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Product Lifecycle Management Maturity Model Development

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Marko Paavel

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TALLINNA TEHNIKAÜLIKOOL
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Toote elutsükli halduse küpsusmudeli arendus

MARKO PAAVEL

TTÜ KIRJASTUS

Contents

LIST OF ABBREVIATIONS

AHP	-	Analytic Hierarchy Process
BOL	-	Beginning Of Life
BOM	-	Bill Of Material
CAD	-	Computer Aided Design
CAM	-	Computer-Aided Manufacturing
CAx	-	Computer-Aided Technologies
CEO	-	Chief Executive Officer
CFO	-	Chief Financial Officer
CI	-	Consistency Index
CIO	-	Chief Information Officer
CKM	-	Customer Knowledge Management
CMM	-	Capability Maturity Model
CPI	-	Continuous Product Improvement
CPO	-	Chief Product Officer
CR	-	Consistency Ratio
CRM	-	Customer Relationship Management
EOL	-	End-Of-Life
ERP	-	Enterprise Resource Planning
FAHP	-	Fuzzy Analytic Hierarchy Process
IQR	-	Inter Quartile Range
KPI	-	Key Performance Indicator
LCA	-	Life Cycle Assessment
MOL	-	Middle-Of-Life
MRO	-	Maintenance, Repair and Operations
MRP	-	Material Resource Planning
NPDI	-	New Product Development and Introduction
NPI	-	New Product Introduction
OMS	-	Organization Memory System
PCMA	-	PLM Components Maturity Assessment
PDM	-	Product Data Management
PEID	-	Product Embedded Information Devices
PIM	-	Product Information Management
PLM	-	Product Lifecycle Management
ROI	-	Return on Investment
SCM	-	Supply Chain Management
SD	-	Standad Devaition
SMEs	-	Small and Medium-sized Enterprises
TDM	-	Technical Data Management
TIFO	-	TechnoWare, InforWare, FunctionWare, OrgaWare
TIFOS	-	TechnoWare, InforWare, FunctionWare, OrgaWare, SustainWare
TIM	-	Technical Information Management

INTRODUCTION

In the modern world, changes are taking place very fast and we need to adapt to them. To manage all the transformations, companies are looking for activities that ensure advantages over other companies. There are different opportunities in this journey. Companies are offering a product, the definition of which can range from a physical product to a certain service. All these products are based on certain documentation, which needs managing. The aim of this PhD thesis is to provide first feedback of the current situation in the company through the proposed model. Also, to give feedback of the To-be situation. Focus of the thesis research is mainly on SMEs.

The topic was selected because of the need for better document management and for other functionalities of the modern PLM system. Because the PLM implementation process is a complex and costly project task, it needs multi-sided comprehensive help. Current thesis research focuses on the assessment of the current PLM maturity based on the maturity model. For a start, different maturity models were analysed and taken as a basis.

The task of the thesis is to develop a maturity model for PLM maturity assessment by giving existent As-is and hoped To-be situation. The situation is described through numerical value that corresponds to a certain description. As an extra, As-is and To-be situation is given through metrics characterization.

First, the questionnaire containing input information for maturity assessment is described. The questionnaire or the enterprise analysis model was developed with the participation of an expert group. The questions and answers selected were evaluated by the expert group and an analysis was performed to see how the results are influenced by the expert opinion. The results were analysed by using different outlier methods to see how overall results are changing by removing different evaluations from the selection.

The background index used shows the weight of the answer through the position and experience of the employee. It considers the current working position with the different score and experience through worked time in the position and field. The background index is needed because the questions are asked at the different levels of the company. The current model is considering the opinion of all the respondent employees rather than a single person opinion.

Benefits were sorted out based on expert group experience and employees' answers. The results were processed by using the FAHP and overall recommendations for maintaining a company focus are proposed.

The components of different models were analysed and the different modules, functionalities etc. used were considered in the development of the new model.

Finally, a case study in a manufacturing company was performed by giving a numerical value and description current As-is and To-be situation. Based on the information, the company was able to assess its current maturity in the field of PLM and set their further actions.

The novelty is in giving the As-is and To-be situation in numerical value and the results are based on multiple opinions in the company. Another important feature is that, the position and experience of current employees was taken into account, and it was combined with expert group opinion.

The main results of this work are presented in 2 pre-reviewed journals and presented in 2 international conferences.

1 LITERATURE REVIEW

1.1 Background

Development of Computer Aided Design (CAD) systems in the 1980 created a need for managing the data. Product Data Management (PDM) was developed to offer easy, quick and secure access during the product design process (Ameri et al., 2005).

There are several acronyms for PDM: Product Information Management (PIM), Technical Data Management (TDM), Technical Information Management (TIM), Image Management (Philpotts, 1996). But all of them mean a system for storing, archiving and managing product engineering data and related workflows (Stark, 2011).

PDM can be seen as an integration tool between different areas to ensure that the right information is available to the right person at the right time in the right form throughout the enterprise (Liu et al., 2001). PDM system is considered as a forerunner of Product Lifecycle Management (PLM) (Ameri et al., 2005). PLM's management focus is on all data, processes and applications concerned with entire product lifespan (Abramovici, 2007).

PLM can be considered as a system and a concept. Both have a wide range of definitions.

System, it means a certain program for helping the management of product information in the whole lifecycle. PLM can be also considered as a concept how information is managed during the whole lifecycle. PLM concept is a strategic business approach for the effective creation, management and use of corporate intellectual capital, from a product's initial conception to its retirement (Amann, 2002). According to Saaksvuori, PLM is a holistic business concept developed to manage a product and its lifecycle including items, documents and BOMs. It supports the company from documentation like analysis results, test specifications, environmental component information, quality standards, engineering requirements, changing orders, manufacturing procedures, product performance information, component suppliers to system capabilities, including workflow, program management, and project control features that standardize, automate and speed up product management operations (Saaksvuori et al., 2008).

According to Stark," PLM is the business activity of managing in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it's retired and disposed of" (Stark, 2011).

The Product Lifecycle Management is derived from two areas: management of product information including management of product information during the product lifecycle, consisting initially of Computer Aided Design, Computer-Aided Manufacturing (CAM), and Product Data Management. Secondly, from enterprise management, it includes Material Resource Planning (MRP), Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), and Supply Chain Management (SCM). In the second case, as a tool for decision making (Lee et al., 2008).

PLM systems can be divided roughly into two types:

- Document oriented Organization Memory System (OMS), with the content given in the form of documents, including CAD and office files, commonly used in machinery, mechanical engineering;

- Product Data-oriented OMS, processing information at data level and providing alphanumeric data management functionalities; used, for example, in textile sector companies (David et al., 2016).

The main focus of the PLM is on the product, not the customer, supply chain, company's finances, human resources or information system, which are covered by ERP, CRM, SCM, etc. The focus is on maximizing the value of the current and future product (Stark, 2007).

According to Stark (Stark, 2011), the whole product lifecycle is divided into five stages/phases, starting with an imaging stage when the product is on the idea level. In the definition phase, a detailed description is performed. Realization phase turns it into final physical form used by the customer. Usage phase is on customer side and at the end is disposal when the product is no longer needed.

Table 1.1 PLM categories (Stark, 2011).

Beginning of Life	**Middle of Life**	**End of Life**
Imagine Define Realise	Support Maintain Use	Retire Dispose

Kiritsis (Kiritsis et al., 2003) has divided product lifecycle into three main phases that are current issues: Beginning of life (BOL) including design and manufacturing, Middle-of-life (MOL) including distribution, use and support and End-of-life (EOL) where products are retired. The concept is widely acknowledged, see Table 1.1.

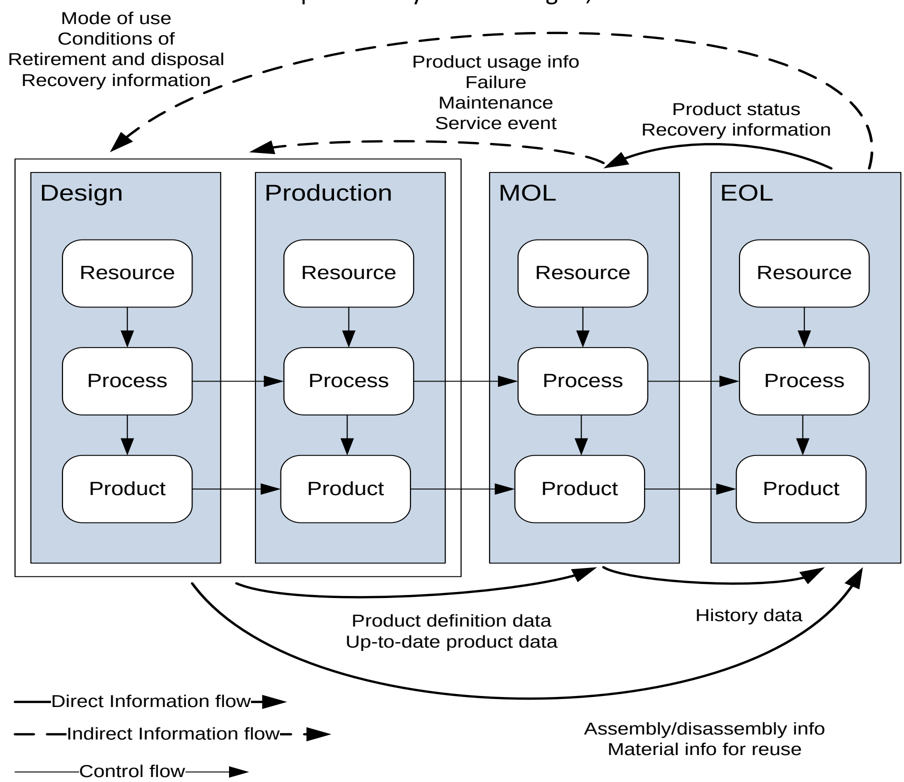

Figure 1.1 Information flow between the different stages of PLM (Jun et al., 2007).

At the beginning of 2000, a new term called closing the loops in different variations became an important issue. It started with PROMISE approach for closed loop product life cycles. The aim of that program is that product information can be tracked, controlled and managed at any phase of its lifecycle (Kiritsis et al., 2003). Many studies have been reported in this field. For example, Jun has studied the information movement in forward and backward directions (Jun et al., 2007), shown in Fig. 1.1. Kiritsis has demonstrated product embedded information devices (PEID) (Kiritsis, 2007). Focus has also been on the reduction of CO_2 emission, energy usage and environmental damage by using products that are communicating with each other in closed-loop product lifecycle (Främling et al., 2013).

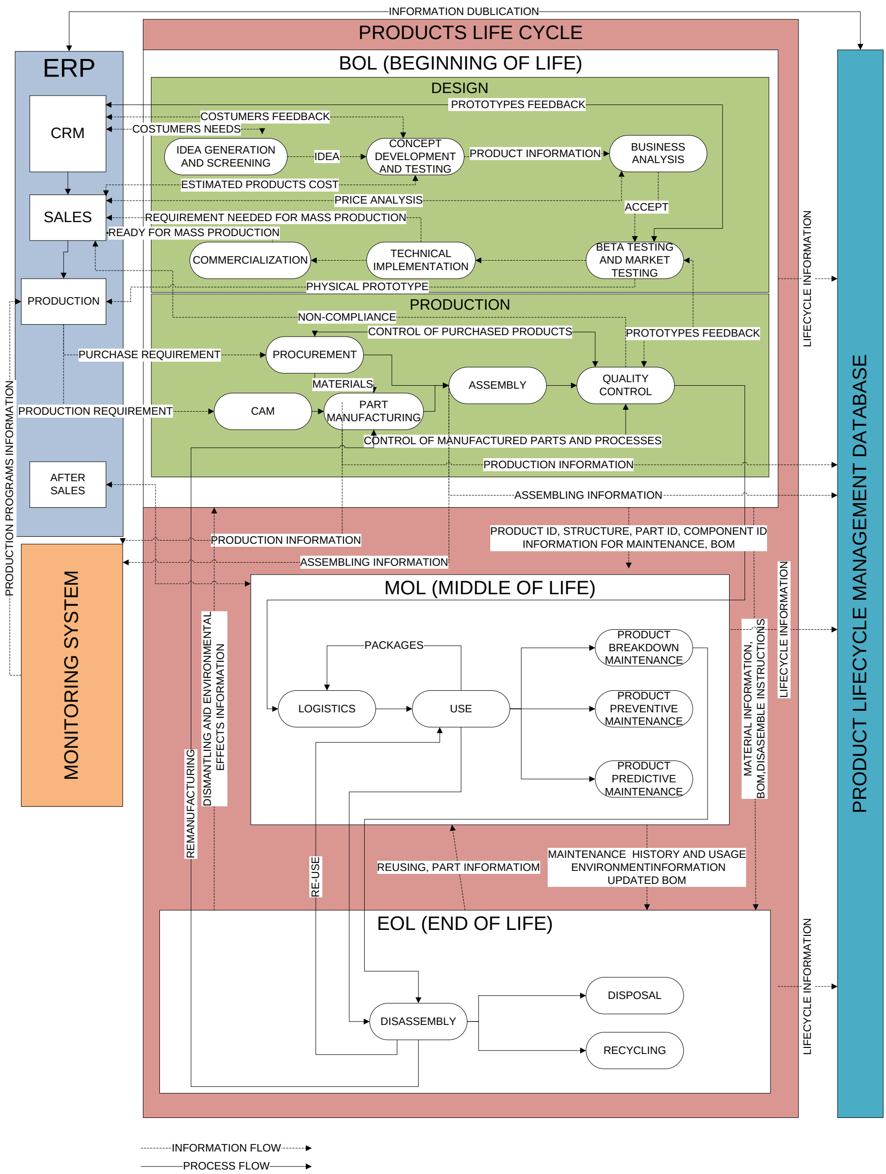

Figure 1.2 Information movement in lifecycle.

Closed-loop is the basis that the information is moving in product lifecycle from one phase to another.

Main operations in the closed-loop PLM are based on the assumption that there is communication between PLM agent, PLM system and a product. The PLM agent is gathering all the information from product lifecycle through PEID to the PLM system. After processing it is capable of sending it through the information network to the interested parties (Jun et al., 2007, 2012; Kiritsis et al., 2003; Kiritsis, 2007, 2011; Terzi et al., 2010). It means that this information can be used in different phases of the lifecycle. An example is brought out in Fig. 1.2.

The area of PLM is extensive and covers many different fields. The activities that are related directly or indirectly have been studied to a large extent. Studies range from discussions of how green manufacturing can be achieved through using PLM (Vila et al., 2015) to how PLM is helping companies who want to servitize their business by combining service and product (Wiesner et al., 2015). Analyses describe how through combining PLM system with visual product architecture representation has eased modular product family's development (Bruun et al., 2015) and a PLM is used in the aerospace industry (Mas et al., 2015; Cantamessa et al., 2012; Alemanni et al., 2008). For illustration, Saaksvuori has shown the different fields of PLM, presented in Fig. 1.3. (Saaksvouri et al., 2008).

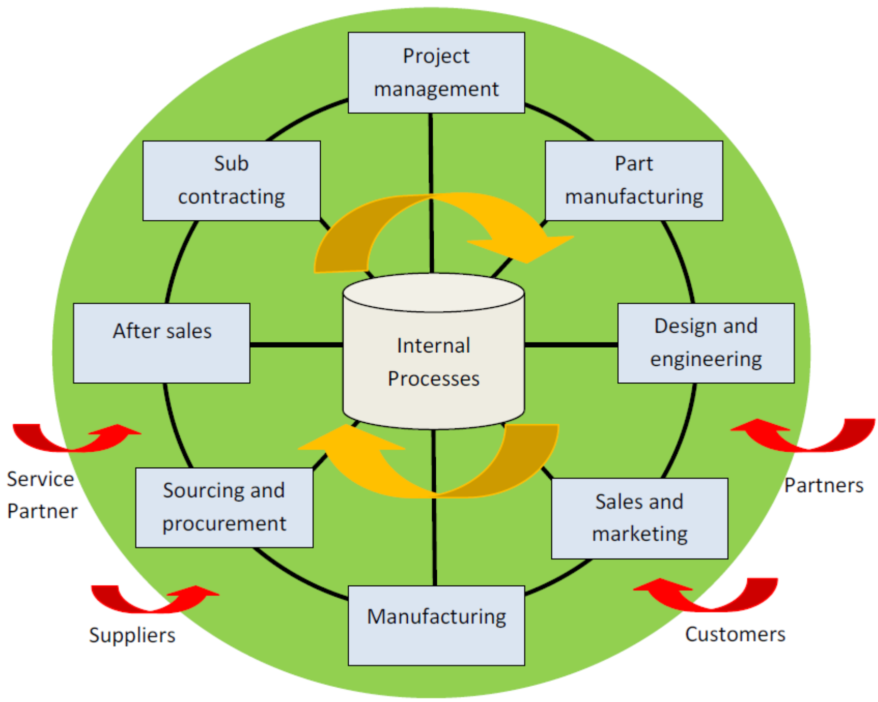

Figure 1.3 The wide range of functions and properties of PLM system (Saaksvouri et al., 2008).

Several frameworks have been created for the development of PLM and its functionalities like product information modelling framework by Sudarsan (Sudarsan et al., 2005) for product lifecycle management where information goes through the core product model. A framework for Big Data use in PLM has been proposed by Zhang (Zhang et al., 2017) where Big Data can be gathered and through analysis turned into decision-support knowledge. Marchetta (Marchetta et al., 2011) has presented a reference framework where product information model and architecture of applications are used. A framework by Prashanth (Prashanth et al., 2017) enables resolving the syntactic and semantic data conflicts between PLM and ERP. Process oriented framework by Schuh (Schuh et al., 2008) supports PLM implementation.

Abramovici (Abramovici et al., 2013) has pointed out that the future PLM has to cover the whole lifecycle, from planning, development process, manufacturing, use and the product optimization and reconfiguration phase for several products at the same time. The information is used and sent into another phase. According to Gerhard (Gerhard, 2013), the future challenges of PLM are directly connected to complexity. He specifies three main categories: product and system complexity, process and organization complexity, and IT landscape and tool complexity. Wogum (Wognum et al., 2008) has indicated a gap between research and practice. The question raised is - how to react to the additional driver in the form of society who is playing more and more important role next to technology and market (Persson, 2016).

Increasing competition forces companies to consider PLM implementation. Companies are expecting cost reduction, quality improvement, time saving, and better business decisions (Stark, 2011).

Many parallel trends exist between ERP implementations in the late of 1980s and early 1990s and PLM implementations in the 2000s like inaccurate executive management expectations, high implementation cost, frustrated end-users, armies of IT consultants, and unclear return of investment (Hewett, 2010).

The three primary challenges are (Hewett, 2010): cultural issue around the “product engineer”, a lack of standard engineering processes as a foundation of PLM and the failing of the PLM technology itself.

The implementation of PLM is the most complicated task for small and medium size companies (SMEs). Large groups and large companies have the resources for the implementation of the PLM system, but SMEs need to choose thoroughly the range of implementation. This means that these companies must choose a certain area of implementation very carefully. Antonelli (Antonelli et al., 2012) has discussed and analyzed product lifecycle management fitting to small and medium enterprises.

Many different tools and approaches are available of how to find out the real need for PLM and its functionalities.

Several different maturity models have been reported for evaluating company’s current maturity. Röglinger et al. (Röglinger et al., 2012) have compared maturity models in the business process management. The history of PLM maturity models dates back to the middle of 2000. The first widely known maturity model was that of Batenburg (Batenburg et al., 2005). Other well-known models have been created by Stark, Saaksvuori and Schuh. Pulkkinen has studied the relations between PLM maturity, architecture and business processes (Pulkkinen et al., 2013). Bensiek has studied a maturity model for improving virtual engineering (Bensiek et al., 2012) on SMEs; Walton has analyzed aspects that are important in the PLM maturity model (Walton et al., 2013) etc. A wide range of well-known model descriptions are discussed in the next chapter.

The aim of using a PLM maturity model is to obtain information of the current situation. Based on the analysis, it would be possible to start planning the real implementation of the system. Figure 1.4 shows what the implementation of PLM should look like.

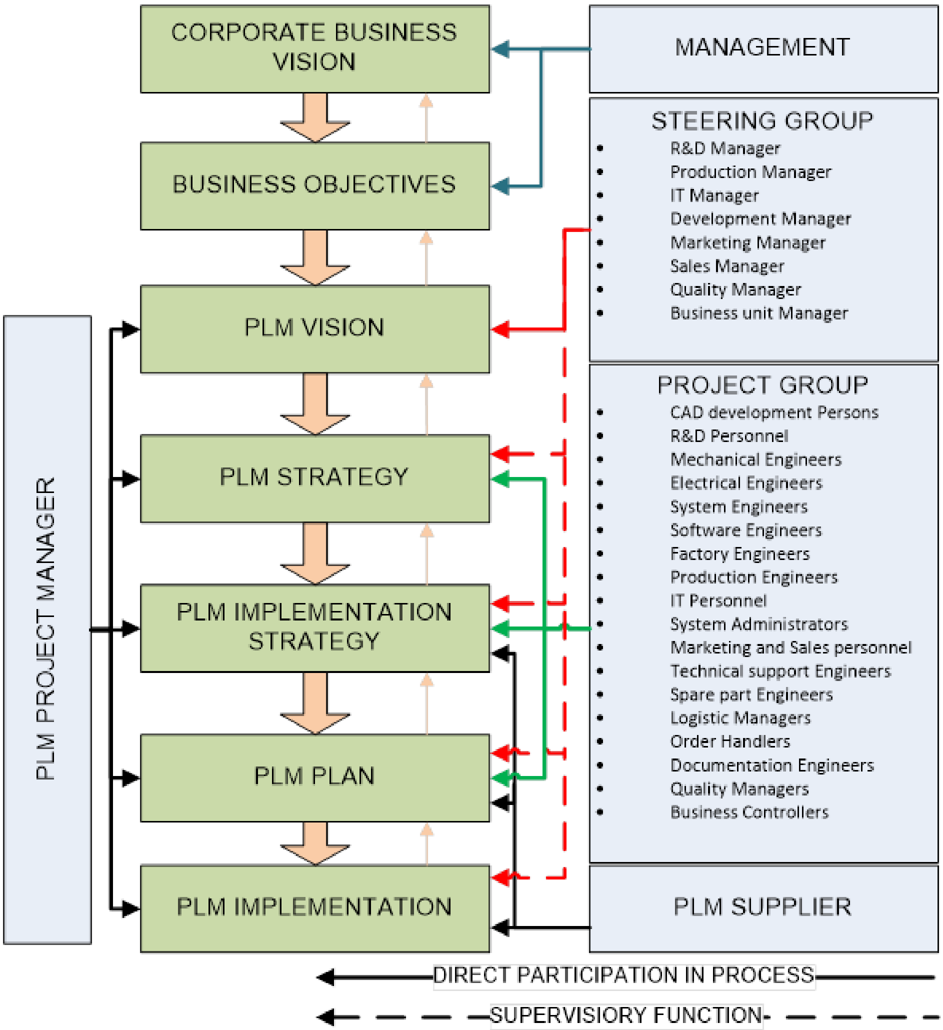

Figure 1.4 PLM implementation process.

The real challenge in PLM implementation is to obtain the right input, especially in SMEs where the number of people is smaller, and the potential rate of knowledge is lower. Therefore, all the extra information received will improve the quality of implementation.

1.2 Objectives of the research

The aim is to gain deeper understanding of PLM and how to identify the real needs of SMEs for PLM implementation, based on the information, to assess the current situation and to identify the expected situation.

The main goal of the study is to develop advanced PLM maturity model for SME.

The posed goal can be reached by:

- Analysis of current maturity models;
- Development of a questionnaire for gathering input information for an enterprise analysis model;
- Evaluation of all the questions with the help of an expert group and identification of the deviations by using different outlier methods;
- Development of the background index;
- Development of the model for mapping the company's expectations;
- Analysis of the current PLM components, functionalities etc.;

Development of the methods to establish current As-is and To-be situation.

The working hypothesis can be formulated as:

Hypothesis 1: Detailed analysis and comparison of existing PLM maturity models, their advantages and limitations/shortcomings can be identified.

Hypothesis 2: Improved PLM maturity model for SMEs can be developed taking into account the advantages and limitations of the existing models.

Hypothesis 3: Based on optimized questionnaire the methodology for estimation current expectations, also As is and To be situation in enterprise can be introduced.

2 ANALYSIS OF EXISTING MATURITY MODELS

2.1 Overview of existing maturity models

The history of concepts that can be counted as the first maturity models reaches back to the 1970s. Since then, a number of different approaches have been developed for evaluating and comparing the maturity models (Mettler et al., 2009). The maturity models proposed by Batenburg, Schuh, Stark, Kärkkäinen, and Saaksvuori are considered herein as most widespread in the literature. Additionally, the Zhang model is included due to its different logic and dynamic development over time.

2.1.1 Batenburg model

Batenburg developed a maturity model based on the literature analysis and empirical research. Batenburg has described his model as "PLM framework for the assessment and guidance of PLM implementations" in two different sources. The framework covers two fields: PLM maturity and Business/IT-alignment. In one source, the aim was to "explore the 'optimal' deployment strategy for companies to accomplish significant added value and hence competitive advantage through PLM" (Batenburg et al., 2005). On the other side, "develop a roadmap model for PLM implementations, which enables a stepwise approach towards PLM deployment to increase implementation success" (Batenburg et al., 2006). The concept, structure and case study are the same to meet that set of goals.

Batenburg relies on business dimensions by Turban et al. (Turban et al., 1999) and their extensions. The five crucial business dimensions that need to be integrated are:

- Strategy and policy;
- Monitoring and control;
- Organization and processes;
- People and culture;
- Information technology.

Batenburg is following Scheper`s framework of (strategic) business/IT alignment, i.e., the concept of PLM maturity and PLM alignment in one framework. In the model, the capability maturity concept is used. Four maturity levels with their descriptions are presented in Table 2.1 (Batenburg et al., 2005, 2006).

Batenburg's framework works in the self-assessment method, where employees evaluate the current situation, which gives guidelines for PLM implementation as output (Batenburg et al., 2005, 2006) like:

(a) Current PLM maturity and alignment;
(b) Benchmark maturity;
(c) Desired PLM maturity and alignment;
(d) Identify items to be improved;
(e) Define the PLM roadmap.

Table 2.1. Maturity level descriptions (Batenburg et al., 2005, 2006).

No PLM investment, or on 'ad-hoc' basis only (level 0) - Nobody is responsible for PLM and there is no vision available for PLM. Therefore, there are no consistent PLM processes and supporting systems. At this level, information about a product is scattered throughout the organization, which hinders strategic decision-making.
On departmental level ('silo' orientation) (level 1) - PLM is seen as a data management problem that should be dealt with on departmental level, but there is no overall vision to coordinate local initiatives. Often the development or engineering department is the first department that starts to implement PLM systems. At this level, at least all information regarding the early stages of a product is stored in a central system. PLM is seen as a data management problem that should be dealt with on departmental level, but there is no overall vision to coordinate local initiatives. Often the development or engineering department is the first department that starts to implement PLM systems. At this level, at least all information regarding the early stages of a product is stored in a central system.
On the organizational level (cross-departments) (level 2) - On the organizational level (cross-departments) (level 2). PLM is interpreted as a business problem that requires a corporate vision and an integral approach. Besides engineering and development also other departments are heavily involved. PLM processes are defined that cross departmental borders and company wide PLM systems are implemented to support these processes. Moreover, PLM systems are integrated with other major enterprise systems, such as ERP. At this level, all product information within the company is stored in a central system and there is control information available regarding PLM processes.
On the inter-organizational level (cross supply chain partners) (level 3) - PLM is seen as a business problem that spans the complete product lifecycle. Therefore, the supply chain should be involved in defining a PLM vision. PLM processes are defined that cross organizational borders and PLM systems are integrated with those of the suppliers to enable collaboration. At this level, all product information across the product lifecycle is stored in a central system making the product lifecycle become transparent enabling proper decision making concerning a product.

For data collection from the model, a computer-aided questionnaire was used. The questions covered five business dimensions. Questions are shown in Table 2.2.

Table 2.2. Questions in the questionnaire (Batenburg et al., 2005, 2006).

Strategy & Policy
PLM strategy is Described PLM strategy and its changes are communicated PLM strategy is aligned with the corporate strategy PLM strategy is Evaluated PLM strategy is adapted if needed PLM strategy is translated into an action plan Document management is included in PLM strategy PLM strategy addresses the main PLM processes
Management & Control
Responsibility for intime product delivery is defined Time-to-market of new products is monitored Rules about cost allocation during product development are defined Explicit processes for quality control are defined Metrics for product quality are defined Product quality after market introduction is monitored Status of lifecycles of products is known Project management method for managing a product through its lifecycle is applied

Table 2.2. continued.

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Organization & Processes
Procedures to support PLM are implemented PLM process descriptions are maintained PLM process descriptions are standardized Product lifecycle teams are organized PLM procedures are formally described PLM drives the product release process PLM includes a document revision process PLM includes change management procedures
People & culture
Task and job descriptions contain references to PLM processes/procedures Employees raise suggestions to influence product lifecycle decisions PLM training benefits the organization Employee reward system is related to product performance throughout its lifecycle Employees actively support the PLM strategy Employees collaborate on product lifecycle issues Employees are actively involved in the implementation of PLM software The concept of PLM is clearly understood
Information Technology
PLM software is used in the company PLM software is integrated with other information systems PLM software includes functionality to manage product configurations PLM processes are automated by workflow management functionality PLM software includes functionality to manage documents roadmap for the implementation of new PLM software is defined PLM software is based on compatible industry and technological standards PLM software includes functionality to manage product changes

YES/NO category was used in the questionnaire to see whether the certain issue is arranged or noticed at all. If the answer was “YES”, then the integration of maturity level contained an extra question. The levels are described in Table 2.1. The pre-structured answer categories give a score to each business dimension in scale 0 to 4. Through the questions, the information about the processes, objects and employees is gathered.

The maturity model was tested in 23 Dutch companies, where 11 were medium size companies (size 15-1000 employees) and 12 large size companies (over 1000 employees), covering different areas like equipment and transport, ICT solution providers, product software companies, and financial services (Batenburg et al., 2006).

2.1.2 Zhang Model

The maturity model proposed by Zhang is described through five different sources, showings how it has changed during time and adapted to new deployments. The used sources are: "Selection of product lifecycle management components based on AHP methodologies" (Zhang et al., 2013a), "PLM Components Selection Based on a Maturity Assessment and AHP Methodology" (Zhang et al., 2013b), "A PLM component monitoring framework for SMEs based on a PLM maturity model and FAHP methodology" (Zhang et al., 2014a), "PLM Maturity Evaluation and Prediction Based on a Maturity Assessment and Fuzzy Sets Theory" (Zhang et al., 2014b), and "Sustainability consideration within Product Lifecycle Management through Maturity Models Analysis" (Zhang et al., 2014c). All of these are presenting Zhang maturity model at a certain period.

Table 2.3. Criteria of Zhang TIFOS framework (Zhang et al., 2013a).

TechnoWare - Collaboration and System tools, Enterprise Application, Machinery, CAD/CAM/CAPP/ERP, Hardware and Software integration, Innovative ideas and collaboration works, Customization, flexibility and information security, Internet technologies.
InforWare - Document management and data collection, Measurement and information analysis, Automation information of daily work assignment, Work plan changes based on market information, Workflow management information supply, Information of employees capabilities, Standards and rules consistency, Enhanced project and program management, Information on requirements (manpower, products).
FunctionWare - PDM/PLM software and hardware, Configuration management of functionalities, Notifications and alerts, Visualization management, Bill of material management, Broadened opportunities in market.
OrgaWare - Employees management, Training management, Standards of application platform, Social corporate responsibility, Regulatory compliance, Innovation awareness.
SustainWare - Emission reduction (carbon footprint), Low energy consumption, Life cycle assessment (LCA), Cost effective materials and supply chain, Green PLM awareness and innovation.

All the Zhang models are based on the TIFOS framework, which is an extended TIFO framework. First, Sharif described how technology can be classified into four components (Sharif, 1995; Sharif, 1997): TechnoWare, HumanWare, OrgaWare, and InforWare. Vengugopalan put HumanWare together with OrgaWare and by adding FunctionWare getting TIFO framework (Vengugopalan et al., 2008). Zhang has extended the TIFO framework by adding SustainWare. The TIFOS framework and related criteria are presented in Table 2.3 (Zhang et al., 2013a). The TIFOS criteria considered are comparable with business dimensions of other maturity models.

Zhang has proposed 15 PLM components that vary in different implementations (Zhang et al., 2013a, 2013b, 2014a, 2014b, 2014c) and are shown in Table 2.4.

The principles of the Zhang model have changed over time. First, Zhang started with the AHP decision making process. Pairwise comparison matrix using 15 PLM components was generated for each criterion (or sub-criterion) of TIFOS (Zhang et al., 2013a). During this, local weights and global weights were calculated, consistency was checked. As a result, overall weight was calculated and it was possible to compare the current situation with To-be situation (Zhang et al., 2013b).

Table 2.4. 15 components proposed by Zhang.

	Selection of the product lifecycle management components based on AHP methodologies	**PLM Components Selection Based on a Maturity Assessment and AHP Methodology**	**A PLM components monitoring framework for SMEs based on a PLM maturity model and FAHP methodology**	**PLM Maturity Evaluation and Prediction Based on a Maturity Assessment and Fuzzy Sets Theory**	**Sustainability consideration within Product Lifecycle Management through Maturity Models Analysis Article**
BOM management		X	X	X	X
Business management	X	X	X	X	X
Collaborative development	X	X	X	X	X
Eco-Friendly & Innovation		X	X	X	
Financial Management	X	X	X	X	X
Green concept			X	X	
Life cycle assessment			X	X	
Maintenance & Repair operations management		X	X	X	X
Measurement	X				
Metrics maintenance	X				X
New products and skills	X	X			X
Organizational Interoperability	X				
PDM	X	X	X	X	X
People	X	X	X	X	X
PLM applications	X	X	X	X	X
Process Management	X	X	X	X	
Product data	X				
Product management	X				
Quality Compliance management		X	X	X	X
Sourcing Supply chain management		X			
Strategy and Supervision	X	X	X	X	X
Techniques and Practices	X	X	X	X	X

In the further developments, Zhang has calculated final maturity score per PCMA (PLM Components Maturity Assessment) dimensions. All the questions asked in the interview are evaluated through maturity level descriptions (see Table 2.5) by calculating the weight sum of the KPI in each dimension. The mean score of fifteen dimensions is shown through the overall PCMA maturity. Priorities are pointed out based on each dimension of business profit (Zhang et al., 2013b).

In the next studies, Zhang has worked with categories cost, time, quality, defects, safety, integrity, and ownership. For each category, KPIs are proposed and specific questions are asked based on the content. The answers to the questions are evaluated and processed. FAHP method with fuzzy scale is used to guarantee the preservation of the preferences. In the first step, all the categories are compared using pairwise comparison and the fuzzy triangular numbers are indicated. After that, the calculation matrix for each criterion is presented to find an optimal component to balance the category. After finding local weights, global weights are calculated and brought in number, based on the categories for each PLM component (Zhang et al., 2014a).

Table 2.5. Maturity level description (Zhang et al., 2013b).

1 Ad-hoc, Process unpredictable - The activity is done with expediency. Nobody is responsible for PLM. Documentation is at the lowest point to satisfy operational needs. PLM software system and processes have deficiencies.
2 Managed, Process reactive - The activity is defined and managed, but it is repetitious. Documentation and record is carefully studied. Mutual actions are finished in processes and departments. No effort has been made to consider about recycling.
3 Defined, Process proactive - The activity is formalized and supported by standards. Documentation and record is studied and shared. Personal actions are carried out efficiently. PLM systems are easily implemented. Environmental awareness occurs.
4 Quantitatively managed, Process measured & controlled - Activities run smoothly. PLM systems cooperate with other enterprise systems. The products run efficiently and are effective. Progressively eliminates errors and failures.
5 Optimized, Continuous process improvement - The activity runs optimally. PLM system helps company make improved decisions. Best practices and innovative ideas are considered.

Zhang has proposed to evaluate needed PLM components in a circle by proposing PLM components, PCMA maturity model for evaluating current AS-is situation. Components are selected and based on KPIs evaluation and analysis. Optimal selection is performed by using the FPP (Fuzzy preference programming) methodology. Suitable PLM models are investigated and after six months or one-year, feedback loop can be used to find out that these components are on track in reaching a new maturity level (Zhang et al., 2014a).

In the last studies, Zhang has put more effort on SustainWare to reduce the waste and pollution; design eco-friendly products; using new materials and supply chain; minimizing damage to environment and human and consuming low energy (Zhang et al., 2014c).

Zhang model was used in Italian Prefabrication Company where maturity score evaluation through PCMA for one unit was performed. Also, PLM components for meeting the right business targets were selected (Zhang et al., 2013b). The second study was performed in the swimming industry (Zhang et al., 2014a, 2014b). The third study was performed in Central-South Italy in a construction and precast company (Zhang et al., 2014c).

2.1.3 Schuh model

The process oriented framework to support PLM implementation proposed by Schuh has academic background. The existing initiatives and recent research results about PLM are combined into guidelines for PLM implementation. Based on that, it is not possible to evaluate current maturity and set up current as is or to be situation. The framework proposed by Schuh is presented in Table 2.6.

Table 2.6. The framework proposed by Schuh (Schuh et al., 2008):

PLM definition – Sets up the boundaries where the model is detailed. For closing necessary information loops Schuh has divided this category into seven key elements which need to be thought through. Integrated management of ideas, projects and product portfolio supports new ides managements and how they should be thought through and are connected to current projects, portfolio and its planning. Dynamic requirements management means that product requirements must be managed through whole lifecycle and the identification of impact from changes. Integrated product design and process specification is brought here to show importance of product and production process development. End-to-end configuration control is supporting the control, identification, accounting and auditing of characteristics of products or certain product part. Total lifecycle costing brings together all cost in different phases of lifecycle for better analyses, also brings out the total cost of ownership. Lifecycle environmental impact analysis is here to hold focus on minimizing the total product environmental impact from materials, energy usage, recycling in each lifecycle phase. Service and maintenance data reuse at product development means gathering information from usage phase and utilizing in development phase.
PLM foundation – is directly connected to robust product structure and is a basis for PLM implementation. Product structure describes relationships between items that product consist of, also integrates product related information and documents.
The set of process reference models – Describes the reference models used in the field. Schuh focused on the machinery industry and pointed out eight key PLM processes and their definitions. All this because it is very hard to bring out certain best practices due to the large number of different characteristics that can affect the results. Eight Key processes brought out by Schuh in the machinery industry are: Idea management, Requirements management, Product structuring, Product program planning, change management, project controlling, risk management, and quality controlling.
Vendor neutral software description – is a necessary part of the whole system because the number of vendors is large, and the functionalities can be very different. In this study, Schuh has proposed vendor neutral PLM software requirements. The catalog consists of four functional areas which are divided into 13 functional groups. The first area, Core data management, includes the central data that defines a product, consisting from product planning, product structuring and change and configuration management. The second area, product data generation, consists of production planning, sourcing, quality management, service and maintenance, environment management. The third area, process management, consists of project management, document management, R&D controlling and collaboration. The fourth are is system integration and management.

Table 2.6. Continued.

Vendor neutral software description – is a necessary part of the whole system because the number of vendors is large, and the functionalities can be very different. In this study, Schuh has proposed vendor neutral PLM software requirements. The catalog consists of four functional areas which are divided into 13 functional groups. The first area, Core data management, includes the central data that defines a product, consisting from product planning, product structuring and change and configuration management. The second area, product data generation, consists of production planning, sourcing, quality management, service and maintenance, environment management. The third area, process management, consists of project management, document management, R&D controlling and collaboration. The fourth are is system integration and management.
PLM software support – based on survey thought for vendors in 2006. Schuh has pointed out that at that time, fulfilment for classic PDM functionalities like system integration, document management, change and configuration management, product structuring, project management and collaboration is higher than for extended functionalities like product planning, service and maintenance sourcing, quality management, production planning, environmental management and R&D controlling. This stresses the importance of mapping vendors at the certain time against current needs.
PLM knowledge base – means organizing employee education in relation to PLM topics in the concept, methods and tools field. All this is to simplify PLM implementation through better theoretical background, structured methods, hardware and software solutions.
PLM benefits – expected benefits are derived through changes in company's processes. Schuh has proposed and indicated that benefits related to idea management are: higher innovation through more and better products, higher turnover share with new products through a broad innovation portfolio, continuous improvement of products and processes through employee incentives, higher customer focus and better coupling of product development and customers through customer integration into idea management. For requirement management: reducing the number of iterations through better input, reducing the number of unnecessary product variants through systematic evaluation, higher first-pass-through through better integration of mechatronic disciplines (mechanic, electronic, software), documentation of changes and their impacts, fast product documentation through reuse of existing documents enabled by better structure. For product structuring: faster engineer-to-order process through efficient reuse of components, smaller better focused product program, higher margins through better pricing opportunities (basis, options, customizing), lower development efforts through avoiding re-developing existing solutions, lower complexity costs through less parts in product program. For product program planning: better market focus through systematic planning process and alignment of products and services, optimized product variety through planning process, decrease of development costs through parts reuse, Identify possible synergy potential within production and purchase. Change management through improve cycle time for changes through better information availability, faster reaction to customer changes through robust processes. Project controlling through improve possibility to decide on projects, improve employee productivity in development through better resource allocation, reduce efforts for collecting project information through automization, risk management through early identification of project deviations through better information availability, better planning results through better planning basis data. Quality controlling through improvement of customer satisfaction through better product and service quality and earlier identification of quality problems.

Schuh proposed the following 10 step approach for PLM implementation (Schuh et al., 2008):

1. Define the goal of the PLM implementation: according to the PLM definition companies can identify the most important points to focus on;
2. Analyse the existent PLM foundation: the ability of the current product structure to support PLM must be analysed and if necessary enhanced;
3. Rank processes: the processes to be implemented can be selected from the PLM process list, considering company aims and the expected benefits;
4. Identify company maturity level (as-is process): comprehends the mapping of company current processes (only for the previously selected processes);
5. Select an appropriate reference model: from the provided set of reference models it is possible to identify the process type that best suits company characteristics;
6. Customize reference model: although processes that target different kinds of company are available, processes must still be refined to reflect very specific business needs. The customized processes picture the to-be PLM scenario;
7. Specify requirements for system selection: the vendor neutral software requirement catalogue related to the already configured processes provides the system specification;
8. Select software solution: based on previously defined requirements and considering detailed software profiles;
9. Define the evolution path and implement software solution: the differences between the as-is and to-be processes allow the definition of implementation roadmaps, including the necessary implementation of the selected software solution;
10. Teach employees: the knowledge base connection to the processes indicates the new necessary qualification and provide the necessary training material and context.

In the references it is not possible to see how this model is used and how information for decision making is gathered. In the framework, different aspects to be considered and how to move on from current situation are indicated.

2.1.4 Stark model

Stark has described his levels from three different viewpoints;

1. Company;
2. Product development;
3. Product Data Management (PDM).

Stark's model works based on a questionnaire. Unfortunately, from the publications it was impossible to find his questionnaire and references to its implementation. Descriptions of maturity is presented in Table 2.7.

Table 2.7. Description of different maturity levels (Stark, 2011).

Traditional level - From company's viewpoint meaning that company has little or no focus on customers and take little account on their requirements. In latter case new products are developed individually from scratch and here is not understanding of PLM and product lifecycle. The company has pyramid structure and is organized by functional departments. The product development is not considered as process and the value of product data is not realized. Such a company does not use modern product development practices and techniques or use them in standalone applications, have no understanding of product development as value adding process and don't pay any attention of performance only on performance of products. The engineering, manufacturing engineering, manufacturing departments are divided and the structure of the product is unclear. From PDM viewpoint company has no understanding of PDM and does not use the lifecycle practices and techniques. Capacious work with databases is performed in different departments but here is no data exchange between the databases and with customer. There is no description of the products, configuration management and workflows.
Archipelago of PLM Islands - Company has started focusing on quality and may have achieved some certificates for approval. But still lack a real focus on customers. Has tried to rearrange its pyramid structure and remove layers from it. Has various functional entities in place. Understands the existence of processes but don't have the full understanding on it. Has started developing products but is not valuing product data. Has realized that might be using out of date practices and techniques. From product development side there is no contact with customers. The product requirements are managed badly, and the data management is under a low priority. Understanding that that the product development is an important part of company's processes and few modern development techniques and practices are used. Focus on product performance but performance of product development is first mentioned. Standalone CAD applications are used for individual products. The reuse of parts between product is discovered. From PDM point of view there is a lack of people who understand the PDM concept and independent stand-alone system is used in different apartments. Don't interact with customer electronically and limited electronical inhouse data exchange. Has manual engineering drawing, release and change management system. Company is not using lifecycle practices and techniques.
Frontier-Crossing PLM - Company has good understanding of current state and what need to be achieved. Has programs what are focused on customers. The platform products have been identified and the development process has been started. The structure of the organization is combination from pyramid and partly flat. The cross-functional team across the company is used. The company is aware the value of product data and has started implementing the best practices and applications. There is direct contact with customers. The product development process is clearly defined, and the metrics are fallowed to evaluate the performance of product development. From the PDM side the company has wide understanding of product data and PDM applications. The product data are communicated between different apartments electronically. The PDM integration with ERP is in simple level.
Enterprise-Wide PLM - Company has strong focus on customers and there are regular contacts between them. The customers and suppliers are involved in development process. The organization works based on business units and with flat cross-functional structure and cross-functional teams. The PLM strategy is defined and noticed PLM importance for achieving business objectives. The processes and ownership is clearly defined and understood. The PDM and PLM concepts are Enterprise wide and majority of the functionalities of the PDM and PLM applications are used. The PDM is implemented over the lifecycle. The data transfer between customers, different departments and suppliers works electronically.
Patchwork PLM - Meaning improvement of certain field of activity described in Archipelago of PLM Islands to Enterprise Wide PLM

Table 2.7. Continued.

Enterprise-Wide, Enterprise-Deep PLM - Meaning that concept of PLM is clearly understood, and it is seen as competitive advantage. The company has a PLM Vision, Strategy, plan and metrics. PLM strategy is aligned with corporate strategy. The product data model is enterprise wide and the responsibilities are defined.

Stark can be considered as a practitioner who is more active in consulting than in the academic field. Therefore, over time Stark has pointed out different approaches how to move on with PLM implementation in different stages during implementation.

Different approaches for moving forward from one phase to another are as follows (Stark, 2011):

- A Stand-alone – addresses a small, well defined part of the company also gives benefits for small addressed part of company;
- A Step-by-step – means going further with small understood footsteps. Problem is that due to small steps you don't get or realize hoped benefits;
- A Reengineering approach focuses attending on business processes. By putting focus on processes it is possible to make major changes but the risk remains by ignoring product data and people;
- A Balance approach addresses all components at the same time. Need clear understanding and lot of work;
- A Big Bang approach meaning implementation of all the changes at the same time. Great improvement or disaster can be achieved quickly.

10 step approach for PLM Launch and how to start if you are on the low maturity level and want to continue with improvements in the field of PDM and PLM (Stark, 2011).

1. PLM, status review, Data Gathering – Evaluation of current As-is situation and expected to-be situation;
2. Executive PLM Education and Awareness – Presentation of potential benefits and opportunities of PLM;
3. Best Practice Positioning – opportunities, strengths, weaknesses of current best practices what can be achieved;
4. PLM Concept Generation and Analysis – presentation of current concept and advantages in front of other concepts;
5. PLM Scope definition; Roadmap and Plan Generation – Definition of scope, presentation of roadmap and plans;
6. Business Benefits & Business Case Development – report based on expected benefits and cost. Value added;
7. ROI Calculation – Realistic calculation of return on investment;
8. Management Report Preparation – presenting current plan for management;
9. Executive Presentation – presentation to get the full understanding of the PLM proposal;
10. Executive Decision Support – decision to go with it further or quit.

For continuous improvement, Stark has defined a generic five-step process that is suitable for each level and does not depend on the current level of evolution (Stark, 2011):

1. Understand the current (as-is) situation;
2. Understand the desired future (to-be) situation;
3. Develop an implementation strategy to go from the current to the future situation;
4. Develop detailed implementation plans corresponding to the implementation strategy;
5. Implement the plans.

2.1.5 Kärkkäinen model

Although the model is named Kärkkäinen model, the description or improvement of the model is put together from different publications (Siventoinen et al., 2009, 2010, 2011; Kärkkäinen et al., 2009, 2012).

Defining the customer dimensions of the PLM maturity model is academic research where the company can evaluate the PLM maturity on the questionnaire basis. The questionnaire was filled during interviews and discussions. The model works on the basis of the self-assessment method. In the first studies (Kärkkäinen et al., 2009; Silventoinen et al., 2010, 2011) Kärkkäinen and Silventoinen used the following business dimensions described by Batenburg: Strategy and policy, Monitoring and control, Organization and processes, People and culture, Information technology. In the latter study, the Customer orientation was added (Kärkkäinen et al., 2012). The questions used for assessment of maturity were the same as in the Batenburg model described above; evaluation was based on the same principle.

Table 2.8. Scale of maturity dimensions (Silventoinen et al., 2011).

Dimension / state	Initial state	Ideal state
Strategy	not defined	defined, shared
Processes	ad hoc, individual	optimized to support strategy
Structures	not defined	product structures and configuration easily adjustable
People and culture	no shared understanding on PLM	common view on how PLM is executed
IT architecture	no IT support for PLM	integrated product information

In the first studies (Kärkkäinen et al., 2009; Silventoinen et al., 2010), the description of maturity levels introduced by Batenburg was used: Ad Hoc, Departmental, Organizational, Inter-organizational. In 2011 Silventoinen proposed a new approach for describing maturity levels where the initial and ideal states only were described (see Table 2.8).

Table 2.9 outlines the description of maturity stages focused on PLM customer dimensions.

Table 2.9. Description of maturity stages by Kärkkäinen (Kärkkäinen et al., 2012).

Level I Chaotic stage - Level of coordination is low - customer knowledge is fragmented in isolated IT tools and in product lifecycle phases and stays mostly in people's heads. Quality of customer knowledge: information cannot be explicated and easily transferred to other people. The customer knowledge is used in reactive way for the strategy and product processes. The customer knowledge management (CKM) is random, no connection with PLM exists. Organization has no formal processes, structures and tools for gathering, sharing and using customer information and knowledge for business strategy, product portfolio management and product development. The individuals may have ample knowledge but do not know how to harness it in a structured manner in order to derive business benefits. The information technology does not support systematic communication and collaboration in relation with customer information and knowledge.
Level II. Conscientious stage - Level of coordination is mainly at functional level. Part of customer knowledge can be explicated and transferred / understood in the same manner mainly at functional level. The organization recognizes the necessity of making scattered customer knowledge in isolated IT tools, product lifecycle phases and heads of individuals as part of strategy and product processes. A practical definition of CKM within organization is explored and consideration of its applicability for PLM is made. The strategy, customer and product processes are partly considering also customer knowledge management tasks, but transferability of customer knowledge is weak. The organization recognizes the need to have formal processes, structures and tools for gathering, sharing and using customer information and knowledge for the business strategy, product portfolio management and product development. The processes and communication are supported by isolated IT tools.
Level III. Managed stage - Level of coordination is reaching cross-functional and company level. The customer knowledge is partially integrated to processes, structures and IT tools for the business strategy, product portfolio management and product development. The quality of the customer knowledge is satisfactory. Systematic CKM - formal processes, structures and tools - has been described and established within an organization for gathering, sharing and using customer information and knowledge for the business strategy, product portfolio management and product development. The customer knowledge is partly integrated with PLM. There is some evidence of the business value of capturing lessons learned, transferring and using the customer knowledge. Some IT tools for organization wide communication and collaboration are in use.
Level IV. Advanced stage - Level of coordination is dyadic in inter-organizational relationships. The organization is capable to use systematic CKM, thus fully integrating customer, strategy and product processes with PLM throughout product lifecycle phases, thus capable to use the customer knowledge proactively in short term. Co-creation is carried out with individual partners to create and transfer new customer knowledge. The managers are able to harness customer knowledge from all the touch points in the organization and realize the business benefits from it. The systematic process management, measures of performance are used to plan and track processes. Advanced IT tools are used for communication and collaboration within organization and with individual stakeholders mainly at dyadic level.

Table 2.9. continued.

Level V. Integration stage - Level of coordination is extensive, reaching interorganizational networks. The organization has customer-centric and future-oriented business culture, based on continuous improvement, flexibility and self-optimization as well as well-defined, information-rich communication and cooperation networks with customers and other important actors (e.g. suppliers, partners). Co-creation and co-experimenting between customers and partners is widely adopted to create new customer knowledge and enable it to be transferred effectively within the collaborative inter-organizational and intra-organizational networks. Thus the organization has clear vision about future customer needs, and it possesses and systematically develops the capabilities to adapt flexibly and in a proactive manner to meet new customer needs and requirements in changing business environment. These capabilities are presented in the integration and fusion of internal, external, existing, and up-to-date customer knowledge and information regarding product, service, operational processes and management discipline throughout all product lifecycle phases and value networks. The quality of the customer knowledge is at high level.

In Kärkkäinen study (Kärkkäinen et al., 2012), the customer orientation came strongly in and new levels or stages of maturity were described.

In earlier stages of development, several case studies were made. From the first development stages, the Batenburg maturity models and the level descriptions used are available. The case studies were made with Finnish/Finland-based engineering companies operating in the metal industry. The first company is operating in the Finnish market, with about ten persons working, but this is a part of a larger group (Kärkkäinen et al., 2009). The second company is operating in the global market and has different locations; there are about 500 employees working (Kärkkäinen et al., 2009). Also, six Finnish companies were studied in 2010 (Silventoinen et al., 2010)

2.1.6 Saaksvuori model

Saaksvuori and Immonen have proposed the maturity model of Product lifecycle management, which refers to combining generic CMM and COBIT framework (Saaksvuori, 2014; Saaksvuori et al., 2008; Vezzetti et al., 2014). The maturity model has academic background. The idea of the model is based on the evaluation of different stages like: Processes, Structures, IT systems, PLM strategy, People in PLM change management. They can be referred to as business dimensions (Saaksvuori et al., 2008; Vezzetti et al., 2014). Business dimensions according to evaluations are divided into the levels described in Table 2.10.

Guidelines for PLM implementation (Saaksvuori et al., 2008):

- Define the goal of the PLM implementation;
- Analyze the existent PLM foundation;
- Rank processes;
- Identify company maturity level (as-is process);
- Select an appropriate reference model;
- Customize reference model;
- Specify requirements for system selection;
- Select software solution;
- Define the evolution path and implement software solution;
- Teach employees.

Table 2.10. description of maturity model levels (Saaksvuori et al., 2008).

Level 1, Unstructured - The PLM topic has been recognized and its importance agreed. Work must be done to define and develop the PLM concept and standards. However, at present, there are no defined approaches concerning lifecycle management; all lifecycle and product management issues are resolved by individuals on a case-by-case basis.
Level 2, Repeatable but intuitive - Lifecycle and product management processes have been developed to the stage where similar procedures are followed by different people undertaking the same task (i.e. the processes function on ad hoc bases). There is no formal development, definition, training, or communication of standard processes; all responsibility is left to the individuals. There is a high degree of reliance on individual knowledge and therefore errors occur.
Level 3, Defined - Lifecycle and product management processes have been developed to the stage where similar procedures are followed by different people undertaking the same task (i.e. the processes function on ad hoc bases). There is no formal development, definition, training, or communication of standard processes; all responsibility is left to individuals. There is a high degree of reliance on individual knowledge and therefore errors occur.
Level 4, Managed and Measurable - It is possible to monitor and measure the compliance between processes and to take action where processes are not functioning well. The processes and concepts are under constant improvement and provide best practices. IT systems support PLM processes well. Process automation is used in a partial or limited way. The processes and concepts are developed through clear vision throughout the corporation. The state of uniformity of processes is clear.
Level 5, Optimal - The processes and concepts have been refined to the level of best practice, based on continuous improvement and benchmarking with other organizations. IT is used in an integrated manner and process automation exists on an end-to-end basis.

It all has to be started from a plan that consists of: change management, how to develop modes of actions, what skills to develop, goals and targets, the role of management, learning process and risk management; continue with execution: estimate maturity, participation, training and support, communication, coaching, diminishing change resistance; end with a follow-up: commitment, training, support and direction of change (Saaksvuori et al., 2008).

In another Saaksvuori's concept model of Product management maturity model & assessment, a rough level is described how the company and its management team can move on with product management to improve performance. Focus is on the stages that the company goes through as it adapts to new cultural issues, processes, management practices, business concepts and modes of operation. Stage descriptions with different business dimensions are given in Table 2.11 (Saaksvuori, 2014).

Table 2.11. Description of maturity stages according to different business dimensions (Saaksvuori, 2014).

Level 1 [best 25%]
Role & Skill & Learning: Executive leadership facilitates product management success. Corporate level product management development is in place. The role of product manager is documented, implemented and known. Everyone throughout the product management (including commercialization) process understands his role and task role. Senior manager position for innovation management exists. Continuous learning and competence development is in use. Process: Standardized processes for product management and product lifecycle management are in use and continuously developed. Product portfolio management process is in place with comparison metrics including competitive, sustainability, lifecycle, product strategy role balanced scoring (not only cash flow). New product idea process is managed and visible on corporate level. Governance procedure is known through-out the company. Development funnel has ratio of 20 ideas to 5 concepts to 1 product waiting for decision making. Development projects are killed early and often during portfolio reviews. The voice of the customer captured as standard process on an ongoing basis. Fully implemented gated development process across multiple teams with management and reporting automation. The process roles are uniform and used in similar way through the company. Tool & System: Product lifecycle management can be executed without manual data feed between systems. The PLM system is implemented and covers the whole lifecycle of a product definition as well as product instances (delivery configuration, customization and installed base management) when relevant. Product management can access product related data for decision making on-line (idea funnel status, portfolio with product lifecycle status, product cost, product change activity etc.). Product roadmaps tied to development project execution and corporate strategy via PPM. Entire product portfolio (catalog) of under development, in-market products, market stop, sales stop, legacy products can be accessed. Self-service configurable reports and metrics are delivered across the organization. The customer requirement management is fully supported by IT-system and requirement assessment with implementation easiness criteria is in use, decision making has standard procedure. Information content: The product content is documented according commonly agreed corporate level principles, documents are available, managed and restricted when applicable, templates exist for new definitions. Each product lifecycle stage and gate in the product development process has definition content criteria. Product lifecycle management concept is defined and implemented throughout the company with lifecycle status definitions, status criteria, product architecture, product related information objects etc.
Level 2 [average +]
Role & Skill & Learning: The product management process managers and gatekeepers have clear direction, metrics, and ownership. Formalized portfolio manager positions at business unit and enterprise levels exists, multiple strong champions for innovation. The project teams consist of cross-functional team members. Start of open innovation, co-development, and the use of external innovation consultants. The product management development is done in some subdivision of the organization. Process: The product management process covers idea to launch, in life management and end of life. The product development process and project are clearly separated. The product to be developed is documented in separate documents than the development project. The processes and basic concepts are standardized, defined, documented, and communicated through manuals and training. It is possible to monitor and measure the compliance between processes and to take action where processes are not functioning well. The processes and concepts are under continuous improvement. Regular product portfolio reviews and post-mortems are conducted. The voice of the customer becoming more formalized. The governance workflow is not yet consistently repeatable. A few projects being killed, but later than optimal.

Table 2.11. continued.

Tool & System: The PLM system is implemented and covers the product lifecycle partially lifecycle (product definition as well as product instances (delivery configuration, customization and installed base management) when relevant or more extensive implementation covers only one or some business areas. There is no end-to-end product management process supporting IT systems, all work is completely or partially manual from the process point of view. IT systems support individual parts of processes. The Product Portfolio Management system is in place. Ideation is centralized but not using a purpose-built tool. Dedicated tool for capturing voice of the customer and customer requirement management exists. Executive and project-level reporting and analytics are available and modifiable. Information content: The product content is documented, documents are available, managed and restricted when applicable, some templates exist for new definitions. Most of the lifecycle stages and gates in the product development process have definition content criteria. The product lifecycle management concept is defined and implemented partially with lifecycle status definitions, status criteria, product architecture, product related information objects etc.
Level 3 [average -]
Role & Skill & Learning: Established roles in the product management (incl. commercialization process): product manager, project manager, lead engineers, product engineers, documentation specialists, test managers, production engineers, as well as and process gate-keepers are in place. Process: The product development project portfolio reviews are more project status updates. The metrics for evaluating innovation are purely financial. Early realization of silo inefficiency and value of gated processes with cross-functional participation. The product management & product development processes vary throughout the company, the reporting is sporadic and manual. The role of product management and product managers are not harmonized and are not fully understood by other functions. Tool & System: The PLM system is planned or partially implemented and covers the product definition lifecycle partially. Manual portfolio management using spreadsheets. Ideation matured to being captured and prioritized. Standard library of some reports exists. Information content: Basic PLM concepts are not best-of-the-breed, nor are they uniform throughout the corporation, however they are formalized.
Level 4 [low performer 25%]
Role & Skill & Learning: Individual leaders own day-to-day processes and are responsible for developing and delivering the product roadmap. The product managers are not following industry best practices consistently. The role of product manager is not documented or implemented. The product management is executed in multiple functions with overlap. The product ownership is fragmented in multiple places. Cross-functional project teams are not optimized for efficiency. No cross-functional organization focused on innovation. The decision making about the product portfolio is performed by executive leadership only, often with less than optimal data. Informal development project leadership; resources assigned verbally. Execution and product launches happen slow and steady. Process: The processes are departmentally focused and not documented. No formal gated process or templates for product development; projects rarely killed. The lifecycle and product management processes have been developed to the stage where similar procedures are followed by different people undertaking the same task (i.e. the processes function on ad hoc bases). There is no formal development, definition, training, or communication of standard processes; all responsibility is left to individuals. There is a high degree of reliance on individual knowledge and therefore errors occur. Limited visibility into actuals, forecasts, post-mortem assessment, or roadmaps; no portfolio reviews. Processes surrounding ideation, road mapping,

Table 2.11. continued.

product development or management, and portfolio reviews do not exist. Informal process for innovation and idea flow, no common templates in use.
Tool & System: Despite to fact that the human factor is important, there is very limited IT-support for product management process, all work is completely or partially manual from the process point of view. The IT systems support some individual parts of processes. There is no formal development, definition, training, or communication of IT-systems for product management.
Information content: The PLM concept topic has been recognized and its importance agreed. Work must be done to define and develop the PLM concept and standards. However, at present, there are no defined approaches concerning lifecycle management; all lifecycle and product management issues are resolved by individuals on a case-by-case basis. The product development process gates are informal and standard content and gate deliverables are missing.

The maturity model works based on self-assessment. The information is gathered through likert-like questionnaire. The questions are divided into different categories and there is an answering option for each question (Saaksvuori, 2014). The questions are given in Table 2.12. The answering option points out the current maturity level of processes, objects, people and other dimensions.

Table 2.12. Questions according to categories (Saaksvuori, 2014).

Product Management Role & Skill & Learning
Role of product manager is documented, applied and known; Role of product manager is recognized by and product manager tasks are aligned with key partner functions of the company (e.g. sales, marketing, supply, operations, services) Senior manager position for innovation management exists in the company Continuous learning and competence development of product management is in use, product management is trained on regular basis Established roles in the product management process (incl. product development, commercialization, continuous product improvement CPI, product maintenance process): product manager, project manager, lead engineers, product engineers, documentation specialists, test managers, production engineers, as well as and process gate-keepers are in place and used Product management is executed in multiple functions with overlap Product ownership is fragmented in multiple places Product managers are work on both strategical (e.g. product strategies, customer segmentation for needs collection) and operational product management (claims handling, product support) Commercial, technical & marketing tasks of product management are separated, clear and their execution is without overlap with other functions of the company Top 3 skill, capability, organization or role related GAP's

Table 2.12. continued.

Product Management Process
The product management process is in place with clear phases, activities and deliverables There is an organization taking care of the product management process development, enhancements and support The product management process related governance is in place with clear roles and responsibilities in relation to decision making around the product to be managed The product development project and the product to be developed are clearly separate entities (e.g. product related documentation specifications, descriptions etc. can be separated from project related documents) The product portfolio management is a process functioning on a continuous and regular basis throughout a calendar year providing clear decisions to kill, enhance, maintain, develop products, change pricing etc. The product management process has key performance indicators that are followed on The product development funnel has clearly more ideas and concepts under management than product development projects Customer needs collection, customer / market insight gathering and market analysis + customer feedback collection are integral parts of product management process The idea management process is known and used by all employees Top 3 product management process related GAP's
Product Management Tools and Systems
The product portfolio is managed in an IT-system with visibility of product lifecycle status of each product to all relevant employees of the company Generic product definition (with BOM's, items, sales materials, manuals etc.) for each product is managed in an IT-system Generic product definition (with BOM's/service elements, items/service delivery process, sales materials, manuals etc.) for each can be accessed and contributed by external business partners Common libraries for good, reusable design solutions (partial designs to be used as parts of a product), common components or service elements are in use The product configurations can be created in sales context with a support of an IT-system The customer specific configurations are managed on serial number level (up-to-date customer instance specific data can be accessed later when needed) The IT-system architecture exists in the company The product management system is integrated with ERP and CAD systems, service provisioning, CRM or delivery in services The product lifecycle related data is consolidated to reports from the product management systems for decision making purposes in product management Top 3 product management system or tool related GAP's

Table 2.12. continued.

Product Related Information
There is a definition for product architecture (product related information objects and their relationships)
There is a clear definition what sets of documentation / data needs to be in place for approved and complete product definition (released product)
There is an organization collecting, validating and sharing product related information as well as developing methods to define products
The product lifecycle has been defined with related characteristics and lifecycle criteria
The product data / definitions + related quality criteria are connected with product lifecycle statuses
The product performance related data (product dashboard) is defined, collected and used in product management
The product data related to past deliveries and product maintenance is utilized for analytical decision making and product enhancements
New product feature or function can be traced from idea, to related development project. The cost of development & implementation on a new feature and the market impact of it can be analyzed
Product roadmaps are documented in a standard format and available for product management
Top 3 product data / information related GAP's
Product Manager Skills Survey
I can follow our competitors in a systematic and beneficial way
I can collect customer needs for segment-based product management
I can address various customer segments with good value propositions and differentiate my products in relevant segments
I can break down my product cost in an analytical way and develop cost competitiveness of my products
I can create product strategies for my products
I can manage my product portfolio (what to develop, what to enhance / improve, what to kill / phase out)
I can analyze the lifecycle value and cost of my product
I know how to address value adding services around my product
I can follow-up the business performance and customer satisfaction of my product
I can interact with sales, (channels) marketing and supply organizations
I can drive innovative product development for my product area
I know how to create a product supply strategy
I know how to meet product regulations
I know how launch products
I can address product claims and warranty issues

No direct information about the use of the model can be found in the literature. It is pointed out that the model can be employed for capital goods manufacturing, Life Science/medical devices and Pharmaceutical, Electronics, Software, Consumer Good Manufacturing, Telecoms, Healthcare, Financial & Insurance, business professional Service, IT-Services, Packaged consumer goods, Fashion, Construction etc. The size of the business can range from 1 to 5000 plus employees and turnover from 0 to 1000 plus M€ (Saaksvuori, 2014).

2.2 Basic principles for evaluation of maturity models

For the evaluation of different maturity models, Mettler has proposed three different viewpoints (Mettler et al., 2009):

- General model attributes;
- Maturity model design;
- Maturity model use.

General model attributes

In general, model attributes give the basic characteristics of a maturity model to provide potential model users an overall overview of the maturity model, starting with the name and acronym. If available, primary source and secondary source are included. It also indicates the type whether academic or practice and if it is the target audience management-oriented or technology focused the year and the mode of access are presented (Mettler et al., 2009).

Maturity model design

The concept of maturity shows process maturity and how far is it defined, managed, measured, controlled and how effective it is. Object maturity shows when a certain object reaches the proposed level of maturity. Personnel capability shows the level of knowledge creation and when the improvement of skills can be reached (Mettler et al., 2009).

Composition of maturity can be divided into three components: the Maturity grids, the Likert-like questionnaires and the CMM-like models (Fraser et al., 2002). The Maturity grids are given in the form of text and share descriptions of a certain sample. The Likert-like questionnaires are focused more on good practices not too much on describing overall levels. The CMM-like models are based on specifying a number of goals and key practices to reach a certain level. Due to the wide range of scales and subscales used, the CMM- like models are more complex (Mettler et al., 2009; Vezzetti et al., 2014).

Reusability is an important criterion in the maturity models and it can be described through reliability. This is shown through the validation or verification of the maturity model (Mettler et al., 2009).

The last characteristic, mutability from the maturity design group, shows how this model can adapt to the changes coming from the environment. It can be evaluated through form (meta model) or functioning (how maturity is assessed). There is also a possibility that the mutability is not part of the model (Mettler et al., 2009; Vezzetti et al., 2014)

Maturity Model Use

Mettler has proposed three attributes for describing maturity model use: method of application, support of application and practicality of evidence.

Self-assessment is the first approach of how to collect data for evaluating maturity. In this case, the company is gathering information by using own capabilities. Third party assisted assessment means that the company is using an external expert for assessment. Third opportunity is to use certified practitioners whereas in this case everything is outsourced (Mettler et al., 2009; Vezzetti et al., 2014).

The support of applications is described in three possible ways (Mettler et al., 2009; Vezzetti et al., 2014):

- No supporting materials, which implies that no guidelines are available of how to collect data and how it should be used;
- Textual description or a handbook gives an overview of how to configure the deployment of the model;
- Support of applications is in form of software assessment tool where installation is described and evaluated.

The last characteristic considered is the practicality of evidence, giving overview of how well current model can be used for certain activity, process or skill (Mettler et al., 2009; Vezzetti et al., 2014), etc.

2.3 Analysis of the maturity models

Batesburg's model is based on the publications "The maturity of product lifecycle management in Dutch organizations: A strategic alignment perspective" (Batenburg et al., 2005) and "PLM roadmap: stepwise PLM implementation based on the concepts of maturity and alignment" (Batenburg et al., 2006).

Zhang's model is based on the publications "Selection of product lifecycle management components based on AHP methodologies" (Zhang et al., 2013A), "PLM Components Selection Based on a Maturity Assessment and AHP Methodology" (Zhang et al., 2013B), "A PLM component monitoring framework for SMEs based on a PLM maturity model and FAHP methodology" (Zhang et al., 2014A), "PLM Maturity Evaluation and Prediction Based on a Maturity Assessment and Fuzzy Sets Theory" (Zhang et al., 2014B) and "Sustainability consideration within Product Lifecycle Management through Maturity Models Analysis" (Zhang et al., 2014C).

Schuh's model is based on the publication "The process oriented framework to support PLM implementation" (Schuh et al., 2008).

Kärkkäinen's model is based on Kärkkäinen and Silventoinen publications "A Roadmap for Product Lifecycle Management Implementation in SMEs" (Siventoinen et al., 2009), "Assessing maturity requirements for implementing and using product lifecycle management" (Kärkkäinen et al., 2009), "PLM maturity assessment as a tool for PLM implementation process" (Silventoinen et al., 2010), "Towards future PLM maturity assessment dimensions" (Silventoinen et al., 2011), and "Defining the customer dimension of PLM maturity" (Kärkkäinen et al., 2012).

Saaksvuori's model is based on the books "Product Lifecycle Management" (Saaksvuori et al., 2008) and "Product management maturity model & assessment" (Saaksvuori, 2014).

Stark's model is based on the books "Global Product, Strategy, Product Lifecycle Management and the Billion Customer Question" and "Product lifecycle management, 21st century paradigm for product realisation" (Stark, 2007; 2011).

General model attributes, Maturity Model design, Maturity Model Use

All the mentioned models are with academic background, except for Stark's model that is more of consulting nature (Vezzetti et al., 2014); Saaksvuori's model also involves consulting. Saaksvuori maturity model with Immonen was published in 2004 in the previous edition. However, Batenburg's maturity model even with further additions is the oldest (Batenburg et al., 2005) in this comparison. Shuch's model is from 2008. The model proposed by Kärkkainen and Silventoinen was developed from 2009 to 2012, while Zhang's model was developed from 2013 to 2014.

Batenburg's model consists of five business dimensions: strategy and policy, monitoring and control, organization and processes, people and culture, and information technology. Table 2.1 presents the description of the four different levels: no PLM investment, or on 'ad-hoc' basis only (level 0), on departmental level ('silo' orientation) (level 1), on the organizational level (cross-departments) (level 2), and on the inter-organizational level (cross supply chain partners) (level 3).

In Zhang's model, five criteria of the TIFOS framework are considered: TechnoWare, InforWare, FunctionWare, OrgaWare, and SustainWare. Descriptions of the criteria are presented in Table 2.3. 15 different components in Table 2.4 are divided into five criteria. Five maturity levels (1 ad-hoc, Process unpredictable, 2 Managed, Process reactive, 3 Defined, Process proactive, 4 Quantitatively managed, Process measured & controlled, 5 optimized, Continuous process improvement) are described in Table 2.5.

Shuch's framework consisting of the following: PLM definition, PLM foundation, The set of process reference models, Vendor neutral software description, PLM software support, PLM knowledge base, PLM benefits and description is presented in Table 2.6.

Stark's model based on two books focuses on Company, Product development and PDM. Table 2.7 describes the maturity levels of the model as follows: Traditional level, Archipelago of PLM Islands, Frontier-Crossing PLM, Enterprise-Wide PLM, Patchwork PLM, Enterprise-Wide, Enterprise-Deep PLM.

The model proposed by Kärkkäinen consists of six business dimensions: Strategy and policy; Monitoring and control; Organization and processes; People and culture; Information technology; Customer orientation. Table 2.8 compares the initial and ideal state to show the different extremes. Table 2.9 describes the Level I Chaotic stage, Level II Conscientious stage, Level III Managed stage, Level IV Advanced stage, Level V Integration stage.

Saaksvuori has proposed two different models. In his older model, the idea is based on the evaluation of Processes, Structures, IT systems, PLM strategy, People in PLM change management. Table 2.10 presents the description of Level 1 Unstructured, Level 2 Repeatable but intuitive, Level 3 Defined, Level 4 Managed and Measurable and Level 5 Optimal. The newer model is based on the evaluation of Role & Skill & Learning, Process and Tool & System. In the evaluation, the results are divided into categories Level 1 [best 25%], Level 2 [average +], Level 3 [average -] and Level 4 [low performer 25%], described in Table 2.11.

Table 2.13 describes general model attributes and the maturity model design. It shows the sources, background and orientation from the general model side and the concept and comparison of maturity from the design side.

Table 2.13. General model attributes, Maturity Model design.

General model attributes						
name/ acronym	**Batesburg's model**	**Zhang's model**	**Schuh's model**	**Kärkkäinen's model**	**Saaksvuori's model**	**Stark's model**
Sources	Batenburg et al., 2005; Batenburg et al., 2006	Zhang et al., 2013a Zhang et al., 2013b Zhang et al., 2014a Zhang et al., 2014b Zhang et al., 2014c	*Schuh et al., 2008*	Siventoinen et al., 2009 Kärkkäinen et al., 2009; Silventoinen et al., 2010 Silventoinen et al., 2011 Kärkkäinen et al., 2012	Saaksvuori, 2014; Saaksvuori et al., 2008	Stark, 2011
Academic/ Practice	Academic/ Practice	Academic/ Practice	Academic/ Practice	Academic/ Practice	Academic, No evidence	Academic, No evidence
Managem ent/ technology	Management	Management/ Technology	Management/ Technology	Management	Management/ Technology	Management/ Technology
Maturity model design						
Concept of maturity	Maturity is evaluated in 5 business dimensions and in each dimension the maturity has description, See Table 2.1.	15 components are compared (Table 2.4) in benefit categories. Maturity levels are described in Table 2.5.	Seven main point according to Schuh is brought in Table 2.6.	Maturity dimensions are brought in Table 2.8 and the description of the stages is brought out in Table 2.9.	Dimensions are brought in Chapter 2.1.6. and maturity levels described in table 2. 10. Additional approach is proposed.	Levels are brought out in chapter 2.1.4 and descriptions of the levels in Table 2.7.
Compositi on of maturity	Likert-like questionnaire	Likert-like questionnaire	Maturity grid	Likert-like questionnaire	Maturity grid	Likert-like questionnaire

In terms of the maturity model use, different types of proposals can be pointed out for implementation. Saaksvuori has recommended the guidelines for PLM implementation. Stark has pointed out a 10-step approach for PLM launch. It is suitable in a low level when the company wants to start or to continue improvements on the level of maturity. It also provides a description of how to move from one phase to another and how to get continuous improvement. Schuh has proposed a 10-step approach for PLM implementation.

All of the models except Batenburg's model and Saaksvuori's proposal have a common feature. Unfortunately, their questionnaires and detailed methods are not publicly available. This makes it difficult to compare them and evaluate in detail. The results presented are generic and superficial, so it is hard to evaluate whether the use of the model actually added something to the company and to what extent. For that reason, Table 2.13 contains no detailed description of the use of the current models.

3 MATURITY MODEL DEVELOPMENT

3.1 Basic concept

Based on the analysis and comparison of the existing maturity models, a new type of a maturity model is proposed (Fig. 3.1). The input for the maturity model was derived from the enterprise analysis model, which gathers information through a questionnaire, answered by employees in different levels in the company.

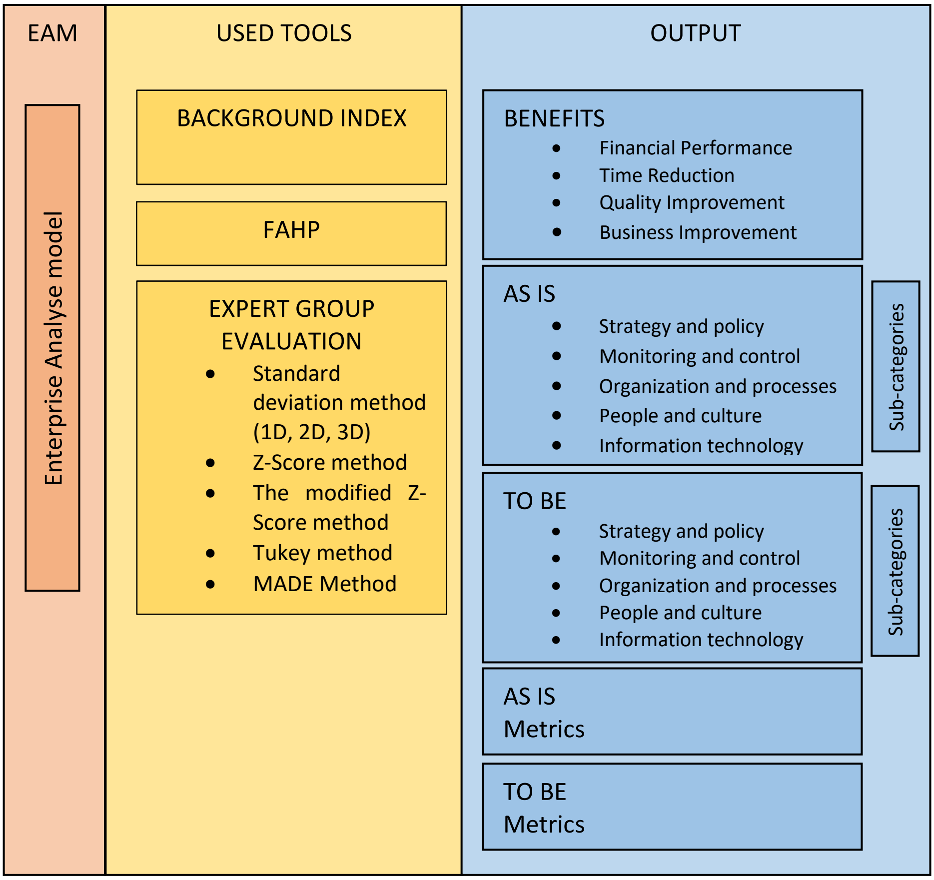

Figure 3.1. Description of the new maturity model.

The tools show different approaches and methods used in the current study. The expert group evaluations play an important role in this model, i.e., all the questions and answering opportunities were previously evaluated by the expert group. The effect of different evaluations in the expert group was checked through removing "incorrect" evaluations by using outlier methods.

The evaluations by the expert group were included also in the development of background index through taking into account the current position and working experience of an employee. In the evaluation of different benefits (Stark, 2011), it is important to point out the most important aspects from the expert point of view. An analysis was performed by utilizing the fuzzy analytic hierarchy process in the main expectation areas. As a final result, a proposal in percentages was made, pointing out the most important benefit categories the company should focus on:

- Financial Performance;
- Time Reduction;
- Quality Improvement;
- Business Improvement.

The model developed provides numeric values of the current As-is, potential maximum of the current As-is, To-be and the potential maximum of To-be for each business dimension proposed by Batenburg:

- Strategy and policy;
- Monitoring and control;
- Organization and processes;
- People and culture;
- Information technology.

The numeric values were calculated by using the input from Enterprise Analysis Model and processed by using expert group evaluations and the background index. Based on these values, the percentages were calculated, and numbers combined with the FAHP results were compared with certain ranges showing the current maturity. As an extra, the results for sub-categories are presented. Special attention was paid to the analyses of the results related to metrics.

Figure 3.2. Phases of maturity model development (De Bruin et al.,2005).

In the model development, guidance from De Bruin who introduced the following phases for development of the Maturity Assessment Model (Fig. 3.2) was used.

3.2 Development of enterprise analysis model

A number of enterprise analysis models can be found in the literature. They are targeted to give a better overview of enterprise current (As-is) situation and/or expected (To-Be) situation. The enterprise analysis model proposed in this chapter is aimed to simplify PLM implementation.

3.2.1 Selection of the first-round questions

The first-round questions selected, and selective answers given are based on the literature. More than 70 scientific and implementation related publications were reviewed. Questions and answering options were paired together and divided into 15 higher categories (see Table 3.1). In total, 259 questions were composed, and 1080 information rows were described to receive detailed information.

Table 3.1. Constructs devination between categories (Paavel et al., 2015).

Area	Different constructs	Questions	Information rows
Customer and Supplier participation	5	9	9
Electronic Data Interchange	38	43	476
Enterprise name	1	1	1
Financial	1	2	2
General information	5	5	46
Human Resource	31	42	66
Logistics	8	14	14
Mission and goals	7	12	12
NPI	21	28	122
Performance management	5	11	45
PLM implementation	13	14	104
Production	28	52	156
Quality management	8	15	16
Respondent information	6	6	6
Sales Management	2	5	5
Sum:	179	259	1080

Table 3.2 describes higher categories.

Table 3.2. Description of higher categories (Paavel et al., 2015):

Enterprise name – gives an opportunity to perform analysis for each enterprise separately. All data are collected to one database
General information- the category describes the location, field where the enterprise is operating and its research areas, also the expectations set by company
Mission and goals – covers the enterprise mission and vision and how are they linked to company's PLM activities, how are long and short-term goals understood and fallowed by company's workers; also describes workers awareness about responsibilities and their connection to overall picture
Respondent information – points out what kind of information is managed out of respondent information about current position, work experience in the current position and in the field of action, age and gender
Customer and Supplier participation – shows how customers and suppliers are involved in company's processes, how company is using acting according to customer and suppliers feedback, gives information how suppliers and customers participate in enterprise early stage
Electronic Data Interchange – describes how information is managed in the company, what kind of activities and processes are used for it, what kind of metrics are followed, how data is stored and how the backups have been done, what kind of programs are used, which type of product data and items are managed and how the information is related. Electronic Data Interchange covers also information movement inside of the company, data or document searching, making a change procedure, its description and notifications, duration of changes and number of changes done in one year, information about revision management, BOMs handling
Financial – shows employees disposition about different financial measures
Human Resource – gives an overview about company's background, distribution of personnel between departments, brings out information about trainings, also the skills of personnel and job satisfaction. This information reflects overall readiness for cooperation
Logistics – describes the situation in company's logistic department and how it is managed, is own or outsourced transport used, information about delivery times and delays
New Product Introduction- information about portfolio: age and the speed of renewal of the product portfolio, number of parts, assemblies are designed and are they cross-functional. Also, which product, process, data and application related metrics are followed during New Product Introduction
Performance management – provides information about performant measures followed by company and employee's opinion on current situation
PLM implementation – describes the overall awareness of the company. Does company have PLM vision, PLM strategy and how these are matching with overall business strategy and vision; Information about feasibility study, PLM ROI and its payback time, what kind of advantages company is hoping to achieve by implementing PLM/PDM system
Production – gives an overview about operating principlesof the enterprise production division, what the main problems in the production field are and where to focus attention in future, parameters measured currently and planned to measure in future
Quality management – describes the problems in the field of quality, what is measured and what are the expectations for quality measurements by the management, also main reasons of reclamations and errors inside the company
Sales Management – provides information about winning of new clients, and the competences of the sales personnel

The questionnaire was published in English and duplicated to Estonian. Second version with the same questions and answering possibilities was prepared in Estonian and duplicated to Russian. The number of questions is high in the first model. However, not all the questions are asked from every employee. Questions were divided into categories based on the job position and for each employee, only the questions corresponding to his/her position were displayed. The questionnaire proposed in the current study covers more than 80 work positions from shop floor to top management. Job positions were grouped according to the field of activity as follows (Paavel et al., 2015):

- R&D Personnel;
- IT Personnel;
- Business, sales and marketing;
- Production;
- Quality;
- Human Resource;
- Purchase and Logistics;
- CEO and Management.

From the literature review, more than 40 different answering scales were introduced. Information was gathered using fact-base scales (Table 3.3) or scales based on employee's opinion (Table 3.4).

Table 3.3. Example of fact-based scale (Lemmik et al., 2014)

Construct: Experience in current position		
Question: How long have you been employed in the current position?		
Code	**Response option in English**	**Response option in Estonian**
YR001	less than 6 months	Vähem kui 6 kuud
YR002	range of 6 months to 1 year	6 kuud kuni 1 aasta
YR003	range of 1 year to 2 years	1 aasta kuni 2 aastat
YR004	range of 2 years to 5 years	2 aastat kuni 5 aastat
YR005	range of 5 years to 10 years	5 aastat kuni 10 aastat
YR006	more than 10 years	Üle 10 aasta

Table 3.4. Example of personal opinion-based scale (Lemmik et al., 2014).

Construct: Visions matching		
Question: The company's overall vision matches the PLM vision?		
Code	**Response option in English**	**Response option in Estonian**
CT001	Strongly agree	Täiesti nõus
CT002	Agree	Nõus
CT003	Inclined to agree	Kaldun nõustuma
CT004	Inclined to disagree	Kaldun mittenõustuma
CT005	Disagree	Ei nõustu
CT006	Strongly Disagree	Ei ole üldse nõus

In some cases, more than one correct answer was possible. The latter situation occurred if the current situation was described through pre-set answers (Table 3.5).

The collected information covers: field of activity of the company, capacity of portfolio, number of employees, current achievements, followed metrics and expectations for the future. Also, information about responders contained position, work experience, age, gender, and education, information about collected product data, number of reviews, BOM managers and multilevel BOMs, number of changes and their implementation time. The questionnaire includes free text areas, providing employees a possibility to express own opinion.

The proposed questionnaire includes a certain number of repetitive questions used for validation. Correct answers to these questions were expected to ensure that the respondent has understood the question and has not just clicked randomly.

Table 3.5. Example of information gathering through pre-set answers (Stark 2011).

Construct: Product related metrics followed in company		
Question: What kind of product related metrics are you following in company?		
Code	**Response option in English**	**Response option in Estonian**
MC001	Percentage of products less than five years old	Toodete protsent, mis on vähem kui viis aastat vana
MC002	Number of product lines	Tootmisliinide arv
MC003	Number of products	Toodete arv
MC004	Number of assemblies	Sõlmede/koostude arv
MC005	Number of parts	Osade/detailide arv
MC006	Number of hierarchical level of product structure	Toote struktuuri hierarhilisete tasemete arv
MC007	Number of generations of product family concurrently worked on	Samaaegselt töös oleva tootepere põlvkondade arv
MC008	Number of complaints per product	Reklamatsioonide arv toote kohta
MC009	Number of new products per year	Uute toodete arv aasta jooksul
MC010	Number of retired products per year	Vananenud toodete arv aasta jooksul
MC011	Number of modified products per year	Modifitseeritud toodete arv aasta jooksul
MC012	Level of part reuse	Osade/detailide korduvkasutuse tase
MC013	Degree of product reliability	Toote töökindluse aste
MC014	Typical product development project times	Tootearenduseprojekti tüüpiline aeg
MC015	The time taken to process engineering changes	Aeg, mis kuulub insineeride muudatuste sissevimiseks
MC016	Average number of levels of Bills of Materials	Keskmine BOMi tasemete arv
MC017	Maximum number of levels of a Bill of Materials	Maksimaalne BOMi tasemete arv

In order to speed up the answering process, the questionnaire was implemented in the LimeSurvey environment. LimeSurvey is a professional tool for online surveys.

3.2.2 Compliance of questions to constructs

Before evaluation of the questions, the construct and question matching was performed. The relevance of constructs and questions was tested (168 of 179 constructs and 234 of 259 questions). The questions and constructs removed were exactly with the same wording, thus obviously irrelevant. Optimal Workshop software was used for pairing the questions with constructs. Constructs and questions were entered to the system by categories.

The testing was performed by the expert group that consisted of 6 staff members of the Tallinn University of Technology and industrial field. After associating the questions and constructs, the conclusions were drawn. Pairing of each construct and question was analyzed. If a question deviated from a correct construct less than 20%, the corrective action was taken. The value of 20% was derived from the Pareto Principe and in this case, it was allowed to have only one difference from the correct pairing. Table 3.6 shows by categories the number of compared constructs, questions and the average correct response percentage.

Table 3.6. Overview of the questions compliance to constructs.

Area	Different constructs	Questions	Average %
Customer and Supplier participation	5	9	68%
Electronic Data Interchange	35	40	87%
Enterprise name	1	1	100%
Financial	1	2	100%
General information	5	5	100%
Human Resource	30	35	82%
Logistics	8	14	100%
Mission and goals	7	10	88%
NPI	19	23	94%
Performance management	5	11	75%
PLM implementation	11	11	82%
Production	28	52	76%
Quality management	5	10	100%
Respondent information	6	6	100%
Sales Management	2	5	100%
Sum:	168	234	90%

For a better overview, Table 3.7 shows the example of an output how the pairing worked in the Optimal Workshop environment. The category ”Mission and Goals“ pairing is described. The results are presented in percentages.

Table 3.7. Example of "Mission and Goals" pairing results.

Question \ Construct	Formulation of task	Enterprise vision	Enterprise goals awareness	Enterprise mission	Enterprise vision	Enterprise long term goals	Enterprise short term goals
I am aware about my responsibilities.	83		17				
Too difficult to decompose goals for lower levels in organization.	50		50				
Management has clear vision of future of company.		100					
Vision of future of the company is strongly formulated.	17	83					
All employees are aware of company's goals, missions and visions.		17	83				
I am clear about the goals and objectives for my job.	17		83				
Enterprise mission:				100			
Enterprise vision:					100		
Enterprise long term goals:						100	
Enterprise short term goals:							100

Corrective actions were taken after pairing questions and constructs. The wording of the questions was made such as to give better information about the construct. After making changes, a new test was performed. It was not in full scale, but a critical number of questions and constructs were added to the test.

3.2.3 Evaluation of the questionnaire

In this phase, the questions were evaluated by the expert group consisting of 11 experts with academic, industrial or vendor background. Table 3.8 presents the background and experience of the expert group. The aim of the evaluation was to get information on the relevance of the current questions and to optimize the number of questions in the questionnaire.

Table 3.8. Expert group background.

Expert	Description
Expert 1	Professor in Tallinn University of Technology, with Industrial background
Expert 2	Professor in Tallinn University of Technology, with Industrial background
Expert 3	Vendor1 representative, Implementation background
Expert 4	Vendor2 representative, Implementation background
Expert 5	Vendor2 representative, Implementation background
Expert 6	Specialist from the industrial field
Expert 7	Specialist from the industrial field
Expert 8	Lecturer in Tallinn University of Technology
Expert 9	Lead Research Scientist in Tallinn University of Technology
Expert 10	Specialist from the industrial field
Expert 11	Emeritus Professor in Tallinn University of Technology

The expert group evaluated all the questions. Evaluation of the questions was done on the basis of the principles: How much will answering to this question benefit PLM implementation? Questions with the average score under 6.0 and maximum scores under 7 were considered insignificant. That kind of restrictions had to be taken into account to decrease the number of questions so that the overall quality would not fall.

By the end of the first selection, the number of questions was reduced from 259 to 115. With these questions, an extra analysis was done to see how the judgment of different expert group members would reflect the overall situation.

First, the expert group evaluation table was composed, where each row describes answers of a particular expert and each column evaluates a particular question, respectively. Next, each column of the evaluation table was sorted ascendingly. Thus, in the new sorted table, the data were not linked to the expert. The average values of the sorted table are given in column 2 of Table 3.9. In column 3 and 4, the differences of the average value of each sorted row from the total average value and median row average value, respectively, are presented.

Different outlier detection methods were used in order to eliminate “incorrect” results. Evaluation of each question was sorted in ascending order. The evaluations were divided into groups, so that row 1 contains the lowest scores for each question constructs and all the other rows are formed on the same principle. Analysis was performed for each row to see how extreme evaluations are influencing the total results. Therefore, rows average was calculated and compared with the overall average and median row average. Table 3.9 shows that the first sorted rows contain larger gaps compared to overall average and median row average where the evaluation scores were lower. Based on this information for verification of the data, the evaluation results were removed from the lower evaluations. After each removal of the result, a new analysis was performed to be convinced in the data appropriateness.

Table 3.9. Overview of results of different ratings.

Row information	Rows average	Overall average-row average	Median row – row average
Row 1 of sorted table	3,49	3,72	3,98
Row 2 of sorted table	4,93	2,28	2,54
Row 3 of sorted table	5,92	1,29	1,55
Row 4 of sorted table	6,60	0,61	0,87
Row 5 of sorted table	7,00	0,21	0,47
Row 6 of sorted table	7,47	0,26	0,00
Row 7 of sorted table	7,94	0,73	0,47
Row 8 of sorted table	8,37	1,17	0,90
Row 9 of sorted table	8,75	1,54	1,28
Row 10 of sorted table	9,21	2,00	1,74
Row 11 of sorted table	9,60	2,39	2,13

The number of evaluations was rather small compared to average data analyses sets. The influence of outliers reflects smaller sample sizes (Cousineau et al., 2010). In the current study, the following five widely used outlier methods were used:

- Standard deviation method;
- Z-Score method;
- The modified Z-Score method;
- Tukey method;
- MADE Method.

Methods were selected based on the literature and analyses. Methods that work on different principles were selected. Some of them depend on the mean and standard deviation, others do not.

Standard deviation method

Standard deviation is one of the most commonly used methods for determining outliers. The principle was introduced by the German mathematician Carl Friedrich Gauss (1777-1855). According to him, 68% of the values drawn are ± standard deviation from the mean. 95% of the values are in ± standard deviation from mean and 99.7% of values are in ± standard deviation from the mean, as shown in Fig. 3.3.

Standard deviation method assumes that the distribution of results as well as outliers is normal. If this principle is working based on the mean, then one or two extreme outliers will affect the mean value rapidly. Through the mean value, it reflects standard deviation (Miller, 1991). The influence of outliers is larger when the selection of data is smaller (Cousineau et al., 2010).

Even though the method has some weaknesses, analyses according to standard deviation methods were done. Based on Eqs. (3.1), (3.2), and (3.3), calculations were done to find 3SD, 2SD and 1SD boundaries.

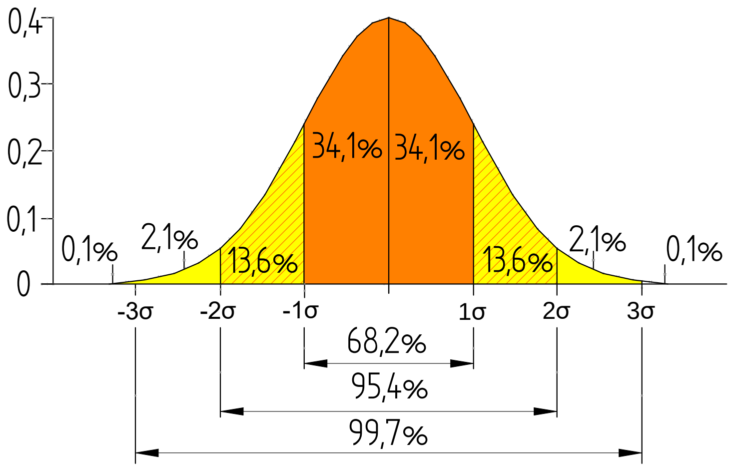

Figure 3.3. Standard deviation.

$$3SD = \bar{x} \pm 3SD \quad (3.1)$$

$$2SD = \bar{x} \pm 2SD \quad (3.2)$$

$$1SD = \bar{x} \pm 1SD \quad (3.3)$$

In Eqs. (2.1.-2.3.), $\bar{x}$ stands for standard mean and SD for standard deviation.

Table 3.10 summarizes the results for 1SD, 2SD and 3SD. Evaluations are presented on increasing order. Each question was analyzed separately, by calculating mean and standard deviation. All the evaluation rows were compared with the boundaries set for each deviation principle. Table 3.10 shows the percentages of evaluations that met the set of boundaries.

Table 3.10. Percentages of evaluations that met the set of boundaries.

Row information	**$1SD_1$**	**$1SD_{10}$**	**$1SD_9$**	**$2SD_{11}$**	**$2SD_{10}$**	**$2SD_9$**	**$3SD_{11}$**	**$3SD_{10}$**	**$3SD_9$**
Row 1 of sorted table	3			56			100		
Row 2 of sorted table	39	4		100	76		100	100	
Row 3 of sorted table	86	49	9	100	100	87	100	100	99
Row 4 of sorted table	99	87	50	100	100	99	100	100	99
Row 5 of sorted table	100	96	83	100	100	99	100	100	99
Row 6 of sorted table	100	100	99	100	100	99	100	100	99
Row 7 of sorted table	100	99	99	100	100	99	100	100	99
Row 8 of sorted table	97	99	99	100	100	99	100	100	99
Row 9 of sorted table	85	84	83	100	100	99	100	100	99
Row 10 of sorted table	50	49	47	100	100	99	100	100	99
Row 11 of sorted table	28	25	21	100	100	98	100	100	99

When using 3SD boundaries, all the expert group evaluations are in that area. It does not depend on whether the number of evaluations is reduced by excluding the minimum values in each row. The results with 3SD boundaries remain the same. The only deflection describes the situation where all the evaluations that were left are the same. For that reason, the percentage is not 100.

When boundaries are set on 2SD, the smallest values are outside of the boundaries. In other rows, the percentage is maximum or near maximum. This shows that occasionally the lowest values might be possible outliers.

Using 1SD boundaries, maximum and minimum evaluations remain far from the mean.

Based on 1SD, 2SD and 3SD, current results of the analyses show that evaluations are according to normal distribution.

Z-Score method

The Z-Score method is based on the use of mean and standard deviation values for screening potential outliers (Warner, 2016). Z-Score is suitable for detecting one outlier whose values are differential from the others.

$$Z_i = \frac{x_i - \bar{x}}{\sigma} \tag{3.4}$$

In Eq. (3.4) $X_I \sim N(\mu, \sigma^2)$, and σ stands for the standard deviation.

If the evaluation follows normal distribution $N(\mu, \sigma^2)$, then Z follows standard normal distribution.

The Z-Score shows the difference between the values of interested data points and the mean. It also provides consistency of interpretation through the entire range of values. Also, it is a good model for comparing changes in the data sets. The value in Z-Score can be either positive or negative. This shows that either the data point is numerically greater or smaller than the mean of the population (Warner, 2016).

Table 3.11. Evaluation results by using Z-Score.

Row information	Min Z-Score	Max Z-Score
Row 1 of sorted table	-2,922	-0,944
Row 2 of sorted table	-1,941	-0,379
Row 3 of sorted table	-1,35	0,375
Row 4 of sorted table	-1,010	0,375
Row 5 of sorted table	-0,862	0,517
Row 6 of sorted table	-0,698	0,758
Row 7 of sorted table	-0,419	0,913
Row 8 of sorted table	-0,055	1,090
Row 9 of sorted table	0,367	1,325
Row 10 of sorted table	0,375	1,773
Row 11 of sorted table	0,375	2,023

Z-Score is not good for outlier labelling with small data sets since detecting the outlier Z-Score must be over 3. In the current study, 11 evaluations were used. This is the absolute minimum number of evaluations to apply Z-Score because maximum Z-Score is dependent on sample size. This is interpreted as $(n-1)\sqrt{n}$ (Shiffler, 1988). Based on this calculation, only 11 evaluations were made and no smaller evaluations were eliminated.

The evaluations are given in increasing order. Each question was analyzed separately, by calculating the mean and standard deviation. In each row, minimum and maximum results were gathered, shown in Table 3.11.

All the evaluation results meeting the expectations are under number 3. Based on the analysis results obtained, no outliers were detected. Even though in the first row, the smallest score is nearby.

The Modified Z-Score method

The modified Z-Score principles are different. Instead of mean and standard deviation, it uses median and the median of the absolute deviation of the median (MAD) (Iglewicz et al., 1993). An advantage is that MAD is not reflected from the sample size. This applies until at least 50% of the results are infinite (Leys et al., 2013).

The modified Z-Score (M_i) was computed for large normal data as

$$M_i = \frac{0{,}6745(x_i - \tilde{x})}{MAD}, \text{ where } E(MAD) = 0{,}675\ \sigma. \quad (3.5)$$

In Eq. (3.5) $MAD = median\{|x_i - \tilde{x}|\}$ where $\tilde{x}$ is the sample median

Possible outlier is an evaluation where the value $|M_i| > 3{,}5$ (Iglewicz et al., 1993). Each question was analyzed separately. Table 3.12 shows the percentages of the categorized evaluations that meet the set requirement. These evaluations as possible outliers would reflect the overall results.

Table 3.12. Evaluation results in percentage by using modified Z-Score.

Row information	Modified Z-Score (11)	Modified Z-Score (10)	Modified Z-Score (9)
Row 1 of sorted table	89	-	-
Row 2 of sorted table	99	81	-
Row 3 of sorted table	100	94	100
Row 4 of sorted table	100	99	100
Row 5 of sorted table	100	100	100
Row 6 of sorted table	100	100	100
Row 7 of sorted table	100	100	100
Row 8 of sorted table	100	100	100
Row 9 of sorted table	100	100	100
Row 10 of sorted table	100	100	100
Row 11 of sorted table	99	98	99

As can be seen from Table 3.12, the evaluations percent is high enough to stay in the mentioned boundaries. Even lowering the boundaries to $|M_i| > 3{,}0$, it will reflect the result in a small scale.

Tukey's method (BOXPLOT)

Tukey's method, also known as the boxplot method, is less sensitive to extreme values of data. Tukey's method uses median, lower quartile and upper quartile for evaluations. The method is not very suitable for small data slots where the values can vary significantly (Tukey, 1977).

Tukey's method is based on fences where IQR (Inter Quartile Range) is the distance between the lower quartile (Q1) and the upper quartile (Q2). Inner fences are located 1.5 IQR below lower quartile and 1.5 IQR above upper quartile [Q1-1,5IQR, Q3+1,5IQR]. Outer fences are located 3 IQR below lower quartile and 3 IQR above upper quartile [Q1-3IQR, Q3+3IQR]. A value between the fences is a possible outlier and a value outside of the IQR and fences is a probable outlier.

Numbers 1.5 and 3 were not meant to be rules for declaring outliers, but to call attention to the data that need to be further investigated (Hoaglin, 2003).

Table 3.13 shows the categorized evaluations that will meet the set requirement in percentages. This is the percentage of evaluations that are outside of boundaries.

Table 3.13. Evaluation results in percentage by using Tukey's method.

Row information	**Inside of Tukey's fences or IQR (11)**	**Inside of IQR (11)**	**Inside of Tukey's fences or IQR (10)**	**Inside of IQR (10)**	**Inside of Tukey's fences or IQR (9)**	**Inside of IQR (9)**
Row 1 of sorted table	100	63				
Row 2 of sorted table	100	89	97	72		
Row 3 of sorted table	100	100	100	94	95	83
Row 4 of sorted table	100	100	100	100	95	92
Row 5 of sorted table	100	100	100	100	100	100
Row 6 of sorted table	100	100	100	100	100	100
Row 7 of sorted table	100	100	100	100	100	100
Row 8 of sorted table	100	100	100	100	100	100
Row 9 of sorted table	100	100	100	100	100	100
Row 10 of sorted table	100	100	100	98	96	96
Row 11 of sorted table	100	100	100	97	95	91

The results of the analyses according to Tukey's method show that a great majority can be counted as non-outlier. [Q1-1,5IQR, Q3+1,5IQR] in a normal distribution presents approximately 2.7 standard deviation and [Q1-3IQR, Q3+3IQR] presents approximately 4,72 standard deviation (Schwertman et al., 2004).

MAD_E method
MAD_E method is similar to the standard deviation method. However, it uses the median and MAD_E instead of the mean and standard deviation. This method is not very effective for extreme evaluations. Two different MADE methods; 2 MAD_E Eq. (3.7) and 3 MAD_E Eq. (3.8) are used.

$$\bar{x} \pm 2MAD_E \quad (3.7)$$
$$\bar{x} \pm 3MAD_E \quad (3.8)$$

where $MAD_E = 1{,}483 \times MAD$, MAD calculation was done in Eq 3.5.

In the analyses, the evaluations were put in increasing order. Each question was analyzed separately. Table 3.14 shows in percentages the categorized evaluations that will meet the set requirement. This is the percentage of evaluations that are inside the boundaries according to the methods.

Table 3.14. Evaluation results in percentage by using MAD_E method.

Row information	$2MAD_{E(11)}$	$2MAD_{E(10)}$	$2MAD_{E(9)}$	$3MAD_{E(11)}$	$3MAD_{E(10)}$	$3MAD_{E(9)}$
Row 1 of sorted table	30			70		
Row 2 of sorted table	60	49		90	73	
Row 3 of sorted table	86	67	72	97	83	83
Row 4 of sorted table	96	83	86	97	93	88
Row 5 of sorted table	97	93	93	97	96	93
Row 6 of sorted table	100	99	100	100	99	100
Row 7 of sorted table	100	99	100	100	99	100
Row 8 of sorted table	100	97	98	100	98	100
Row 9 of sorted table	97	91	90	99	97	96
Row 10 of sorted table	90	80	77	97	95	90
Row 11 of sorted table	83	69	62	97	91	84

If we use the MAD_E method that depends on the median, it can cause a problem that the extreme evaluations are pointed out as outliers.

3.2.4 Discussion and conclusions
Table 3.15 shows the results when no outlier methods are used. The question is - what is the average when a row with one or two smallest values in question is removed.

Table 3.16 shows the differences of the calculated average by using different methods for finding potential outliers.

Table 3.15. Comparison of averages by using different outliers sets.

Number of outliers	**11**	**10**	**9**
Number of rows	1265	1150	1035
Average	7,21	7,58	7,87

Table 3.16. Comparison of averages by using different outliers sets.

	Rows left/ percentage from maximum rows			**Average (based on rows left)**		
Row / **Method**	**11**	**10**	**9**	**11**	**10**	**9**
3SD	1265/100	1150/100	1035/100	7,21	7,58	7,87
2SD	1214/96	1122/98	1012/98	7,36	7,65	7,89
1SD	906/72	795/69	676/65	7,54	7,74	7,89
Z-Score	1265/100	1150/100	1035100	7,21	7,58	7,87
Modified Z-Score	1250/99	1118/98	1034/100	7,26	7,66	7,87
Tukey inner	1209/96	1105/96	991/96	7,35	7,66	7,89
Tukey upper	1265/100	1146/100	1012/98	7,21	7,59	7,86
2MAD	1080/86	951/83	894/86	7,53	7,68	7,83
3MAD	1250/99	1063/92	959/93	7,32	7,64	7,83

Tables 3.14 and 3.16 show that using some of outlier methods (3SD, Z-Score and Tukey upper), the results remain unchanged. In this case, the boundaries are too far from the current validation results and all the results are eligible. In these circumstances, reducing the selection of evaluations will not reflect the results. The results obtained by applying different outlier methods were found to be in good agreement.

3.3 Background index

The information gathered through the questionnaire presented in the Enterprise analysis model was derived from different levels of the enterprise. Based on this, the background index here was introduced such that it will take into account four different aspects with a different percentage on the responder, like:

- Current position in enterprise 50%;
- Working period in current position 25%;
- Working period in enterprise 15%;
- Working period in current field 10%.

The percentages proposed rely mostly on the experience and expectation that the people with the right knowledge are on the right positions. The method was discussed with the expert group. Therefore, the percentages related to position and experience are higher than just the overall knowledge in the current field.

In the questionnaire presented in the Enterprise analysis model, more than 80 different positions in the enterprise were involved. These positions were divided into groups and each group was evaluated by the expert group (Table 3.17). Given score presents the expertise of the current group. The average score of the expert group was taken into consideration.

Table 3.17. The average scores of position groups.

Group of employees	Average score
R&D Personnel	8,66
IT Personnel	8,26
business, sales and marketing	7,05
Production	7,17
Quality	7,38
Human Resource	6,18
Purchase and Logistics	7,16
CEO and Management	7,73

Through the questionnaire, information was gathered about the working period in the current position, in the enterprise and in the current field. Expert group evaluated the possible present answering opportunities and the result of average scores is presented in Tables 3.18, 3.19 and 3.20.

Table 3.18. Average score of working period in the current position.

How long have you been employed in the current position	Average score
less than 6 months	5,18
range of 6 month to 1 year	5,91
range of 1 year to 2 years	6,73
range of 2 to 5 years	8,36
range of 5 to 10 years	9,18
more than 10 years	9,73

Table 3.19. Average score of working period in the current enterprise.

How long have you been employed in the current enterprise	Average score
less than 6 months	5,64
range of 6 month to 1 year	6,27
range of 1 year to 2 years	7,09
range of 2 to 5 years	8,55
range of 5 to 10 years	9,18
more than 10 years	9,73

Table 3.20. Average score of working period in the current field.

How long have you been working in the current area of work	Average score
less than 6 months	5,45
range of 6 month to 1 year	6,09
range of 1 year to 2 years	6,91
range of 2 to 5 years	8,45
range of 5 to 10 years	9,18
more than 10 years	9,73

The background index can be computed as,

$$BI = CP \times CP_{EV} + WP_{CP} \times WP_{CP.EV} + WP_{E} \times WP_{E.EV} + WP_{CF} \times WP_{CF.EV} \quad , (3.9)$$

where:
CP- coefficient of the current working position in percentages;
CP_{EV}- expert group evaluation of the current working position;
WP_{CP}- coefficient of the working period in the current position in percentages;
$WP_{CP.EV}$- expert group evaluation for the period of working in the current position (Table 3.18);
WP_{E}- coefficient of the working period in enterprise in percentages;
$WP_{E.EV}$- expert group evaluation for working period in enterprise (Table 3.19);
WP_{CF}- coefficient of the working period in current field in percentages;
$WP_{CF.EV}$- expert group evaluation for working period in current field (Table 3.20).

The background index computed varies from 9,20 to 6,20.

3.4 Benefits

In business each activity has a purpose. Activities that help gain an advantage or benefit are realized. To understand company's expectations, the results expected are defined.

In the proposed model, the benefits were divided into four larger categories (Stark, 2011):

- Financial Performance;
- Time Reduction;
- Quality Improvement;
- Business Improvement.

Table 3.21 shows an example of how certain benefits are asked in the questionnaire and evaluated by the expert group. Average scores were computed based on expert group evaluations.

Table 3.21. Sub-categories of benefits.

Options available	Financial performance	Time reduction	Quality improvement	Business improvement	Average
Product faster time-to-market				x	8,45
Improved product cycle times		x			8,00
Fewer Errors			x		7,9
Less scrap & rework			x		7,8
Greater productivity	x				8,00
Greater Design efficiency				x	8,27
Better product quality			x		8,09
Decreased cost of new product introduction	x				8,27
Insight into critical processes		x			6,64
Better reporting and analytics				x	7,27
Standards and regulatory compliance				x	7
Improved design review and approval processes			x		7,91
Improved communication				x	7,64
Reduced product cost and greater profitability	x				8,00
Better resource utilization		x			7,55
Improved integration and communication with extended supply chain				x	7,64

In the model, four benefit categories were evaluated by the expert group by using the FAHP methodology. Sub-level in Table 3.21 was taken into account as average scores.

In section To-Be, specific topics beside expected benefits that company considers as important are discussed.

3.4.1 Fuzzy Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) proposed by Saaty (Saaty, 1980) is a widely used method for making multiple-attribute decisions (Saaty, 1980; Franek et al., 2014). It takes the pair-wise comparisons of different alternatives and provides support for decision making for multicriteria decisions. The objectives are on the first level, the criteria are on the second level, sub-criteria on the third level and alternatives are found on the fourth level (Kilincci et al., 2011).

For comparisons, Saaty has proposed a scale of numbers to indicate how many times one element is important or dominant over another element in the field where they are compared (Saaty, 2008).

Fuzzy Analytic Hierarchy Process (FAHP) is an extension of the AHP method. The FAHP method uses fuzzy logic. Fuzzy sets and fuzzy numbers determine the ranking of a certain criterion (Chang, 1996).

The Fuzzy Set Theory (FST) was introduced by Zadeh to deal with the uncertainty and vagueness (Shu etc., 2006). A tilde "~" is placed above a symbol if the symbol shows FST. The membership function $\mu_A(x)$of a triangular fuzzy number can be introduced as (Kaufmann et al., 1988):

$$\mu_A(x) = \begin{cases} 0 & x < 1 \; or \; x > u, \\ \frac{x-l}{m-l} & l \leq x \leq m, \\ \frac{m-x}{u-m} & m < x \leq u. \end{cases} \tag{3.10}$$

The main difference between the AHP and FAHP is shown in Table 3.22 where the different scales are presented. In the AHP comparison, one number is taken into account using fuzzy logic and a set of numbers is considered.

Table 3.22. Saaty's 9 point scale with fuzzy logic (Ayhan, 2013)

Saaty scale	Definition	Fuzzy triangular scale
1	Equally importance	(1,1,1)
3	Weakly important	(2,3,4)
5	Fairly important	(4,5,6)
7	Strongly important	(6,7,8)
9	Absolutely important	(9,9,9)
2	The intermittent values between	(1,2,3)
4	two adjacent scales	(3,4,5)
6		(5,6,7)
8		(7,8,9)

Based on the subject, pair-wise comparison of elements was performed, as shown in Table 3.23. Comparison was performed by users or experts.

Table 3.23. Example of pair-wise comparison.

EXAMPLE	**C1**	**C2**	**C3**
C1	(1,1,1)	(4,5,6)	(1,2,3)
C2	(1/6,1/5,1/5)	(1,1,1)	(6,7,8)
C3	(1/3,1/2,1/1)	(1/8,1/7,1/6)	(1,1,1)

The geometric in the fuzzy comparison values means that all criteria are computed by use of the following formula (Ayhan, 2013):

$$l_i = \left(\prod_{j=1}^{n} l_{ij}\right)^{\frac{1}{n}}, \qquad (3.11)$$

$$m_i = \left(\prod_{j=1}^{n} m_{ij}\right)^{\frac{1}{n}}, \qquad (3.12)$$

$$u_i = \left(\prod_{j=1}^{n} u_{ij}\right)^{\frac{1}{n}}, \qquad (3.13)$$

where n stands for the number of decision criteria. The i-th triplet corresponding to geometric mean values is as follows:

$$\tilde{G}_i = (l_i, m_i, u_i). \qquad (3.14)$$

The normalized values or eigenvectors of l_i, m_i and $u_i$can be computed as

$$[\bar{l}_i, \quad \bar{m}_i\,, \quad \bar{u}_i] = \left[\frac{l_i}{\sum_{j=1}^{n} l_i}, \frac{m_i}{\sum_{j=1}^{n} m_i}, \frac{u_i}{\sum_{j=1}^{n} u_i}\right]. \qquad (3.15)$$

For evaluation of the results, the consistency ratio CR was calculated for $\mathrm{m_i}$. The value less than 0,1 indicates that the judgements are at the limit of consistency (Kong et al., 2005)

$$CR = \frac{CI}{RI} < 0{,}1, \qquad (3.16)$$

where CI stands for consistency index and the RI is constant, coming from the matrix size shown in Table 3.24.

Table 3.24. Values of RI (Kong et al., 2005)

Size of matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

The consistency index CI is determined as (Saaty, 1980)

$$CI = \frac{\lambda - n}{n-1}, \qquad (3.17)$$

where n is the dimension of the matrix $M = [m_{ij}]$ and λ is the maximum eigenvalue of the comparison matrix.

In the following sections, the FAHP method is applied for the evaluation of benefit categories.

3.4.2 Evaluation of benefit categories

Expert group evaluations for four benefit categories are shown in Table 3.25.

Table 3.25. Expert group evaluations for benefits.

	Financial performance	**Time reduction**	**Quality improvement**	**Business improvement**
Financial Performance	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)
Time Reduction	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)
Quality Improvement	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(1,1,1)
Business Improvement	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(1,1,1)

By using formulas (3.11), (3.12), and (3.13) the numerical values of l_i, m_i and u_i, also their sums are presented in Table 3.26.

Table 3.26. The geometric means of fuzzy comparison values.

Criteria	$\boldsymbol{l_i}$	$\boldsymbol{m_i}$	$\boldsymbol{u_i}$
Financial Performance	1,00	1,68	2,28
Time Reduction	0,44	0,59	1
Quality Improvement	0,76	1	1,32
Business Improvement	0,76	1	1,32
Sum	2,96	4,27	5,92

The eigenvectors of the relative importance were normalized by using Eq. (3.16) and can be computed as shown in Table 3.27.

Table 3.27. Eigenvectors of fuzzy comparison values.

Criteria	$\boldsymbol{\bar{l}_i}$	$\boldsymbol{\bar{m}_i}$	$\boldsymbol{\bar{u}_i}$
Financial Performance	0,34	0,39	0,39
Time Reduction	0,15	0,14	0,17
Quality Improvement	0,26	0,23	0,22
Business Improvement	0,26	0,23	0,22

The eigenvector values are not making 100% do through approximation.

3.4.3 Mapping of expectations

To acquire a better overview of current expectations, the questionnaire contained relevant questions. Through the expert group evaluation of the questions and answering opportunities and employee answering options, the relative importance can be calculated.

The employees were selecting hoped benefits in the questionnaire and as a result, the recommendation in percentage shows further focus (categories).

Based on the optimized questionnaire, the weights of the questions and answers determined by the expert group, the background index of the employees, the score reflecting current expectations, can be introduced as

$$C = \sum_{j=1}^{PC} BI_j \sum_{i=1}^{QC} QW_i \times Q_{ji} \sum_{k=1}^{AC_i} AW_k \times A_{jik}, \tag{3.18}$$

where

PC – Person count;

QC – Question count;

AC_i – Answer count for question number;

BI_j – Background index;

QW_j – Question weight;

AW_k – Answer weight;

O_{ji} – is equal to 1 if the question is from person *j* and equal to zero otherwise;

A_{jik} – is equal to 1 if the employee considers this answer important and equal to 0 otherwise.

After evaluation of the current expectation based on each benefit group, the score of maximum expectations for each benefit group was calculated using the following formula:

$$C_{max} = \sum_{j=1}^{PC} BI_j \sum_{i=1}^{QC} QW_i \times Q_{ji} \sum_{k=1}^{AC_i} AW_k \, , \quad (3.19)$$

where

PC – Person count;

QC – Question count;

AC_i – Answer count for question number;

BI_j – Background index;

QW_j – Question weight;

AW_k – Answer weight;

O_{ji} – is equal to 1 if the question is from person *j* and equal to zero otherwise;

A_{jik} – is equal to 1.

Based on the information, the final score can be computed to bring out final expectations by employees. The final score is given as the ratio $C_F = C/C_{max}$, i.e., as the relative value of the score. Using this information with the results given through the FAHP analysis, the final number in percentage can be obtained.

3.5 Selection of model components

The proposed maturity model was developed based on the analysis of several existing models (previous chapter), and hundreds of components and functions found in the literature. The components were sorted and categorized into sub-categories based on the Batenburg business dimensions. To keep the number of sub-categories reasonable, the sub-categories were formed such that each sub-category covers a number of relevant PLM components, as shown in Figure 3.4.

After categorizing the PLM components into sub-categories, the Batenburg business dimensions and corresponding sub-categories were discussed in more detail in the next sub-paragraphs:

- Strategy & Policy;
- Management & Control;
- Organization & Processes;
- People & Culture;
- Information Technology.

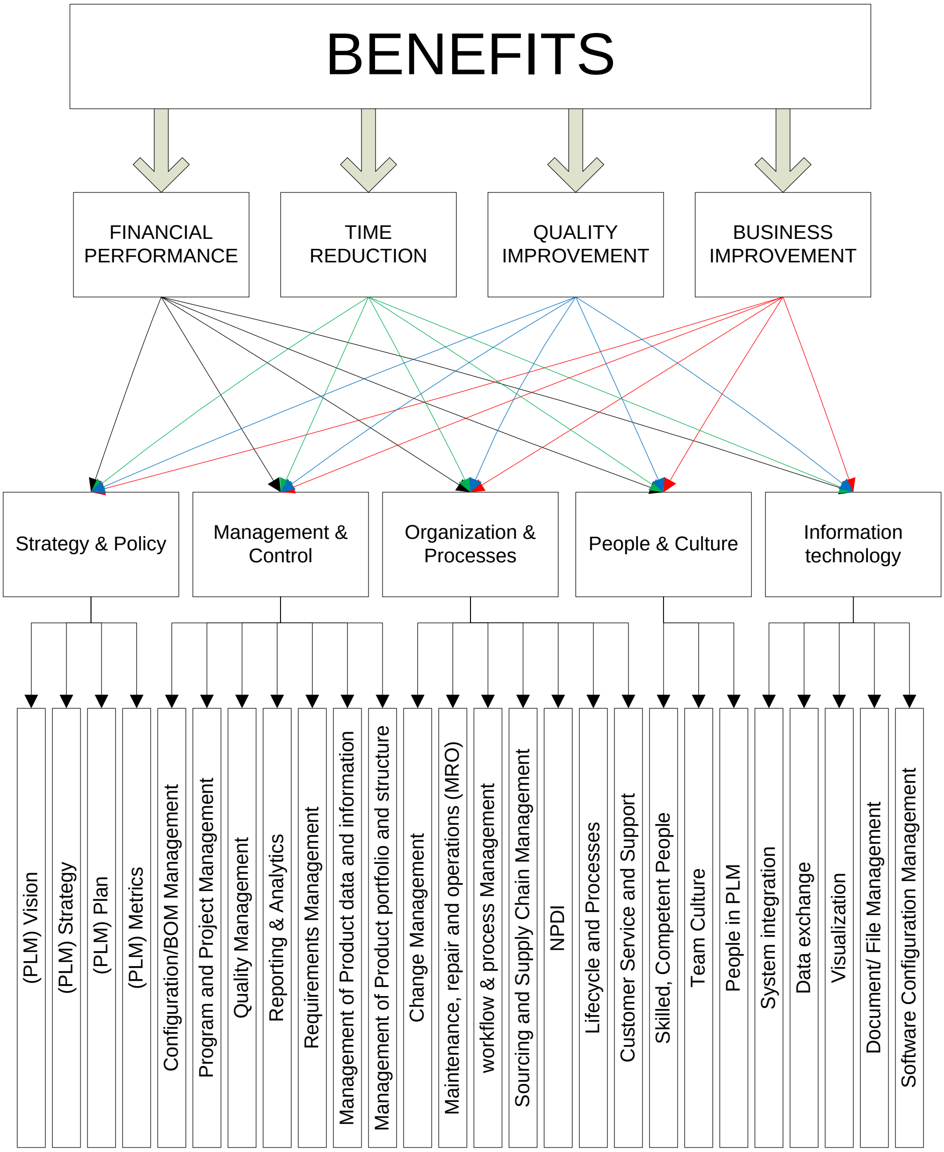

Figure 3.4. Relationships between sub-categories and PLM components.

3.5.1 Strategy & Policy

The Strategy and Policy is one of the five business dimensions, which are used to evaluate the PLM maturity model; it consists of Vision, Strategy, Plan and metrics. Table 2.8 shows the whole input.

(PLM) Vision

The Sub-category Vision gives a better understanding of the current situation concerned with the enterprise mission and vision. We will try to answer the next points: how this is formulated and communicated in the enterprise now and after a five-year perspective; if the enterprise has performed a feasibility study or ROI of PLM implementation; what kind of PLM related metrics the enterprise is following at the current time and what metrics the enterprise wishes to follow in the future.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category PLM vision: and brought out in Table 3.28.

(PLM) Strategy

The Strategy describes the current situation about PLM strategy and how this is linked to the enterprise overall and PLM vision, what is the progress with feasibility study, ROI, and PLM strategy. Or implementation strategy is already subscribed and is trying to answer the question: what benefits does the enterprise hope to achieve?

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category PLM strategy and are brought out in Table 3.28.

(PLM) Plan

The sub-category Plan specifies the current situation of the PLM Plan, whether it is on general level or implementation Plan level.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category PLM Plan and are brought out in Table 3.28.

(PLM) Metrics

Current category Metrics indicates engineering change, people, product, process, (product)data, application and other PLM related metrics that the enterprise is following at the current time and wishes to follow in the future.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category PLM Metrics and are brought out in Table 3.28.

Table 3.28. References of Strategy & Policy.

Strategy & Policy	(PLM) Vision	(PLM) Strategy	(PLM) Plan	(PLM) Metrics	References
PLM Vision	X				PLM Analytics Maturity Assessment Program, 2014; Stark, 2007
PLM organization	X				PLM Analytics Maturity Assessment Program, 2014
Concept and ideation	X				PLM Technology Guide, 2017
PLM strategy		X			Saaksvuori et al., 2008; Silventoinen et al., 2011
Policies		X			Batenburg et al., 2005, 2006; Kärkkäinen et al., 2009, 2012, 2014; Silventoinen et al., 2010;
Development process		X			Silventoinen et al., 2011
Planning		X			Vila et al., 2015
Product families and products		X			Stark, 2007
Applications		X			Zhang et al., 2013a, 2014c; Savini et al., 2012;
Benefits		X			Schuh et al., 2008
Definitions		X			Schuh et al., 2008
Foundations		X			Schuh et al., 2008
Organization		X			PLM Analytics Maturity Assessment Program, 2014
Responsibilities		X			Stark, 2007
Processes		X			Silventoinen et al., 2011
Structures		X			Silventoinen et al., 2011
Progress with Customers			X		Stark, 2007
Progress with lifecycle			X		Stark, 2007
Progress with processes			X		Stark, 2007
Progress with people			X		Stark, 2007
Progress with culture			X		Stark, 2007
Progress with Products			X		Stark, 2007
Progress with vision				X	Stark, 2007; Stark, 2011
Progress with Plan				X	Stark, 2007; Stark, 2011

3.5.2 Management & Control

Management and Control is one of five business dimensions employed for evaluating PLM maturity. It consists of Configuration/BOM Management, Program and project management, Quality management, Reporting & Analytics, Requirements management, Management of Product data and information, Management of Product portfolio and structure, and Management of Product portfolio and structure. Table 2.29 presents the input for Management and Control.

Configuration/BOM Management

Configuration and BOM management gives extra information of how BOMs and configurations are managed. This dimension shows who the people are in the enterprise BOM management and what the procedures are. In addition, it shows how different variants and configurations are managed.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category configuration and BOM management and are brought out in Table 3.29.

Program and project management

The sub-Category describes how programs and projects are managed in the enterprise and what kind of systems are used and how the program and project management is performed.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category program and project management and are brought out in Table 3.29.

Quality management

The Quality management shows how quality is guaranteed at the enterprise and how continuous quality level is ensured at different time periods.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category quality management and are brought out in Table 3.29.

Reporting & Analytics

Reporting & Analytics shows which activities and results of activities are reported and analyzed. In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Reporting and Analytics and are brought out in Table 3.29.

Requirements management

This sub-category provides the requirements concerned with product and its preparation prepetition process, as well as requirements that are currently followed in the different departments.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Requirement management and are brought out in Table 3.29.

Management of Product data and information

This sub-category shows how the information of the product is managed: what kind of activities are performed to create and manage product data and information; what kind of different programs and systems are used for managing the information; what the different types of product related data are.

In the proposed maturity model, the following PLM elements, components, functions, modules were selected in the sub-category Management of product data and information and information and are brought out in Table 3.29.

Management of Product portfolio and structure

This sub-category points out how the current product portfolio is managed and what kind of methods are used for portfolio management; what the exact activities and processes used for product portfolio management are. It shows the size of portfolio and the current structure, and if product families are thought through and organized. Data is shown in Table 3.29.

Table 2.29. References of Management & Control.

	Configuration/BOM Management	**Program and project management**	**Quality management**	**Reporting & Analytics**	**Requirements management**	**Management of Product data and information**	**Management of Product portfolio and structure**	**References**
BOM	X							Zhang et al., 2014a; 2014b, 2014c; PLM Technology Guide, 2017; Introduction to Product Lifecycle Management, 2017; PLM Analytics Maturity Assessment Program, 2014; Schuh et al., 2008
Configuration management	X							Tornincasa et al., 2008; Brandao et al., 2008; PLM Technology Guide, 2017; Zancul, 2012; Stark, 2005; Cholewa, 2011; PLM Analytics Maturity Assessment Program, 2014
Program management		X						PLM Technology Guide, 2017; Capability maturity assessment, 2017
Project management, integration, planning.		X						Terzi, 2005; Schuh et al., 2008; PLM Technology Guide, 2017; Silventoinen et al., 2011; Zancul, 2012; Stark, 2005; Cholewa, 2011; Brandao et al., 2008
Risk management methods and planning			X					Schuh et al., 2008; Zancul, 2012
Quality management			X					Schuh et al., 2008; Zhang et al., 2013b, 2014b; Zancul, 2012; PLM Technology Guide, 2017; PLM Analytics Maturity Assessment Program, 2014
Quality management and control			X					Bouhaddou et al., 2012; Zancul, 2012; Schuh et al., 2008
Management & Control				X				Batenburg et al., 2005,2006
Monitoring & Control				X				Kärkkäinen et al., 2009, 2014; Silventoinen et al., 2010;
Reporting & analytics				X				PLM Analytics Maturity Assessment Program, 2014; PLM Technology Guide, 2017
Product cost analysis and estimation				X				Zancul, 2012
validation of Production				X				Capability maturity assessment, 2017

Table 2.29. continued.

validation of Production				X				Capability maturity assessment, 2017
Analysis of performance and feedback				X				PLM Technology Guide, 2017
Requirement management					X			Tornincasa et al., 2008; Capability maturity assessment, 2017; PLM Analytics Maturity Assessment Program, 2014; Schuh et al., 2008; Brandao et al., 2008; PLM Technology Guide, 2017; Zancul, 2012
Management of customer needs					X			Silventoinen et al., 2011
customer requirements					X			Bouhaddou et al., 2012
Environmental management					X			Schuh et al., 2008; Bouhaddou et al., 2012; Zancul, 2012
Requirements of Functional, performance, quality, cost					X			Introduction to Product Lifecycle Management, 2017
Component management						X		PLM Analytics Maturity Assessment Program, 2014
Part management						X		PLM Technology Guide, 2017; Zancul, 2012; Terzi, 2005
Data management						X		Stark, 2007; Tornincasa et al., 2008; Introduction to Product Lifecycle Management, 2017
Document and file management						X		PLM Analytics Maturity Assessment Program, 2014, 2014; Schuh et al., 2008; Terzi, 2005; Silventoinen et al., 2011; Zancul, 2012; PLM Technology Guide, 2017
Product Data Management						X		Stark 2011; Zhang et al., 2013a, 2013b, 2014a, 2014b, 2014c; Silventoinen et al., 2011; Brandao et al., 2008; Capability maturity assessment, 2017; Stark, 2005; Cholewa, 2011
Product data						X		Zhang et al., 2013A; Savini et al., 2012
Component management								PLM Analytics Maturity Assessment Program, 2014
Financial management							X	Zhang et al., 2013a, 2013b, 2014a, 2014b; Savini et al., 2012
Portfolio management							X	PLM Analytics Maturity Assessment Program, 2014; Brandao et al., 2008; PLM Technology Guide, 2017; Zancul, 2012; Stark, 2005; Cholewa, 2011
Product management							X	Zhang et al., 2013A; Tornincasa et al., 2008
Product planning							X	Schuh et al., 2008, Zancul, 2012
Product structuring							X	Schuh et al., 2008; Zancul, 2012
Product management process, tools and systems							X	Saaksvuori, 2014

3.5.3 Organization & Processes

Organization and processes is one of the five business dimensions used for evaluating PLM maturity, consisting of Change Management, Maintenance, repair and operations (MRO) and metrics, workflow & process management, Sourcing and Supply Chain Management, NPDI, Lifecycle and Processes, and Customer Service and Support. Table 3.30 shows the input for Organization and Processes.

Change Management

This sub-category indicates the change management process, revision management process and the current procedure for making a change in the system.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category change management and are brought out in Table 3.30.

Maintenance, repair and operations (MRO)

The sub-category shows which procedures are concerned with machines and equipment needed for production in PLM systems.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category maintenance, repair and operations and are brought out in Table 3.30.

Workflow & process management

This sub-category points out the different workflows and processes in PLM and shows how they are managed; what the exact activities are starting from the design phase and ending with disposal.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Workflow and process management and are brought out in Table 3.30.

Sourcing and Supply Chain Management

The sub-category shows the current status of sourcing and supply chain and how they are connected to other product related activities; how suppliers are involved in processes and how their activities are affecting the product and its actions.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Sourcing and Supply Chain Management and are brought out in Table 3.30.

NPDI

This sub-category shows how a New Product is introduced in an enterprise and what the linked actions are; how the different departments are involved in the process and how this is followed.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category NPDI and are brought out in Table 3.30.

Lifecycle and Processes

The sub-category joins all the lifecycle processes together and focuses mainly on those processes that are not covered in other areas.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Lifecycle and Processes and are brought out in Table 3.30.

Customer Service and Support

This sub-category describes the activities done in the customer service and supporting phase; how quotations and offers are managed; what is done with customer remarks and feedback and how this moves further to interested parties.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Customer Service and support and are brought out in Table 3.30.

Table 3.30 References of Organization & Processes.

	Change Management	**Maintenance, repair and operations (MRO)**	**workflow & process management**	**Sourcing and Supply Chain Management**	**NPDI**	**Lifecycle and Processes**	**Customer Service and Support**	**References**
Change management	X							Schuh et al., 2008; PLM Analytics Maturity Assessment Program, 2014; Terzi, 2005; Tornincasa et al., 2008; Brandao et al., 2008; PLM Technology Guide, 2017; Silventoinen et al., 2011
Version, status, validation and approval management	X							Zancul, 2012
MRO		X						PLM Analytics Maturity Assessment Program, 2014; Zhang et al., 2014C
Equipment		X						Stark, 2007
Facilities		X						Stark, 2007
Maintenance planning		X						Zancul, 2012; Bouhaddou et al., 2012
Maintenance management		X						Zhang et al., 2013b, 2014b
Maintenance and after sales service		X						Terzi, 2005; Belkadi et al., 2015; Schuh et al., 2008; Zancul, 2012

Table 3.30. continued.

Workflow & process management			X					Zhang et al., 2013b, 2014a, 2014b; Introduction to Product Lifecycle Management, 2017; Silventoinen et al., 2011; PLM Analytics Maturity Assessment Program, 2014; PLM Technology Guide, 2017; Zancul, 2012
Processes			X					Saaksvuori et al., 2008; Tornincasa et al., 2008; Niknam, 2013; Savini et al., 2012
Process planning			X					Zancul, 2012; Terzi, 2005
Process management			X					Schuh et al., 2008; Zhang et al., 2013a; Introduction to Product Lifecycle Management, 2017; Soldani et al., 2013
Manufacturing			X					PLM Technology Guide, 2017; Belkadi et al., 2015
Manufacturing process management			X					PLM Analytics Maturity Assessment Program, 2014; Terzi, 2005; PLM Technology Guide, 2017
Component and supplier management				X				PLM Technology Guide, 2017; PLM Analytics Maturity Assessment Program, 2014; Zancul, 2012; Brandao et al., 2008
Development chain strategy and partner management				X				Brandao et al., 2008
Sourcing				X				Schuh et al., 2008; PLM Technology Guide, 2017; Zancul, 2012
Sourcing and supply chain management				X				Zhang et al., 2014A; PLM Technology Guide, 2017
Supplier collaboration				X				PLM Analytics Maturity Assessment Program, 2014
Supplier relationship management				X				Stark, 2005
Supplier-oriented applications				X				Stark, 2005; Cholewa, 2011
New product development and introduction					X			PLM Technology Guide, 2017; Zhang et al., 2014c; Terzi, 2005; Capability maturity assessment, 2017
Business management					X			Zhang et al., 2013a, 2013b, 2014a, 2014b, 2014c
Concept development					X			PLM Technology Guide, 2017
Conceptual design					X			Vila et al., 2015
Ideation					X			PLM Technology Guide, 2017
Idea management					X			Schuh et al., 2008; Zancul, 2012; Silventoinen et al., 2011
Product definition					X			Terzi, 2005
Design					X			Bouhaddou et al., 2012; Belkadi et al., 2015; Silventoinen et al., 2011; PLM Technology Guide, 2017; Vila et al., 2015; Terzi, 2005
Product development					X			Stark 2011; Terzi, 2005; Tornincasa et al., 2008; Stark, 2007

Table 3.30. continued.

Engineering					X			PLM Technology Guide, 2017; Capability maturity assessment, 2017
Stage gate management					X			Brandao et al., 2008; Capability maturity assessment, 2017
Eco-friendly and innovation and green concept					X			Zhang et al., 2013b, 2014a, 2014b
Product planning					X			Schuh et al., 2008; Zancul, 2012
Product launch					X			Capability maturity assessment, 2017
Organization and processes						X		Batenburg et al., 2005, 2006; Kärkkäinen et al., 2009, 2012, 2014; Silventoinen et al., 2010
Definition and management of lifecycle processes						X		Cholewa, 2011; Stark, 2005, 2007; Zancul, 2012; PLM Technology Guide, 2017; Kärkkäinen et al., 2012; PLM Analytics Maturity Assessment Program, 2014
Phases of product lifecycle						X		Stark, 2007, Capability maturity assessment, 2017; Terzi, 2005; Silventoinen et al., 2011
Assessment						X		Zhang et al., 2013b, 2014b
PLM applications, benefits, definition and foundation						X		Schuh et al., 2008; Savini et al., 2012
Customer focus							X	PLM Analytics Maturity Assessment Program, 2014; Stark, 2007
Customer orientation							X	Stark, 2005; Cholewa, 2011; Kärkkäinen et al., 2012
Customer service and support							X	Terzi, 2005; Bouhaddou et al., 2012; PLM Technology Guide, 2017
Customer involvement							X	Stark, 2007
Sales and marketing							X	Vila et al., 2015; Terzi, 2005; PLM Technology Guide, 2017

3.5.4 People & Culture

People and Culture, one of the five business dimensions used for evaluating PLM maturity, consists of Skilled, Competent people, Team Culture and People in PLM. Table 3.31 presents the input.

Skilled, Competent people

This dimension shows how people are connected to PLM, which requirements are needed and how the training is organized to satisfy the current needs.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Skilled, Competent people and are brought out in Table 3.31.

Team Culture

This sub-category shows how the employees are understanding the current activities related to product and how they act based on these regulations.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Team Culture are brought out in Table 3.31.

People in PLM

It shows the current number of employees who participate in PLM processes, in addition, the ratio of white and blue collar and the ratio between different departments are indicated.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in sub-category People in PLM are brought out in Table 3.31.

Table 3.31. References of People & Culture.

	Skilled, Competent people	**Team Culture**	**People in PLM**	**References**
Resource management	X			PLM Technology Guide, 2017; Brandao et al., 2008; Vila et al., 2015
PLM organization	X			PLM Analytics Maturity Assessment Program, 2014
Organization structure	X			Tornincasa et al., 2008
People	X			Zhang et al., 2013a, 2013b, 2014a, 2014b, 2014c; Tornincasa et al., 2008; Savini et al., 2012
People and Culture	X			Batenburg et al., 2005, 2006; Kärkkäinen et al., 2009, 2012, 2014; Silventoinen et al., 2010; Stark, 2007
Skills and competences	X			Stark, 2007; Soldani et al., 2013
Team culture		X		Stark, 2007
PLM culture and people		X		Silventoinen et al., 2011
Parts of team culture like Communication		X		PLM Analytics Maturity Assessment Program, 2014; Zancul, 2012
Openness		X		PLM Analytics Maturity Assessment Program, 2014
Relationships		X		Savini et al., 2012
Trust		X		PLM Analytics Maturity Assessment Program, 2014
Techniques and practices			X	Zhang et al., 2013a, 2013b, 2014a, 2014b, 2014c
Roles			X	PLM Analytics Maturity Assessment Program, 2014; Soldani et al., 2013
People in PLM change management			X	Saaksvuori et al., 2008

3.5.5 Information Technology

Information technology is one of the five business dimensions used for evaluating PLM maturity, consisting of System integration, Data exchange, Visualization, Document/ File management, and Software Configuration Management. Table 3.32 shows the input for Information technology.

System integration

The System integration shows how the different programs are integrated to each other and how the information moves from one phase to another; how much time it takes to transfer the information from one phase to another and what the ratio of automation there is.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category System integration and are brought out in Table 3.32.

Data exchange

Data exchange shows the situation with data exchange; what the exact data managed are and needs to move from one process to another through different systems. Components are brought out in Table 3.32.

Visualization

Visualization indicates the visualization and access possibilities to the different form of information.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Visualization and are brought out in Table 3.32.

Document/ File management

Document management introduces the current document and file management, not focusing on directly related product documentation like drawings and schemes. It shows also how this is organized in overall level.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Document/File management and are brought out in Table 3.32.

Software Configuration Management

Software configuration management shows which current software and their configurations are used in the processes, as well as the security issues with data and software.

In the proposed maturity model, the following PLM elements, components, functions, modules are included in the sub-category Software Configuration Management and are brought out in Table 3.32.

Table 3.32. References of Information technology.

	System integration	data exchange	Visualization	Document/ File management	Software Configuration Management	References
CAX system integration	X					PLM Technology Guide, 2017; PLM Analytics Maturity Assessment Program, 2014; Zancul, 2012
Collaboration	X					PLM Analytics Maturity Assessment Program, 2014; Schuh et al., 2008; Stark, 2007; Brandao et al., 2008; PLM Technology Guide, 2017; Zancul, 2012
Collaboration software	X					Stark, 2005; Cholewa, 2011
Collaboration tools	X					Silventoinen et al., 2011
Collaborative design	X					Brandao et al., 2008
Collaborative development	X					Zhang et al., 2013a; Capability maturity assessment, 2017
PLM software and applications	X					Schuh et al., 2008; Zhang et al., 2014a, 2013b
Integration	X					Stark, 2005; Zancul, 2012; Silventoinen et al., 2011
Data exchange		X				Schuh et al., 2008; Stark, 2005, 2007; Cholewa, 2011
Archiving		X				Zancul, 2012
Data export		X				Introduction to Product Lifecycle Management, 2017
Visualization			X			Stark, 2005; Cholewa, 2011; PLM Analytics Maturity Assessment Program, 2014; Zancul, 2012; PLM Technology Guide, 2017
Markup			X			PLM Technology Guide, 2017
Interfaces			X			Stark, 2007
Classification management				X		Zancul, 2012; PLM Analytics Maturity Assessment Program, 2014; PLM Technology Guide, 2017
Central data vault				X		Introduction to Product Lifecycle Management, 2017
Digital data				X		Stark, 2007
Data storage				X		Silventoinen et al., 2011; Bouhaddou et al., 2012; Vila et al., 2015
Software configuration management					X	PLM Technology Guide, 2017
User data access management and user management					X	(Zancul, 2012
Multi-user secured access					X	Introduction to Product Lifecycle Management, 2017
Security					X	Stark, 2007
Data safety					X	Zancul, 2012

3.5.6 Evaluation of model components

For evaluating the different components involved in the maturity model, the FAHP analysis was conducted. Based on each different benefit, separate analyses were performed and results are presented in Tables 3.33, 3.34, 3.35, and 3.36.

Table 3.33. Expert group evaluation of Financial performance (Paavel et al., 2017b).

Financial Performance	Strategy & Policy	Management & Control	Organization & Processes	People& Culture	Information technology
Strategy & Policy	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(3,4,5)
Management & Control	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(2,3,4)	(4,5,6)
Organization & Processes	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1,2,3)
People & Culture	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,1,1)
Information technology	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,1,1)	(1,1,1)

Table 3.34. Expert group evaluation of Time Reduction (Paavel et al., 2017a).

Time Reduction	Strategy & Policy	Management & Control	Organization & Processes	People& Culture	Information technology
Strategy & Policy	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/4,1/3,1/2)
Management & Control	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Organization & Processes	(3,4,5)	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)
People & Culture	(3,4,5)	(2,3,4)	(2,3,4)	(1,1,1)	(1,2,3)
Information technology	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)

Table 3.35. Expert group evaluation for Quality Improvement.

Quality Improvement	Strategy & Policy	Management & Control	Organization & Processes	People& Culture	Information technology
Strategy & Policy	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)
Management & Control	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)
Organization & Processes	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(2,3,4)
People & Culture	(2,3,4)	(1,2,3)	(1,1,1)	(1,1,1)	(2,3,4)
Information technology	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)

Table 3.36. Expert group evaluation for Business Improvement.

Business Improvement	**Strategy & Policy**	**Management & Control**	**Organization & Processes**	**People& Culture**	**Information technology**
Strategy & Policy	(1,1,1)	(2,3,4)	(3,4,5)	(3,4,5)	(1,2,3)
Management & Control	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(2,3,4)	(1/4,1/3,1/2)
Organization & Processes	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)
People & Culture	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)
Information technology	(1/3,1/2,1)	(2,3,4)	(2,3,4)	(3,4,5)	(1,1,1)

The final values for each component group according to the business dimension are presented in Table 3.37. The sub-categories for component groups are presented as an average of expert group evaluation.

Table 3.37. Eigenvectors according to business dimensions.

	Strategy & Policy	**Management & Control**	**Organization & Processes**	**People & Culture**	**Information technology**
Financial Performance	0,38-0,41	0,27-0,29	0,14-0,17	0,09-0,10	0,07-0,09
Time Reduction	0,07	0,12-0,13	0,25	0,38-0,40	0,16-0,17
Quality Improvement	0,10-0,11	O,14-0,18	0,31-0,35	0,30-0,31	0,10-0,11
Business Improvement	0,38-0,40	0,14-0,15	0,11	0,06-0,07	0,29

3.6 *As-is* and *To-be*

In the proposed model, As-is and To-be situation is presented through two different approaches. The first expert group has evaluated the questions and different answering possibilities. The evaluated questionnaire was filled in the company by employees and the information was processed. In the processing phase, scores were calculated based on answers and the background index and compared with maximum possible scores. In the calculation of the possible maximum score, the responders background/attitude was considered. Employees could skip the To-be question if they felt not being competent enough. Output was given for all five business dimensions and for their sub-categories. Based on the scores, the business dimensions were divided into maturity levels based on Saaksvuori’s maturity level descriptions (Table 2.10). Business dimension deviation in percentage is presented in Table 3.38. The absolute maximum is considered 70% because the complete maturity cannot be achieved.

Table 3.38. Maturity level descriptions in percentages.

Level description	Percentages
Unstructured	0-10%
Repeatable but intuitive	10-25%
Defined	25-40%
Managed and measurable	40-55%
Optimal	55-70%

Through filling up the questionnaire, the data were gathered, and the value was transformed into numerical form that will reflect the As-is and To- be situation. Also, the situation of possible maximum was calculated. Therefore, the formulas (3.19-3.20) can be used:

$$D = \sum_{j=1}^{PC} BI_j \sum_{i=1}^{QC} QW_i \times Q_{ji} \sum_{k=1}^{AC_i} AW_k \times A_{jik}. \tag{3.20}$$

where the symbols are the same as in Eq. (3.18).

The score for maximum answering was calculated by the formula

$$D_{max} = \sum_{j=1}^{PC} BI_j \sum_{i=1}^{QC} QW_i \times Q_{ji} \sum_{k=1}^{AC_i} AW_k, \tag{3.21}$$

where the meaning of the variables is the same as in Eq. (3.19).

The second output was derived directly from the questions that are related to the metrics. In this case, comparisons can be made because the structure of the questions and answers is the same as shown in Table 3.39.

Table 3.39. Example of current As-is and To-be questions.

Code	Question	Asked
EL3301	What kind of product related activities are used in your company?	As is
EL3401	What kind of product related activities would you like to use in your company?	To be
EL3501	What kind of product related processes are used in your company?	As is
EL3601	What kind of product related processes would you like to use in your company?	To be

Analysis of metrics was expressed in percentages by comparing As-is and To-be with potential maximums.

4 CASE STUDY

The Case study and PLM maturity model test were performed in an electrical equipment manufacturing company. Company personnel exceeds 200 employees. Employee participation in the study is shown in Table .4.1.

Table 4.1. Cross-section of employees participating in the case study.

Position	**Percentage**
Assembler	8
CFO (Chief financial officer)	2
CIO (Chief information officer)	2
CPO (Chief product officer)	2
Electrical Engineer	8
Foreman in production	8
Head Accountant	2
Head of purchase department	2
Human Resource Specialist	2
Human Resources Manager	2
Installation Electrician	2
Machine Operator	4
Mechanical Engineer	6
Process development Manager	2
Process Engineer	2
Production Manager	2
Production planner	2
Project Manager	2
Purchaser	2
Purchasing Manager	2
Quality Control	2
R&D Manager	2
R&D Personnel	6
Sales Assistant	2
Sales Engineer	6
Sales Manager	14
Technician/Technologist	2
Warehouse Estimator	2
Warehouse Manager	2

In the case study, the cross-section of company's employees indicates that more employees on PLM connected positions participated. The percentage of participation was over 30 from the overall number of employees.

Through mapping the benefits and expert group FAHP evaluation, the scores by percentages were computed by using Eqs. (3.19) and (3.20). By using FAHP scores, the scores were changed into percentages. The results are shown in Table 4.2.

Table 4.2. Company results on benefits.

Area	C	C_{max}	C/C_{max}	FAHP
Financial Performance	12078	35740	0,34	38%
Time Reduction	12573	35791	0,35	17%
Quality Improvement	9406	35152	0,27	20%
Business Improvement	17358	53765	0,32	24%

Based on the analyses of the results, it can be recommended that the company should focus more on activities that are concerned with financial performance. Despite that, the company's expectations relevant to that topic were almost equal with time reduction and business improvement. The second recommendation is to focus more on business improvement.

An output with all the expectations based on the category and selections in percentages can be performed.

As-is and To-be study was performed using the questionnaire; the results are given using formulas 3.21 and 3.22 in Tables 4.3, 4.4, 4.5 and 4.6. Table 4.3 and 4.5 show current As-is situation and Table 4.4 and 4.6 indicate To-be situation. Percentages in To-be tables show the difference between the expectations, which are higher than in the current situation. Figure 4.1 shows the results according to the business dimensions.

Table 4.3. Results of As-is analysis for business dimensions.

As-is analysis	Max	Result	Percentage	No of rows
Strategy & Policy	791330,9	104204,6	13%	117
Management & Control	3080100,6	644902,6	21%	217
Organization & Processes	4920159,5	1022064,7	21%	345
People & Culture	141141,2	41361,9	29%	17
Information technology	556116,9	139002,7	25%	66

Table 4.4. Results of To-be analysis for business dimensions.

To-be analysis	Max	Result	Percentage	No of rows
Strategy & Policy	704251,4	149657,8	21%	97
Management & Control	520754,3	57465,8	11%	81
Organization & Processes	1991650,4	243028,9	12%	241
People & Culture	47278,6	5792,4	12%	11
Information technology	184043,1	30183,0	16%	42

Table 4.5. Results of As-is analysis for subcategories.

As-is analysis	Results			Rows
	Max	**Score**	**%**	
(PLM) Vision	8633,4	2508,4	29	7
(PLM) Strategy	61182,5	10576,7	17	13
(PLM) Plan	10620,8	4951,8	47	5
(PLM) Metrics	710894,2	86167,7	12	92
Configuration/BOM Management	257665,3	79407,7	31	16
Program and project management	268043,9	58393,6	22	16
Quality management	228162,4	55747,0	24	20
Reporting & Analytics	388554,8	61782,5	16	23
Requirements management	230185,7	41414,2	18	16
Management of Product data and information	1411011,8	295040,8	21	86
Management of Product portfolio and structure	296477,0	53116,8	18	40
Change Management	397693,6	82188,8	21	34
Maintenance, repair and operations (MRO)	200786,0	35608,9	18	13
Workflow & process management	723711,2	159637,7	22	50
Sourcing and Supply Chain Management	204935,5	39015,8	19	19
NPDI	574456,5	105586,5	18	49
Lifecycle and Processes	2508321,6	535284,7	21	158
Customer Service and Support	310255,3	64742,3	21	22
System integration	67267,2	6160,2	9	12
Data exchange	23508,6	1999,0	9	8
Visualization	33651,4	4257,7	13	2
Document/ File management	371682,9	118484,0	32	34
Software Configuration Management	60006,8	8101,8	14	10
Skilled, Competent People	23239,9	8094,1	35	5
Team Culture	36800,4	11379,4	31	2
People in PLM	81100,9	21888,4	27	10

Table 4.6. Results for To-be analysis for subcategories.

To-be analysis	Results			Rows
	Max	**Score**	**%**	
(PLM) Vision	1741,9	635,0	36	1
(PLM) Strategy	12024,9	635,0	5	3
(PLM) Plan	1741,9	635,0	36	1
(PLM) Metrics	688742,7	147752,7	21	92
Configuration/BOM Management	31060,2	3007,2	10	4
Program and project management	70296,7	11029,2	16	8
Quality management	84410,5	9590,6	11	11
Reporting & Analytics	72006,9	1830,9	3	10
Requirements management	20664,8	0,0	0	3
Management of Product data and information	61335,6	9668,1	16	14
Management of Product portfolio and structure	180979,7	22339,9	12	31
Change Management	185452,0	26750,9	14	27
Maintenance, repair and operations (MRO)	34645,7	565,5	2	5
Workflow & process management	165177,6	13141,6	8	26
Sourcing and Supply Chain Management	7651,9	0,0	0	1
NPDI	284378,0	62899,7	22	27
Lifecycle and Processes	1227041,5	133038,5	11	144
Customer Service and Support	87303,7	6632,6	8	11
System integration	45019,8	4631,4	10	9
Data exchange	23508,6	5612,8	24	8
Visualization	0,0	0,0	0	0
Document/ File management	90803,6	15265,0	17	17
Software Configuration Management	24711,1	4673,8	19	8
Skilled, Competent People	9059,0	1922,5	21	2
Team Culture	7222,0	1112,4	15	1
People in PLM	30997,6	2757,5	9	8

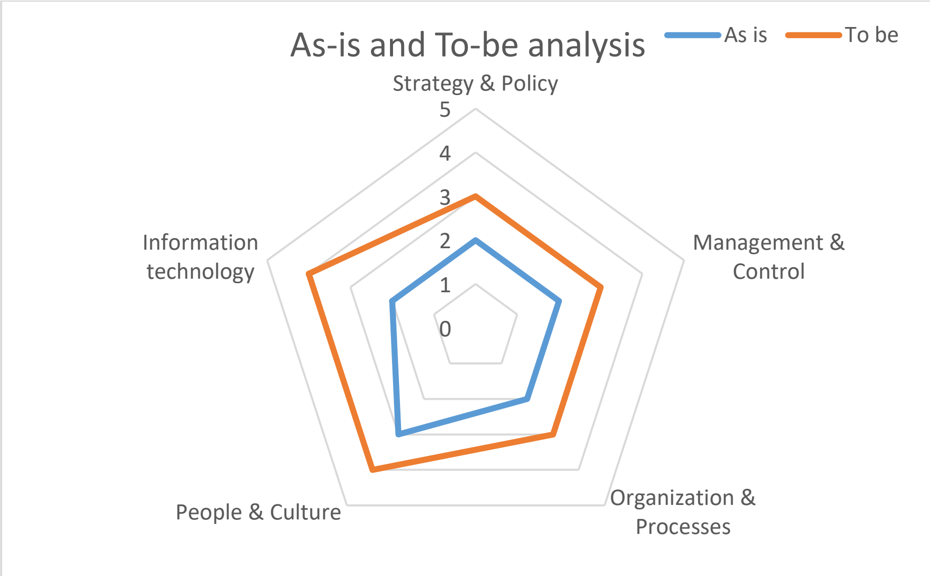

Figure 4.1. Results of current As-is and To-be.

The results show the current low level of maturity. Status for all the business dimensions is repeatable, but intuitive. Management & Control and Organization & Processes in percentages are on the top end but the real weakness results from the Strategy & Policy. This shows that the company is working in the certain field, but the level of preconceived thinking is low, and it might start interrupting fast improvement in gaining better maturity.

The largest gap between As-is and To-be is in the Strategy & Policy. Final Expectations are the highest in information technology and People & Culture sector, but even there the final expectations are in the lower end of managed and measured level. Overall level of expectations is 15%, which is the current step between the levels.

An extra part that has concentrated only on metrics is indicated. Table 4.7 presents the result that focuses only on the metrics.

Table 4.7. Results of As-is and To-be analysis focusing on metrics.

AS is	As-is max	%	To-be	To-be max	%
507161	2552733	20	180175	1442400	12

Based on the analysis, it can be assumed that the company's overall situation concerned with overall maturity is not the highest, as evidenced by the score. To-be score reflects the view how things should be in the future. The 12% score shows that the company has not set high goals for future improvements. An output with all the current situation and To-be situation can be expressed.

The implementation of the model in the company gave proof that the model is appropriate for evaluating PLM maturity. The company received information that they lacked before. On this basis, it is suggested that this model is suitable for manufacturing companies who are operating in the field of mechanics or mechatronics.

5 CONCLUSION

In this thesis research, in-depth research of PLM and problems in the implementation of current maturity models was conducted. Well-known maturity models were analyzed, and the knowledge was used to develop a new maturity model that is suitable for SMEs to ease their PLM implementation.

As a result;

- The knowledge gained from the analysis of current maturity models and frameworks was used for the development of the new model.
- Voluminous questionnaire for supporting information gathering was developed and the compliance of the questions to the topic was checked. The purpose of the questionnaire was to evaluate the current status.
- Evaluation of questions and answering options was performed by the expert group. To check the result of evaluation dependence, different outlier methods were used.
- Background index was proposed to distinguish the different responders in company to show the importance on a certain responder who has more knowledge and or experience.
- Based on optimized questionnaire the methodology for estimation current expectations, also As-is and To-be situation in enterprise was proposed. The weights of the questions and answers determined by expert group, also background index of employees are utilized in analytical score expressions derived for estimating current expectations, As Is and To be situation.
- Analysis of used PLM components, functionalities, modules was performed to identify the current trends.
- New maturity model was developed; its advantages are pointed out in the following section.

The novelty of the presented thesis can be outlined by

- New Maturity model developed allows estimation of As-is and To-be situation through scalar values. Thus, it is possible to compare two different companies with a similar profile and collate the information.
- Evaluation of responders through the background index (not used in models considered) is presented
- Current maturity model is not based on the opinion of a single person. Information was gathered from different departments and levels of the company. To create a model, it is required to survey employees from shop floor to C-level.

Some suggestions for SME-s

- Adaption of recent advanced maturity model(s) in SME allows to save resources, to estimate As Is and To be situation with minimum expenses.
- The PLM maturity model should be used in all company levels. This will faster the PLM system implementation.
- The maturity model(s) validated in one SME cannot be directly converted to other SME, even in similar area. Certain adaption of the model, considering particular features of the company is needed.

The current model needs further development, because it has been tested only in one company. Further development of this kind of model is necessary due to changes in the environment that the model has to adapt to. Resulting from the testing, the recommendations for further development are as follows:

- Extra descriptions/comments are needed for some topics, because the questionnaire is filled by employees with different backgrounds and knowledge.
- The respondent groups should be more general but with a wider description for better selection.
- The current survey involving some larger question groups should be optimized, because the amount of data is extensive and in the end, the focus might scatter.
- Web interface needs to be developed. In the current study, the results were processed manually, which is time-consuming for data processing.

List of Publications

The list of author's publications:

I Paavel, M., Karjust, K., Majak, J. "Development of a product lifecycle management model based on the fuzzy analytic hierarchy process." Proceedings of the Estonian Academy of Sciences. 66(3), 279–286. 2017.

II Paavel, M., Karjust, K., Majak, J. "PLM Maturity model development and implementation in SME." Procedia CIRP. 63, 651 – 657. 2017.

III Paavel, M., Snatkin, A., Karjust, K. "PLM optimization with cooperation of PMS in production stage." Archives of Materials Science and Engineering. 60(1), 38-45. (2013).

IV Paavel, M., Kaganski, S., Karjust, S., Lemmik, R., Eiskop, T. "Analysis Model Development to Simplify PLM Implementation." Proceedings of the 10th International Conference of DAAAM Baltic, INDUSTRIAL ENGINEERING, 12-13 May 2015, Tallinn, Estonia. 69-74. 2015.

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Lühikokkuvõte
PLM küpsusmudeli arendus

PLM on võimas tööriist haldamaks tootega seotud infot. Paljud ettevõtted loodavad saada erinevaid eeliseid PLM süsteemi juurutades. TähTis osa süsteemi juurutamise juures on juurutamisele eelnev teabe kogumine, hetkeolukorra väljaselgtamiseks ja soovitud olukorra kaardistamiseks. Käesolevas töös on arendatud uus PLMi küpsusmudel nii hetkeolukorra ja soovitud olukorra analüüsimiseks. Mudel keskendub rohkem väikeste ja keskmise suurusega ettevõtetele (VKE) aidates neid PLM süsteemi juurutuse algses faasis.

Olemasolevad mudelid ja raamistikud on peamiselt akadeemilise taustaga ja detailne küsimustik ei ole enamasti välja toodud. Paljudel juhtudel on tulemused pealiskaudsed ja mudeli sobivust on raske hinnata.

Antud töös on arendatud küsimustikul põhinev analüüsimudel. Arendamisel on uuritud olemasolevaid mudelid ja raamistike, võetud arvesse nende eeliseid ja puudusi. Ekspertgrupp on kaasatud nii küsimuste kui vastuste hindamisele alates arenduse varasest faasist. Läbi analüüsi on kontrollitud kuidas mõjutavad ekspertgrupi hinnagud üldisi tulemusi. Rakendati erinevaid matemaatilis meetodeid äärmuslike tulemuste kõrvaldamiseks.

Kaasates ekspertgruppi, koostati valemid töötajate taustaindeksi arvutamiseks, hetkeolukorra ja soovitud olukorra hindamiseks. Antud valemid võtavad arvesse vastaja hetkepoisitsiooni ja kogemust.

Lähtudes ekspertgrupi arvamusest, FAHP rakendamise tulemustest ja vastustest küsimustikule on läbi viidud ettevõtte poolsete ootuste analüüs ja tehtud ettepanekud suundadest ettevõtte juhtkonnale. Lisaks on hetkeolukorra kirjeldus ja tuleviku ootused antud põhinedes mõõdikutele.

Arendatud mudelit on katsetatud ühes eesti ettevõttes.

Abstract
PLM maturity model development

PLM is powerful tool for managing information related to product. Many companies are hoping to achieve different advantages through implementing PLM system. Important part of implementation is the information gathering, identifying the current situation and mapping the hoped situation. Therefore, in current study the maturity model is developed for assessing the maturity of PLM through As is and To be analyse. Model is focusing more on SMEs for helping them to ease PLM implementation process in the early stage.

Current studies, model and frameworks developed are mainly with academic background and the actual description of the models in not seen and asked questions are not brought out. In most cases the results are superficial, and suitability of the model is difficult to estimate.

In this theses enterprise analyse model in form of questionnaire is developed. In development phase the current models and frameworks were examined and taken account in developing a new one. Already in the early phases expert group was involved by evaluation questions and answer options. Analyse was performed for indentation how certain expert group opinions are reflecting the overall results. During the analyse different outlier methods were used for evaluation of the sample.

In development of background index, the expert group evaluation was involved through position, and work experience evaluation. By this an extra dimension was given for calculating the overall As is and To be score because experience through working position, and work experience is considered.

By using expert group opinion, FAHP and answers of companies analyse of benefits is performed and suggestions are made for the directions of the company. As is and To be scores are calculated by considering all the respondents in the company. Extra output in As is and To be is made based on metrics perspective.

Model testing was performed in one Estonian manufacturing company who got additional information from model use. Based on the information further steps were considered.

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