulting in only value adding relations on a very detailed level. Using the functions as common ground to relate both sides of context and structures splits the practical and theoretical knowledge fields, enabling separate relating them. This level of relating requires highly detailed knowledge, which is difficult to obtain as broad practical and theoretical specialized knowledge. In this narrow scope of only functions, very detailed PD process aspects and model and method components need to be identified and worked with. The structured approach and level of detail result in a low level of uncertainty and a better theoretical base for proving the existence of the relation.



V-shaped structure of the location and characteristics of relations between company context and models & methods

8.4 Change and implementation theory

Referred to from Chapter 4.5.2: CIP Design brief, page 122

By (2005) compared three models of emergent change for their steps. These steps are examples of possibilities for the CIP design.

Table 4. A comparison of three models of emergent change

Kanter *et al.*'s Ten Commandments for Executing Change (1992)	Kotter's Eight-Stage Process for Successful Organisational Transformation (1996)	Luecke's Seven Steps (2003)
1) Analyse the organisation and its need for change		1) Mobilise energy and commitment through joint identification of business problems and their solutions
2) Create a vision and a common direction	3) Developing a vision and strategy	2) Develop a shared vision of how to organise and manage for competitiveness
3) Separate from the past		
4) Create a sense of urgency	1) Establishing a sense of urgency	
5) Support a strong leader role		3) Identify the leadership
6) Line up political sponsorship	2) Creating a guiding coalition	
7) Craft an implementation plan		
8) Develop enabling structures	5) Empowering broad-based action	
9) Communicate, involve people and be honest	4) Communicating the change vision	
10) Reinforce and institutionalise change	8) Anchoring new approaches in the culture	6) Institutionalise success through formal policies, systems, and structures
	6) Generating short-term wins	
	7) Consolidating gains and producing more change	
		4) Focus on results, not on activities
		5) Start change at the periphery, then let it spread to other units without pushing it from the top
		7) Monitor and adjust strategies in response to problems in the change process

R.T. By's comparison of emergent change models: "A comparison of three models of emergent change" (By, 2005)

8.5 Work packages example

Referred to from Chapter 6.2: Models as tools, page 136

Work packages can help in selecting and tailoring maturity audit steps to the needs of a company. Due to the flexible design concerning duration and depth of assessments, the PDMO and PDPMA model execution can be formed to fit the project best. The table below illustrates an example of such an activity distribution for the PDPMA model into work packages.

Work Package	**Activity description**
WP1 *Maturity Test*	The MTP performed with MRC and MLC steps and the rough relation profile filled in
WP2a *Optimization (Basic)*	The OSP performed resulting in one relation profile for the company context
WP2b *Optimization (Pro)*	The OSP performed with additional scenarios and information structuring functionalities, where multiple relation profiles can be compared and deliberate selection of one is guided
WP3a *Change and Implementation (Basic)*	A static advice for change management and implementation is provided by the external organization with the insights in the relation profiles and information behind that advice
WP3b *Change and Implementation (Pro)*	Dynamically an advices for change management and implementation is created in cooperation with the company, with guidance in prioritizing and detailed steps for activities
WP4 *Implementation guidance*	Optionally a fourth Work Package can be offered for actively guiding the implementation process based on the provided advice. However, this requires additional human resources with experience in change management and implementation in the target group sector.

Work packages illustrating activity sub-sectioning for the PDPMA model

8.6 Validation techniques

Referred to from Chapter 1.4.5: Validation and verification approach, page 45

Chapter 7.1: Global validation *validates the designs. For doing so, the verification and validation theories of R.G. Sargent (2001) and D.K. Pace (2004) are used. This appendix lists the validation procedure as recommended by R.G. Sargent (2010) and validation and verification techniques identified by him. Suitable verification and validation techniques for this research are the ones that do not need quantifiable data or detailed results, since only a concept design as starting point and illustra*tion for a future design is developed.

Recommended procedure (Retrieved from *R.G. Sargent (2010)*)

1. An agreement be made prior to developing the model between (a) the model development team and (b) the model sponsors and (if possible) the users that specifies the basic validation approach and a minimum set of specific validation techniques to be used in the validation process.
2. Specify the amount of accuracy required of the simulation model's output variables of interest for the model's intended application prior to starting the development of the model or very early in the model development process.
3. Test, wherever possible, the assumptions and theories underlying the simulation model.
4. In each model iteration, at least perform face validity on the conceptual model.
5. In each model iteration, at least explore the simulation model's behaviour using the computerized model.
6. In at least the last model iteration, make comparisons, if possible, between the simulation model and system behaviour (output) data for at least a few sets of experimental conditions, and preferably for several sets.
7. Develop validation documentation for inclusion in the simulation model documentation.
8. If the simulation model is to be used over a period of time, develop a schedule for periodic review of the model's validity.

Validation and verification Techniques for models and simulations

Retrieved from R.G. Sargent (2010). Techniques not applicable to (parts of) the designs in this research are visualized in grey.

- Animation: The model's operational behaviour is displayed graphically as the model moves through time. E.g., the movements of parts through a factory during a simulation run are shown graphically.
- PDPMA model results validation: Process animation through Siemens NX to validate relevant parameters resulting from the process
- Comparison to Other Models: Various results (e.g., outputs) of the simulation model being validated are compared to results of other (valid) models. For example, (1) simple cases of a simulation model are compared to known results of analytic models, and (2) the simulation model is compared to other simulation models that have been validated.
- PDPMA model design validation: approach compared to Maturity Audit models for other maturity dimensions
- Extreme Condition Tests: The model structure and outputs should be plausible for any extreme and unlikely combination of levels of factors in the system. For example, if in-process inventories are zero, production output should usually be zero.
- PDPMA & PDMO model scope validation: validating results for set boundaries
- Face Validity: Individuals knowledgeable about the system are asked whether the model and/or its behaviour are reasonable. For example, is the logic in the conceptual model correct and are the model's input-output relationships reasonable.
- PDPMA & PDMO model result validation: are the results reasonable and logic sense for internal process experts; then why are they not yet implemented?
- Historical Methods: The three historical methods of validation are rationalism, empiricism, and positive economics. Rationalism assumes that everyone knows whether the clearly stated underlying assumptions of a model are true. Logic deductions are used from these assumptions to develop the correct (valid) model. Empiricism requires every assumption and outcome to be empirically validated. Positive economics requires only that the model be able to predict the future and is not concerned with a model's assumptions or structure (causal relationships or mechanisms).
- PDPMA & PDMO model design validation: are the steps within the model clearly stated and underpinned based on logic sense
- Internal Validity: Several replications (runs) of a stochastic model are made to determine the amount of (internal) stochastic variability in the model. A large amount of variability (lack of consistency) may cause the model's results to be questionable and if typical of the problem entity, may question the appropriateness of the policy or system being investigated.
- PDPMA & PDMO model result validation: Validating sensitivity of results for inputs from a variety of stakeholders
- Parameter Variability - Sensitivity Analysis: This technique consists of changing the values of the input and internal parameters of a model to determine the effect upon the model's behaviour or output. The same relationships should occur in the model as in the real system. This technique can be used qualitatively—directions only of outputs—and quantitatively—both directions and (precise) magnitudes of outputs. Those parameters that are sensitive, i.e., cause significant

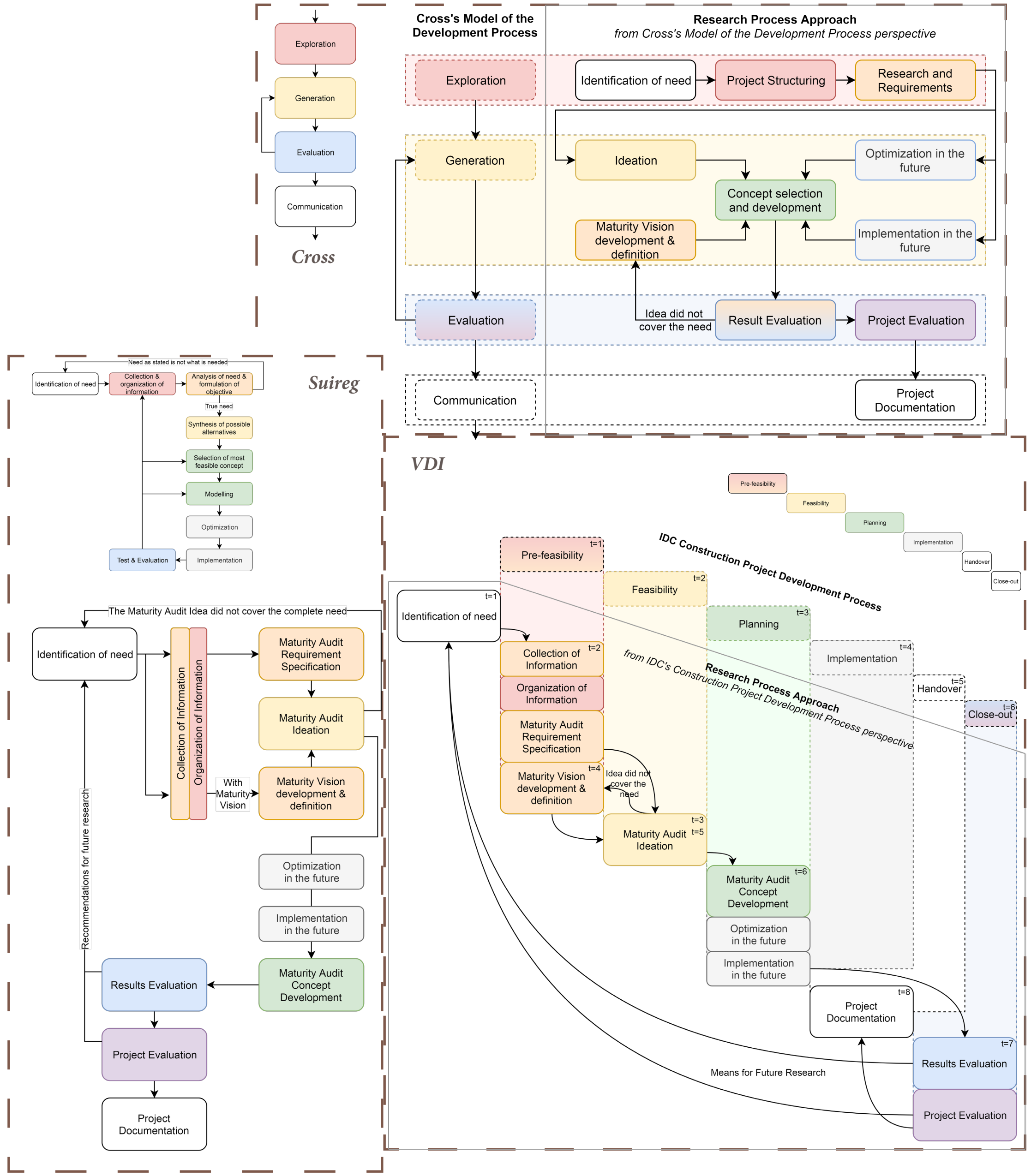
changes in the model's behaviour or output, should be made sufficiently accurate prior to using the model. (This may require iterations in model development.) PDPMA & PDMO model result validation: Validating sensitivity of results for differences in input and making them sufficiently accurate before model utilization

- Traces: The behaviours of different types of specific entities in the model are traced (followed) through the model to determine if the model's logic is correct and if the necessary accuracy is obtained.
- PDPMA & PDMO model design validation: Validating steps within the model and the logic behind them
- Degenerate Tests: The degeneracy of the model's behaviour is tested by appropriate selection of values of the input and internal parameters. For example, does the average number in the queue of a single server continue to increase over time when the arrival rate is larger than the service rate?
- Event Validity: The "events" of occurrences of the simulation model are compared to those of the real system to determine if they are similar. For example, compare the number of fires in a fire department simulation to the actual number of fires.
- Historical Data Validation: If historical data exist (e.g., data collected on a system specifically for building and testing a model), part of the data is used to build the model and the remaining data are used to determine (test) whether the model behaves as the system does. (This testing is conducted by driving the simulation model with either samples from distributions or traces.)
- Multistage Validation: Naylor and Finger (1967) proposed combining the three historical methods of rationalism, empiricism, and positive economics into a multistage process of validation. This validation method consists of (1) developing the model's assumptions on theory, observations, and general knowledge, (2) validating the model's assumptions where possible by empirically testing them, and (3) comparing (testing) the input-output relationships of the model to the real system.
- Operational Graphics: Values of various performance measures, e.g., the number in queue and percentage of servers busy, are shown graphically as the model runs through time; i.e., the dynamical behaviours of performance indicators are visually displayed as the simulation model runs through time to ensure they behave correctly.
- Predictive Validation: The model is used to predict (forecast) the system's behaviour, and then comparisons are made between the system's behaviour and the model's forecast to determine if they are the same. The system data may come from an operational system or be obtained by conducting experiments on the system, e.g., field tests.
- Turing Tests: Individuals who are knowledgeable about the operations of the system being modelled are asked if they can discriminate between system and model outputs.

8.7 Research process evaluation

Referred to from Chapter 7.1.5: Research process evaluation, page 160

Cross' model is selected in the Introduction as guiding and structuring model during this research. However, after comparing the 'as-was' with the 'intended' process, the model of Suireg would have fit this research better.

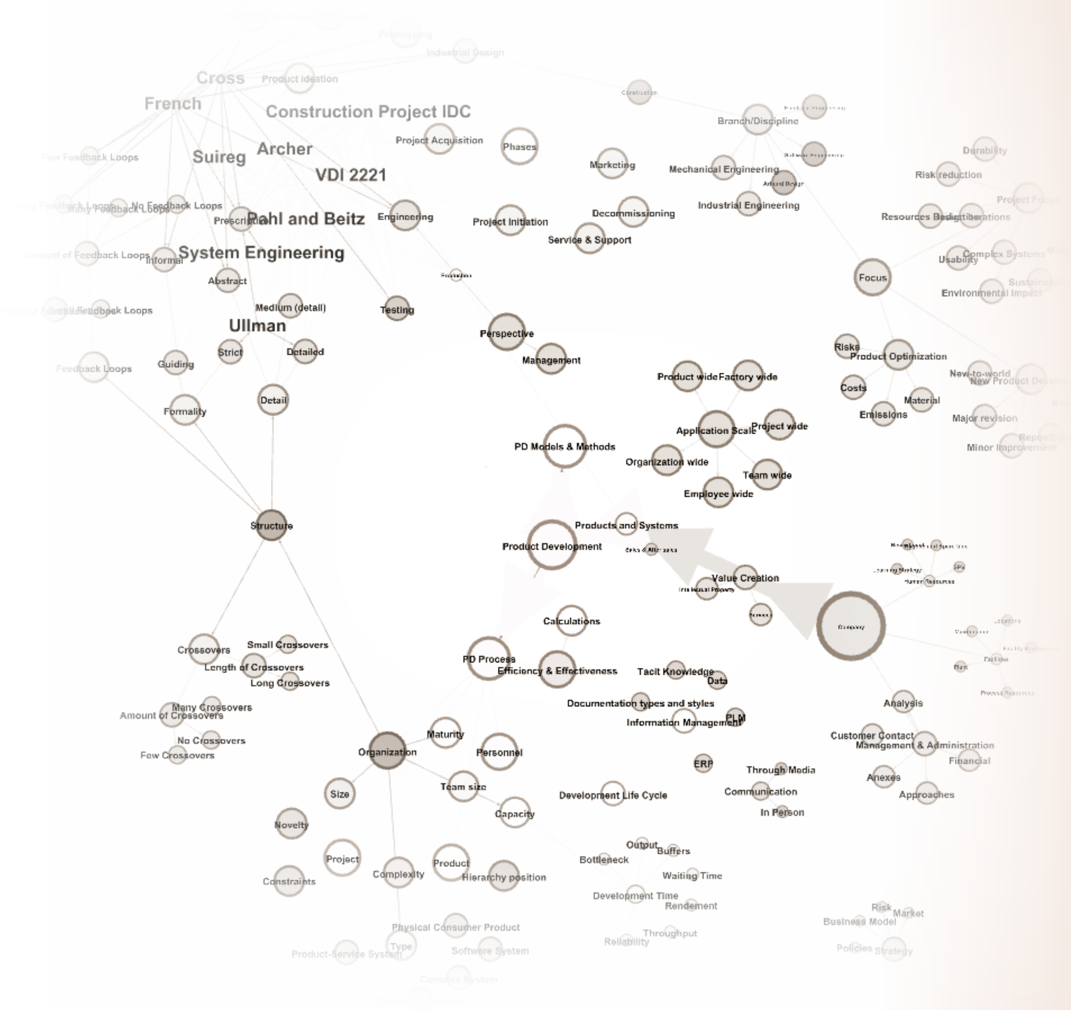


Comparisons of the 'as-was' process with the 'intended' process models

8.8 Research Claims

Referred to from Chapter 7.2.1: Summarizing the research results and key findings, page 163

- *Effectiveness & efficiency are directly influenced by the PD process in the context.*
- *PD process structures support specific contexts' effectiveness and efficiency if related on a detailed level.*
- *Decisions with uncertainties, sensitivities and perspectives can be made objectively from company strategy perspective.*
- *Success on a maturity factor is a required but insufficient condition for success on a maturity dimension.*
- *Insights in uncertainties and sensitivities on decision outcomes enables deliberate decision making.*
- *Quantification of maturity levels, effectiveness & efficiency and capability is fully dependent on the context.*
- *Appropriateness of process structures depends on the context.*
- *Within the research scope, the effectiveness & efficiency of the PD process directly influence the amount of value creation by the company.*
- *Optimization projects roughly follow comparable steps to go from a current into an improved situation.*
- *On a high abstraction level, every PD process uses the same flow of logic, resulting in generality in models & methods.*
- *Process maturity optimizations are known and recognized positively in industry.*
- *Models & methods are able to provide guidance and understanding of processes, systems and situation, contributing to the research objective.*
- *Success of a model or method, results in utility due to their capability to increase value creation and the attention they get from stakeholders.*
- *The value of maturity audits for industry is in objective insights creation for change and implementation activities.*
- *Assessments by external companies contribute to more objective interpretations of maturity levels.*
- *Industry requires and values 'how-to' AND 'why-to' information for optimization.*
- *PD is responsible for a large amount of value creation in industry.*
- *Providing companies with objective, detailed, practical and substantiated insights for improving their PD maturity closes identified knowledge gaps and fulfils identified industrial needs.*



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A product development success?

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