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PRODUCT PORTFOLIO MANAGEMENT AS PART OF PRODUCT LIFECYCLE MANAGEMENT FOR CONFIGURE-TO-ORDER PRODUCTS

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ABSTRACT

Product portfolio management as part of product lifecycle management for configure-to-order products

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Product portfolio management (PPM) research has mainly focused on PPM practices by covering the early stage of the lifecycle and not the whole lifecycle of the product. In addition, lifecycle management has been applied to individual products rather than the entire product portfolio. In this thesis, PPM research focuses on both all lifecycle phases and the entire product portfolio rather than only individual products. The research aims to study how configurable products should be arranged in the case company's future Product lifecycle management (PLM) system. The case company of the thesis is Valmet Flow Control Oy, which delivers flow control technologies and services for different industries. The current Product data management (PDM) system in use is no longer supported and it is seen that the PDM system does not support the company's needs anymore. Therefore, a new PLM system is needed to cover future demands in the case company. The product portfolio is composed of a product series, which refers to a certain product type and model. This thesis focuses on configure-to-order (CTO) products, which are configured based on customers' needs with pre-defined specifications. This thesis proposes, how to present product series level object in the PLM system and what kind of product data it contains. The main result of the research is the created product series object in the future PLM system and how to manage product series through their lifecycle in one centralized system with all internal stakeholders. The availability, traceability, and data use are also essential results. Appropriate exploitation of data allows to reveal the most critical information, enabling the management of the whole product portfolio from one PLM system. This kind of procedure creates transparency in the product portfolio.

Keywords: PPM, PLM, CTO, product data

TIIVISTELMÄ

Tuoteportfolion hallinta osana tuotteen elinkaaren hallintaa tilauksesta määritettäville tuotteille

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Tuoteportfolion hallinnan (PPM) tutkimukset ovat pääasiassa keskittyneet PPM:n käytäntöihin elinkaaren alkuvaiheessa eikä tuotteen koko elinkaaren hallintaan (PLM). Lisäksi PLM:ää on sovellettu yksittäisten tuotteiden tasolla eikä niinkään koko tuoteportfolion tasolla. Tässä diplomityössä PPM:n tutkimus keskittyy sekä koko tuotteen elinkaaren vaiheisiin että koko tuoteportfolioon yksittäisten tuotteiden sijasta. Tutkimuksen tarkoituksena on tutkia kuinka konfiguroitavat tuotteet pitäisi järjestellä tulevaan PLM-järjestelmään tapausyrityksessä. Diplomityön tapausyrityksenä on Valmet Flow Control Oy, joka toimittaa virtauksensäätöratkaisuja ja -palveluja eri teollisuudenaloille. Nykyistä käytössä olevaa tuotetiedonhallinta järjestelmää (PDM) ei enää ylläpidetä eikä PDM-järjestelmä tue yrityksen tarpeita enää. Tästä johtuen PLM-järjestelmää tarvitaan, jotta voidaan kattaa tulevaisuuden tarpeet tapausyrityksessä. Tuoteportfolio koostuu tuotesarjoista, joilla viitataan tiettyyn tuotetyyppiin ja malliin. Tämä diplomityö keskittyy tilauksesta määritettäviin tuotteisiin eli konfiguroitaviin tuotteisiin, jossa tuote konfiguroidaan asiakkaan tarpeiden mukaisesti ennalta määrättyjen spesifikaatioiden avulla. Tässä työssä esitetään kuinka tuotesarjatason objekti kuvataan PLM-järjestelmässä ja mitä tuotetietoja sille tarvitaan. Tutkimuken päätuloksena luodaan tuotesarjaobjekti tulevaisuuden PLM-järjestelmään ja tehdään kehitysehdotus siitä, kuinka tuotesarjoja tulisi hallita niiden koko elinkaaren ajan yhdessä järjestelmässä, ja kaikkien sisäisten sidosryhmien kanssa. Tiedon saatavuus, jäljitettävyys sekä hyödyntäminen ovat myös pääasiallisia työn tuloksia. Tiedon oikeanlainen hyödyntäminen mahdollistaa kriittisimmän tiedon esittämisen ja siten mahdollistaa koko tuoteportfolion hallinnan yhdestä PLM-järjestelmästä.

Avainsanat: PPM, PLM, CTO, tuotetieto

ACKNOWLEDGEMENTS

The main purpose of the thesis is to make improvement propositions related to PPM and PLM for the case company Valmet Flow Control Oy. The study was conducted between January 2023 and June 2023.

The product management courses held during my studies at the university at the beginning of 2021 got my interest in PPM and PLM topics. Later next year, I had an opportunity to start doing my master's thesis about PPM as part of PLM in the case company. Firstly, I would like to thank Ville Hiltunen, the supervisor from Valmet Flow Control, for this great opportunity to be able to write my thesis about this fascinating topic. I would also like to thank all the interviewees and all the colleagues who helped me during this project. The support and help I got were priceless to succeed with my thesis.

I would like to acknowledge my university supervisor Toni Liedes, who gave fundamental feedback and guided the thesis in the right direction during my whole writing process. I am thankful for the course lecturers of mechanical engineering and industrial engineering and management, who have given me the opportunity to gain experience in several interesting topics during my studies. Additionally, thanks to my closest friends for all the moments with you at the university and outside of the university.

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Kiia Kokko

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

3D	Three-dimensional
BOM	Bill of Materials
CAD	Computer-Aided Design
CE	Concurrent Engineering
CPQ	Configure-Price-Quote
CTO	Configure-To-Order
ERP	Enterprise Resource Planning
ETO	Engineer-To-Order
HW	Hardware
IT	Information Technology
IoT	Internet of Things
KPI	Key Performance Indicator
MRO	Maintenance, Repair and Operations
NPD	New Product Development
PDM	Product Data Management
PLM	Product Lifecycle Management
PMD	Product Master Data
PPM	Product Portfolio Management
R&D	Research and Development
RQ	Research question
SW	Software

1 INTRODUCTION

Introduction presents the topic of the thesis and main research questions. This chapter describes the research process and the aim of the thesis. In addition, the case company of this thesis is disclosed. This chapter gives a background for the thesis' topic and why it is important in the case company and in general.

1.1 Introduction to the topic

The current business in the manufacturing industry requires companies to improve their efficiency and to find policies to reduce costs. Rapid time-to-market ambitions and continuous changes in product development have gained the significance of punctual Product data Management (PDM) practices. The subject of this thesis is Product Portfolio Management (PPM) and Product Lifecycle Management (PLM), which both include processes and methods to manage all the products in the company. PPM and PLM are needed to see how to meet company goals and how to build future product strategies for growth and at the same time, cost savings. PPM consists of strategic choices on markets, products and technologies and is used in many fields like projects, IT, and products. The competitiveness today in global markets requires wide and versatile product offering from the company to be successful in markets. That phenomenon obviously increases the number of new products in product portfolio. However, too wide product portfolio can have negative impacts as well. Too many products can, for example, reduce sales per product variant, which decreases the overall profitability. PLM has mainly focused on new product development and other early phase operations. The end-of-life phases have not been focused on that much. PLM is a tool for coping with shortening product and component lifecycles and customer needs. Products must be introduced more quickly and at the same time to get more profit to succeed in global markets. To manage a product portfolio, product structure must be defined, and it must be explicit. This and other preconditions are crucial for PPM. (Tolonen, 2016; Sääksvuori & Immonen, 2010; Kropsu-Vehkaperä, 2012) These preconditions will be explored further in this thesis.

The case company has currently a PDM system, which does not allow several functions that supports company's business needs completely. These functions are, for example, a change management system, requirement management system, centralized and transparent product information, proper PPM and many other functions that enable even more successful business. PDM is a holistic software that integrates and manages all applications, information, and processes around the product through design, manufacturing, and end-user service. According to Martio (2015, pp. 48-49), the PDM system can be divided into following fundamental areas: item management, document management, product structure management, configuration management, change management and integration to other design- and production-related systems. Valmet Flow Control has a vision of PLM, which says that people and product data should be connected to work with unified systems and processes globally. The current state of data within the company is not fully mature and the common data is copied from one department to another, which means that fragmentation of data occurs. The aim of the future PLM system is to create one product data and gather people around integrated systems and processes globally, instead of copying the data. In this way, separate data can be combined to reach all the people and processes. As a result, with PLM, the case company has the potential to transform daily work significantly.

The main purpose of this thesis is to make research on PPM and PLM of the case company. As a result, the product portfolio in PLM is determined and presented in the best conceivable way from the case company viewpoint. In this thesis, product portfolio is examined for the valve products and more specifically, focusing on Configure-To-Order (CTO) products. Referring to CTO means the production process in which the product is customized based on the customer's requirements. The customer orders the product with certain specifications, and this is the point where manufacturing starts. More customizations for products can be done by means of CTO. Product standards and specifications are pre-defined in the PLM system in the future. Currently, product-related data and product structures are in the current PDM system and other separate applications. The results and improvement propositions discovered in this thesis can be utilized in the case company's PPM-related cases as well as to perceive the current state of PPM in the company. The expected benefits of PPM capabilities in PLM are presented for the case company in question.

1.2 Introduction of the case company

Valmet Flow Control Oy is one of Valmet Oyj's business lines, which focuses on flow control solutions and services and valve automation manufacturing. Their valve automation technologies are known for quality, reliability, and high safety. They serve a variety of customers from the field of process industries, including pulp, paper and bioproducts industry, renewable energy, oil and gas refining, mining and metals processing, chemicals, and other process industries. Valmet Flow Control's extensive product portfolio consists of industry leading valves, valve automation solutions and related services. The product portfolio is comprised of Neles™, Neles Easyflow™, Jamesbury™, Stonel™, Valvcon™ and Flowrox™ solutions. The Flow Control business line has eight valve technology centers globally, which are located in Shrewsbury, MA, USA; Horgau, Germany; Chungju, South Korea; Jiaxing & Shanghai, China; Mumbai region, India and Lappeenranta & Vantaa, Finland. (”Valmet's Flow Control Business Line”, n.d.)

Valmet Flow Control has versatile product offering, which consist of valves, actuators, and valve controllers. The newest products in the offering are advanced pumping and pinch valve solutions from Flowrox™. Valves can be categorized by applications or by types. Control valves, on-off valves and emergency shutdown valves are the main applications, while, ball valves, butterfly valves, segment valves, globe valves, eccentric rotary plug valves and pinch valves are different valve types. However, actuators can be grouped by their functionality; pneumatic actuators, Valvcon™ electric actuators, linear actuators as well as manual actuators. Finally, valve controllers can be divided by two control types, On/Off or positioning. The selection of a combination of the following products depends on the customer's demand and use. (”Valmet's Flow Control Business Line”, n.d.). This thesis is targeting to valve products and its product portfolio, more closely to the CTO products.

1.3 Research objective and questions

Valmet Flow Control's valve business is manufacturing type of business which certainly means wide product portfolio. Too wide product portfolio can lead to the explosion of the portfolio, cannibalization between the products and can have business impacts which means an unprofitable product. In addition, renewal of the product offering is usually too slow, which means that disposal of products is rarely done. (Tolonen et al., 2014). The primary objective of the research is to familiarize into PPM and how to carry it out through the whole product lifecycle in the case company. In addition, the objective is to generate improvement propositions for the case company based on existing literature about PPM and PLM and current state analysis of the case company. The expected benefits of PPM utilized in PLM for the case company are also examined.

The above discussion in section 1.1 can be consolidated into the following research questions (RQs):

RQ1: How to improve Valmet Flow Control Oy's PPM by means of PLM?

RQ2: What are the expected benefits if Valmet utilizes the latest PPM capabilities in PLM?

To answer these research questions, the existing literature must be reviewed first to gain an adequate comprehension of product portfolio and product lifecycle management. Literature review is in in next chapter, in chapter 2. Current state analysis gives support with answering the questions by providing comprehension of current way of acting. In the improvement proposition section, concrete propositions are made, and the aim is to give answers to the RQs.

1.4 Research process

The thesis in question is a one-case constructive type of research and it utilizes qualitative research methods. This study distributes into five main chapters. In chapter 2, the first part of the study is a literature review that presents the theoretical background of product portfolio management and product lifecycle management. The majority of references are scientific research articles or volumes, however, business articles, and textbooks are reviewed also. The essential cause of the first part is to form a competent comprehension of the theoretical background and common practices of product portfolio management as part of product lifecycle management and in general. In chapter 3, the current PPM and PLM practices of the case company are analyzed based on empirical analysis. The information for the analysis was compiled from multiple sources: case company's internal material, potential system vendor's material and meetings, case company employee interviews and current tools in use. The aim of this part is to identify the case company's challenges and areas of improvement in product portfolio management. State of the art is made by performing interviews for reference companies. Companies from the field of industry were interviewed with questions composed in advance, which can be found as appendixes at the end of the thesis. In addition, state of the art is revealed by searching current literature about PPM and PLM practices globally and analyzing the information.

Presented improvement propositions of PPM practices as part of PLM practices and the PPM arrangement in new PLM system for the case company are constructed in chapter 4. The propositions are combined by comparing practices learned in the literature review and the improvement areas identified in the current state analysis and taking the state of the art into account. The aim is to obtain the optimal state of PPM in the case company. In chapter 5, the main results are reviewed in accordance with the main research questions and general discussion is conducted. The last part is the conclusion, in which the whole accomplishment of the research, including results, limitations, validity, and further research is discussed and summarized. The whole research process is visualized in Figure 1.

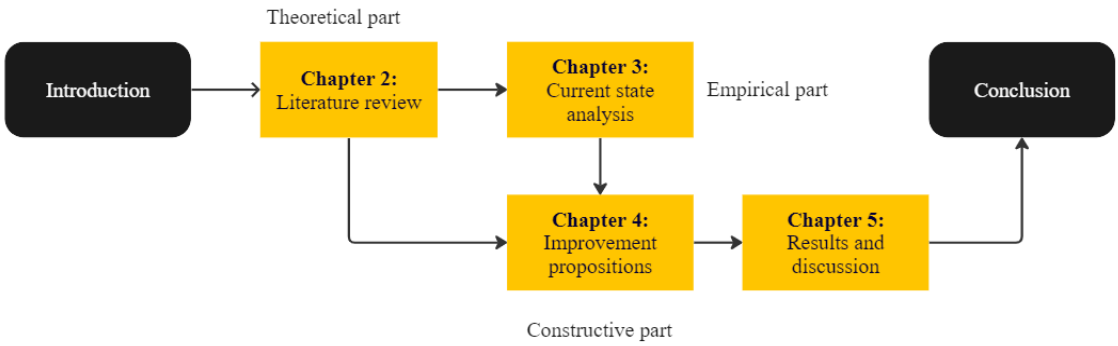


Figure 1. Research process.

1.5 Limitations

This research focuses on CTO valve products and does not cover the whole product portfolio of Valmet Flow Control Oy. Moreover, the research is limited to PPM as part of PLM and the primary focus is on the product portfolio rather than the product lifecycle. However, PLM is an essential topic, as it deals with products for their whole lifecycle to manage product portfolios in the best conceivable way. PLM is not only a system, but it also covers the processes and practices of the company. This research addresses both perspectives in general. The case company is proceeding to validate the new PLM system to replace the existing PDM system. However, PLM system validation and implementation are not executed in this research, even if the topic of the research is done concurrently with PLM system validation in the case company. This thesis is dividual work and not dependent on the PLM system project. In addition, research practices were limited to a few interviews and a predefined schedule set limitations to the time. All the sources of the thesis are as a one matrix as Appendix 5 in the end of the thesis.

2 LITERATURE REVIEW

This chapter reviews the existing literature of product lifecycle management and product portfolio management. In addition, product data management and product-related terminology are reviewed to compose a holistic understanding of the thesis' topic. The literature review is summarized in synthesis in the final paragraph of the chapter.

2.1 Product data management

According to Terzi et al. (2010), Product Data Management is a system for storing, archiving, and managing product engineering data. The data can be drawings, design objects and related workflow. PDM is also known as technical data management or engineering data management. PDM is more settled term nowadays when describing product related data. In addition, PDM tool is beneficial for structuring and maintaining bill of materials (BOM) and for managing product configurations and variants. PDM allows engineers to standardize items, to store and control document files, to maintain BOMs, to control item and to see relationships between parts and assemblies. This essential functionality lets them access standard items, BOM structures and files for reuse and derivation. This reduces the risk of using incorrect design versions and increases the reuse of existing product information. (Sääksvuori & Immonen, 2010, p. 2)

A PDM system enables to provide an access to the right information and exactly the right time for all the users around the product data. Product data can be accessed, retrieved, and reused considerably quicker and easier with PDM. The PDM system provides controlled access to correct versions and configurations as well as it enables tracking of product configurations. Besides, it manages all data defining and related to the product across the product lifecycle as of early-stage idea to the retirement of the product. (Stark, 2015, p. 154). PDM system controls all fundamental data considering how to design, maintain and dispose a product (Kropsu-Vehkaperä et al., 2009). Silvola et al. (2019) cover that PDM systems are also used for the creation of configurable and modular products by means of the automation of the product data integrations, which enables several different solutions for customers, while maintaining minimum number of items in the product portfolio. Configurability and modularity are essential features when it comes to proper portfolio management. Both functions are reviewed more closely in chapter 2.1.3.

Kropsu-Vehkaperä et al. (2009) state that efficient data management practices in engineering and manufacturing companies have become one of the key aspects of business efficiency. For the companies, it will be difficult to get the product under control if product-related data has not been able to control. With the help of PDM, organizing and utilizing data is possible and they enable accelerating time-to-market in consequence of reduced lead-times. Product data can be divided into definition data of the product, lifecycle data of the product and meta data, which represents the product and lifecycle data. Product definition data determines the physical and functional properties of the product such as fit, form and function of the product. Product lifecycle data is connected to the product and the stage of the product or order-delivery process. The last one, metadata is simply information about information of product data. A good PLM system requires one common PDM process, as PDM is the foundation for PLM. (Sääksvuori & Immonen, 2010, pp. 7-8)

Martio (2015, pp.48-49) classifies PDM to the following main areas: item management, document management, product structure management, configuration data management, change management, user authentication and authorization management and interfaces for the main design, documentation, and production management systems, such as Computer Aided Design (CAD) and Enterprise Resource Planning (ERP) systems. Timeliness, validity, and rapid availability of the enterprise's product related data are crucial factors in most of the processes in the enterprise. At this moment, data management is still mainly focused on managing product development and design data, but methods used to collect product data from middle and end-of-life phases are inadequate. However, product data and the competent handling of it is becoming a significant asset for business development. To succeed with PDM, compatibility with other Information Technology (IT) systems is an important element. Nevertheless, the diversity of data formats in a complex product environment, creates a challenge for data management within integrated systems. (Kropsu-Vehkaperä et al., 2009).

2.1.1 Definition of product

It is crucial to understand the definition of a product before diving into the product portfolio and product lifecycle. The product can be tangible such as a cellphone or car, but it can also be intangible, such as service, software (SW), hardware (HW), or a combination of them. Härkönen & Mustonen (2022) present three key elements that a product can consist of, which are Fit, Form and Function. They describe how the product fits to intended use, what is the appearance of it, and what the product does. It can be stated that, new product means it has new Fit, Form or Function, besides, it forms new sales item, which has a new product lifecycle. Product lifecycles are further discussed in chapter 2.2.

Product can be sold, produced, delivered, invoiced, and used or consumed. It can be offered, contracted, ordered, and cared as well. The product remains the same over all lifecycle phases. Product consists of core product and supplementary products, which can be service quality or customer service. (Härkönen & Mustonen, 2022). Sääksvuori & Immonen (2008, p. 1) specifies the tangible product, which refers to a physical good. They distribute products to three different kinds of parts: physical tangible products, services and intangible products which are not services, for example, software. Furthermore, a product can be a package of services, bundle of products and services or a solution containing several products, or however, a solution containing products and services. An example of that kind of solution can be a valve product and the service related to it. (Stark, 2015, p. 5). Tolonen (2016) mentions that a product can be seen differently by different stakeholders, depending on their point of view and interests. The term product family is central when discussing products. By referring to the product family, it is meant the collection of products that share the same assets, such as components, processes and knowledge. (Jiao et al., 2007). Product family is a subset for solution and hypernym for product configuration in a hierarchical structure (Tolonen et al., 2014). Peltonen (2000) specifies, that a product family can have thousands or millions of variants, however, only a small percentage is manufactured.

Krospu-Vehkaperä (2012) emphasizes the importance of understanding the difference between product version and product variant. In today's world, it is necessary to provide new products to the market to fulfill customer's demand and need, so new versions of existing product need to be developed or new variants to be created. A new product version replaces a previous older one to achieve cost reduction or quality improvements. Product variants in turn extend the number of deliverable products and it enables product customisation. Product configuration makes it possible to react to customer requirements by compiling a fixed set of the pre-defined component. Pre-definition is made in a product design phase. Peltonen (2000) describes a configurable product as a set of different product variants, which are closely related to each other. Martio (2015, p. 14) states that when it comes to configurable products, the product indicates to the product family, in which can be specified various variants. The number of products in the portfolio should be handled carefully and be under control. For example, inefficiency in manufacturing can be a consequence of proliferation of products to obtain high variety of products in product portfolio. To achieve profitable business, a company must assess the level of variety and level of complexity of products. (Simpson et al., 2005). The explosion of product portfolio is later discussed in chapter 2.3.1. where product portfolio challenges are addressed.

2.1.2 Product data

When discussing about product data, definition and understanding of it is unambiguous. Stark (2015, p. 11) states product data as it defines and describes the product and it must be available whenever it's needed, wherever it's needed and by whoever needs it over the whole product lifecycle. According to Silvola et al. (2019) product data requirements can be divided into two main categories, to functional and technical. When it comes to functional product data requirements, it is indicated to the ability of the product data to support value creation and optimization, and they are influenced by the product lifecycle. Whereas technical product data requirements are derived from IT system requirements and from data quality principles. Silvola et al. (2019) describes one product data as a triangle that consist of product master data (PMD), IT systems and Business processes related product data. Master data expresses a company's key business objects which form the foundation of the company's business purpose. It is created only once and is processed through the product lifecycle. Usually, PMD is stored in PDM or PLM systems. Master data is comparative to human DNA. Figure 2 presents PMD, business process related product data and integrated IT systems and different kinds of business processes. What is necessary, is that the best possible data quality is needed for completeness, relevance, and timeliness of critical data. This signifies that data will be created, updated, and removed within the product lifecycle. Figure 2 shows that product data requirements determine how PPM, product development, sales, supply chain and service processes operate. (Silvola et al., 2019). Typical way to model manufactured products is to create product structure. It represents the product, information integrated to the product and the relationship between product components. Products structure is a model that enables to perceive product configuration, but it also helps to conceptualize product in PDM systems. (Kropsu-Vehkaperä et al., 2011). BOM is often referred to as a product structure in informal language. To make clear difference between product structure and BOM, Sääksvuori & Immonen (2008, p. 8) specify that BOM stands for manufacturing part list, and it is not a hierarchical structure, so it is not the same as product structure either. A part list is a single-level list of components required for manufacture and assembly of the product, but it does not contain any hierarchical structure.

Hannila (2019) classifies data assets as master data, transaction data and interactional data. Master data is related to product, customer or supplier, transaction data is however comprised as orders, invoices, or deliveries and the last one, interactional data is related to Internet of Things (IoT) data created by sensors, microprocessors, or SW. All the previous data assets have a potential role in data-driven PPM. The master data is seen as critical business information and it must be integrated and managed enterprise-widely at strategic, tactical, and operational levels. According to Kropsu-Vehkaperä & Haapasalo (2015), PMD consists of the core product data, for example item name & code, product lifecycle status and product definitions. They address that each stakeholder group should only have access to the relevant data for their purposes. In addition, the other type of data is grouped as other general data, which can contain work guidelines and instructions for sales and pricing and defines how the product is to be sold, produced, and maintained.

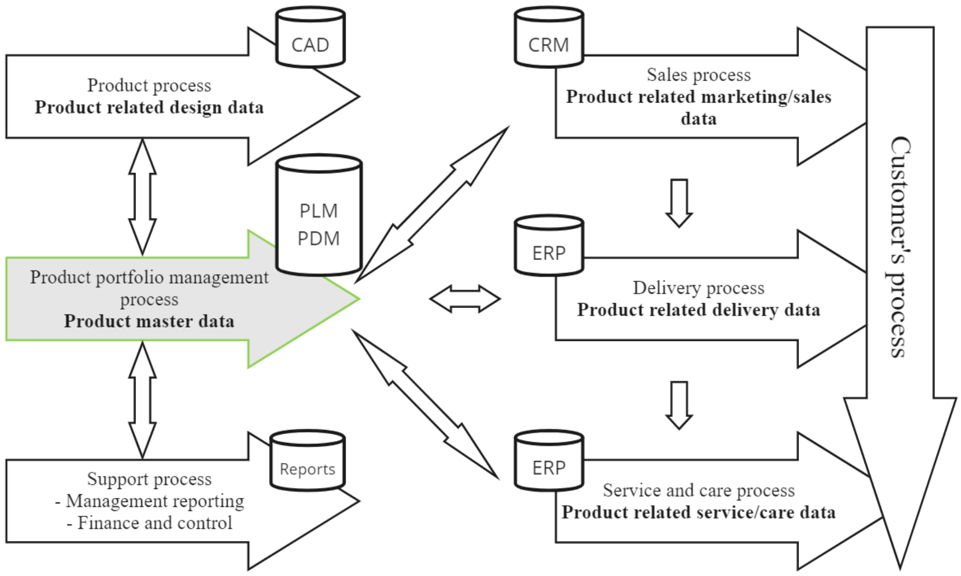


Figure 2. Product master data, business process related product data and IT systems (retell, Silvola et al., 2019).

2.1.3 Product configurability and modularity

According to Sääksvuori & Immonen (2008, p 61), configuration refers to a method of arrangement and a configurator refers to an application that manages the structure of a product and its variations. Features of the configurable products are following: The annual number of pieces produced is typically more than hundred. However, more complex products can have less than a hundred. Legitimated number of different kinds of product variants is remarkably huge, however, huge number of different combinations means that all the possible product variants are not manufactured. The last feature is that the variability of product is predesigned and is defined in configuration model. (Martio, 2015, p. 19). In addition, product configuration can be seen as procedure to react to customer requirements by compiling a fixed set of pre-defined components that are defined on product design phase (Kropsu-Vehkaperä et al., 2011). Tiihonen (1999) states that the main purpose for configuration is to produce products that fulfill varying customer requirements in an economically profitable way.

Configuration process can be divided into two phases, to sales- and production configuration. By grouping these configurations, management of products is eased. A sales configurator deals with product features and dependencies between them, whereas production configuration manipulates the product structure to match the combination of features available from the sales configurator. (Martio, 2015, p. 23). Sääksvuori & Immonen (2008, p. 62) presents an example of a sales configurator function, which controls the rules related to sales properties as well. The rules prevent the choice of a forbidden combination. In the example, the car is equipped with a 70-kilowatt engine which is not available with an automatic gearbox. If the sales item ”engine power” has a value of ”70 kilowatt”, then the sales item transmission must not have the value ”automatic”. Kropsu-Vehkaperä et al. (2011) cover that typical challenges for product configuration formalization are fuzzy product offering and the lack of configuration strategy, mechanisms, and general product structure. A generic product structure needs to be built to support product configurations that cover all product types as HW, SW and services.

There are two paths that can lead a company toward configurable products according to Figure 3. First option is to go from mass production, non-configurable standard products towards configurable products. Companies can increase their competitiveness by offering configurable products. In this case, customer buys products that have been modified individually, concerning to limits and customer’s needs. The second option is to go from individually designed product to configurable products. The reason to proceed to configurable product is to the high price of one-of-a-kind product manufacturing. (Peltonen, 2000).

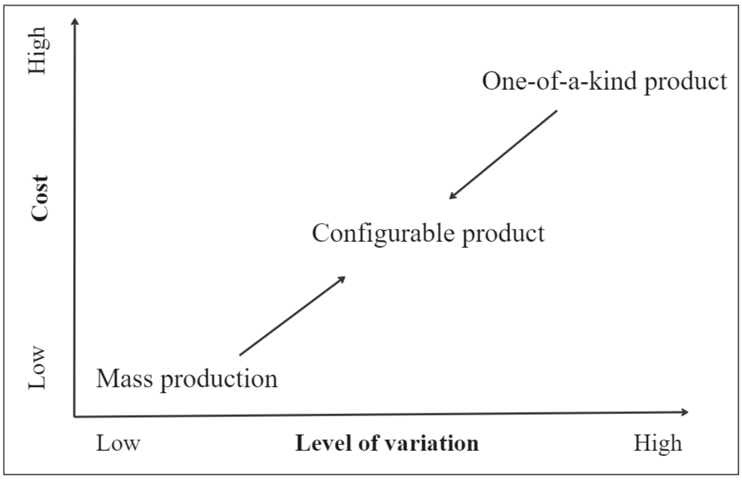


Figure 3. Configurable product location in plot (retell, Peltonen, 2000).

The idea of modularization is to design, develop and produce parts that can be combined in numerous different ways and therefore enhancing the compatibility between product variety requirements and operational performance. Drivers for modularization are variety creation or customizing, to utilize similarities and to reduce complexity. A module is independent function, and it contains a group of standard components. The final configuration is done by matching sets of standard modules and components. (Elmaraghy, 2013; Salvador et al., 2002). By modularization of products, can be affected to delivery times of products, which has an even greater meaning when it comes to configurable products than standardized products because of storage cannot be done in the case of configurable products. (Martio, 2015, pp. 192). In addition, modularity of product affects the operations and efficiency of an enterprise that manufactures product in many ways. The objective of modularization is to increase commonality within product without sacrificing variability. In general, modularization focuses on developing a solid modular architecture for the product portfolio. (Pakkanen et al., 2022). Configurability is often based on modular product architecture. Modularization to create product variants is the most important way to develop the product to be configurable. (Tiihonen, 1999).

In today's manufacturing, speed and customization ability are the key factors. It is objective to offer customers the option to adapt sellable items to their specific needs, with the minimum time to manufacture them. A key enabler to succeed in fulfilling customers' needs, systems must be in place. Configure-to-order, Engineer-to-order (ETO), Make-tostock (MTS) and custom-made are approaches to carry out business models for product management. In this chapter, the following business models are presented more closely. The focus is on the CTO products, which are relevant with respect to this thesis. According to Zhang & Xu (2011), CTO describes a process in which final products are configured from a set of predefined modules and components in accordance with constraints regarding them. Order processing starts the order fulfillment. Sääksvuori & Immonen (2010, p. 111) divide product management businesses into three groups, which are a bulk product to be manufactured in great volumes, a product that is customer-specially configured or customized or a unique engineering product. The second one is the nearest to describe CTO. CTO can be seen as a variant of Make-To-Order product approach; however, configuration starts only after a customer's order is received and product variants will be pre-defined. Product design following an order is not needed because of the product configurator. (Gatehouse Design Ltd, n.d.). Kaattari (n.d.) states that CTO can offer challenges for product development, which needs to actively collect new ideas from different sources such as customers and competitors.

2.2 Product lifecycle management

Stark (2015, p. 1) describes PLM as way to manage both individual parts and individual products as well as the entire portfolio of products. The aim of the PLM is to increase product revenues, maximize the value of the product portfolio and value of current and future products and to reduce product-related costs. PLM gives visibility about product lifecycle occurrences. (Stark, 2015, pp. 13-15). Terzi et al. (2010) present PLM as a product-centric lifecycle-oriented business model, which is supported by Information and Communication Technology (ICT). In PLM, product data are shared among different actors, processes, and organizations in the different phases of the product lifecycle. With the help of PLM, right information at the right time in the right context is possible for enterprises. ICT plays fundamental role in PLM data digitalization, and it also comprises business processes and methodologies. Methodologies, processes, and ICT are seen the three fundamentals of PLM, and which are involved along the whole product lifecycle phases. (Terzi et al., 2010). Ameri & Dutta (2013) represent PLM as a business solution which aims to streamline the flow of information about the product and other related processes through the whole product lifecycle. PLM brings people, data, processes, and systems together to provide product information support (Lim et al., 2020). Venugopalan et al. (2012) describes PLM as a strategic business approach that enables innovation, product development, market deployments and disposal. Sääksvuori & Immonen (2008, p. 3) describe the core of product lifecycle which consist of creation, preservation and storage of information related to the products and company's activities. PLM is a concept and set of systematic methods to control product information. (Sääksvuori & Immonen, 2008, p. 9). In addition, changes made to the plans, designs, product documentation, items, and product structure, are all recorded in the PLM system as well as the reasons for the changes (Sääksvuori & Immonen, 2008, pp. 115-117). Hannila (2019) states that PLM is one of the key concepts when aiming to improve product quality, time-to-market, and costs within manufacturing industries. Distinctive enterprise applications used with PLM can be listed as following:

1. Computer-Aided Design/Computer-Aided Engineering (CAD/CAE) tools
2. PLM/PDM
3. Customer Relationship Management (CRM)
4. Enterprise Resource Planning (ERP)
5. Manufacturing Execution System (MES)
6. Computer-Aided Manufacturing (CAM)
7. Human Resources (HR) systems, Finance & Control (FC) systems and Service & care systems and applications. (Hannila, 2019).

The crucial systems from the thesis point of view are CAD, PLM, PDM and ERP. Especially, the PLM system is researched more closely further in the Improvement propositions chapter.

On average, PLM systems have included Item management, Product structure management and maintenance, User privilege management, Maintenance of the state or status of documents and items, Information retrieval, Change and Configuration management, Management of tasks or workflow management and other features. (Sääksvuori & Immonen, 2008, pp. 15-17). However, PLM system is a holistic system that should cover company's operations from the product management through engineering and supply chain and finally to the after sales and services. In addition, PLM covers operations from the strategy planning to management and the execution phase. From the product management and R&D point of view, strategy phase includes R&D strategy planning, management includes PPM, PLM and offering management. The execution viewpoint includes engineering, product change management, offering data management and PDM. In addition, the PLM can include requirements engineering, model-based systems engineering, PLM process management and product cost management. All mentioned activities during different lifecycle phases are managed in one PLM system ("PLM Solutions", Siemens Teamcenter, n.d.). Configuration and change management as well as product structure management are key features according to this thesis. Ameri & Dutta (2013) emphasize benefits of PLM solutions, which will be gained only if both users and system developers have a clear understanding of PLM regarding to definition, components, functionalities, scope, and its relative positioning within the enterprise. Companies struggle with implementing PLM, which is more a concept than a system. The problems that are faced when implementing PLM can be the large scope of PLM implementation, which leads to difficulties to manage a PLM implementation and to keep it on schedule and within budget. The second organizational problem is that PLM involves changes to existing business processes and working practices as well, which requires organizational change effort. In addition, IT implementations should proceed with business processes and other organizational issues. (Helms et al., 2006). PLM implementation is a holistic process. According to Kärkkäinen et al. (2012), PLM requires new type of skills and capabilities and large cultural and strategic changes. Batenburg et al. (2005) emphasize the difficulties that companies face, which are adopting and implementing the PLM. The notable reason is that PLM affects a wide range of processes within and outside the company and it has extensive changes in intra- and inter-organizational practices.

2.2.1 Product lifecycle management benefits and capabilities

Stark (2015) divides the benefits of PLM into strategic and operational benefits and states that PLM provides benefits through the whole product lifecycle from the first phase to the last stage. To start with strategic benefits, PLM improves the activity of product development and enables a company to grow revenues by reducing time-to-market for new products and providing support and services for existing products. On the other hand, PLM enables a company to reduce product-related costs by focusing on material and energy costs in the early phase of product development. PLM also enables the company to support their customers with their products and view of products is more transparent through PLM. There are two operational benefits mentioned, which states that PLM helps to develop and produce product at different sites, and it enables people to collaborate across the design and the supply chain. PLM helps to bring together the management of products and processes. It also helps to manage compliance with regulations and to manage Intellectual Property. The second operational benefit is that PLM provides transparency about what is happening over the product lifecycle. PLM enables to manage product and to access to the right information to support decision making. (Stark, 2015, p. 21-23)

According to Sääksvuori & Immonen (2008, p. 2), the operational benefits of PLM are incremental savings, yielding greater bottom-line savings and top-line revenue growth, by making necessary changes in current processes, practices, and methods. In addition, it is essential to gain control over product lifecycles and processes during it. The other benefit is useful problem-solving tools and methods for product information and PLM problems that the PLM system brings to the company. (Sääksvuori & Immonen, 2008, p. 24). With the help of PLM, single source and up-to-date information at every phase of the product lifecycle is available. Moreover, PLM enables bidirectional flow of real-time data to support knowledge sharing and collaboration between different stakeholders in a company. (SAP, n.d.). In comparison to PDM, PLM extends the scope from product design to the entire lifecycle and covers the extended enterprises and not only one manufacturer (Liu et al., 2009). Batenburg et al. (2005) state increased innovative ability, less engineering changes late in the lifecycle and less product faults in the field as benefits of PLM. Venugopalan (2012) addresses that the maturity level of an organization offers a good benchmark to rate the success of the operations in organization and the assessment of maturity helps organizations evaluate the extent of their proficiency over a technology or practice being deployed.

Helms et al. (2006) see PLM framework consisting of two aspects, PLM maturity and business/IT-alignment. PLM maturity indicates to the different growth stages that can be identified for PLM. Later, PLM framework can be used for defining the PLM Roadmap that has a target to bring an organization to a higher level of PLM maturity after determining the as-is situation in an organization. In Table 1., PLM maturity levels are divided into four groups according to Helms et al. (2006). The lowest level starts from the ad-hoc level which means that there is no PLM, or it is done for single urgent case. On the other hand, the highest level is inter-organizational level which requires that company must have defined processes and PLM system is integrated with suppliers as well. Sääksvuori & Immonen (2008) present another model of maturity model, which consists of five different level instead of four. The lowest level stand for the level where PLM has been recognized but there are no defined approaches according to PLM. The highest level is so called optimal level in which processes and concepts have been refined based on benchmarking to execute the best practices. Helms et al. have modelled maturity mainly from the broadness point of view, whereas Sääksvuori & Immonen classify maturity more on the operational level. The model can be found as Table 2. Maturity model's idea is to describe, on a rough level, how the company and its management team can develop and extend the use of corporate-wide PLM concept and related processes and information systems. (Sääksvuori & Immonen, 2008, p.70). According to Batenburg & Helms (2005), maturity is usually presented by figuring several growth stages that describes the potential upward development of organizations during several sequential periods of time. Time or periods are on the horizontal dimension and the development level is labeled on the vertical dimension.

Table 1. PLM maturity model (retell, Helms et al., 2006).

PLM maturity model		
Maturity level		**Description of the level**
0	**No PLM investment or on 'ad-hoc' basis only**	A. No responsible persons for PLM B. No consistent PLM processes and supporting systems. C. No strategic decision-making
1	**On departmental level ('silo' orientation)**	A. PLM is seen as data management problem on departmental level B. No overall vision to coordinate local initiatives
2	**On the organizational level (cross-departments)**	A. Different departments are involved B. PLM processes are defined C. PLM systems are integrated with other major systems D. All product information within the company is stored in a central system.
3	**On the inter-organizational level**	A. PLM processes are defined such that cross-organizational borders B. PLM systems are integrated with suppliers to enable collaboration C. Enables proper decision-making concerning a product

In this thesis, maturity stands for the state of being complete and the level indicates the completeness of it. Maturity level also refers to the concept of how advanced the organization is with the PLM implementation. The idea of the models is to offer reference value to the company to consider strengths, weaknesses, and limitations of its current PLM maturity and how to improve the level.

Table 2. PLM maturity model (retell, Sääksvuori & Immonen, 2008).

PLM maturity model		
Maturity level		**Description of the level**
1	**Unstructured**	A. PLM topic has been recognized B. There are no defined approaches concerning lifecycle management C. All lifecycle and product management issues are resolved by individuals
2	**Repeatable but intuitive**	A. There is no definition of standard processes B. Responsibility is left to individuals.
3	**Defined**	A. Processes and basic concepts are standardized, defined, documented, and communicated through manuals and training B. IT systems support individual parts of processes
4	**Managed and measurable**	A. It is possible to monitor and measure the compliance between processes B. IT systems support PLM processes well. C. Process automation is used in a partial or limited way. D. The state of uniformity of processes is clear.
5	**Optimal**	A. Processes and concepts have been refined to the level of best practice, based on continuous improvement and benchmarking with other organizations. B. IT is used in an integrated manner and process automation exists on an end-to-end basis.

2.2.2 Product lifecycle phases

In this chapter, different product lifecycle models are presented and described more closely. According to Martio (2015), the product lifecycle model figures its features and effects on all organizations with the product, such as manufacturer, vendors, purchasers, users, and owners. The lifecycle starts from the product innovation and ends to the disposal of the product. For example, the product development must take into account all factors that affect the product during its lifecycle. The product lifecycle phases can be named as follows: product development, product launch, growth, saturation, recession, and retirement. (Martio, 2015, pp. 158-159). Tolonen et al. (2014) present another model in which there are four lifecycle phases: new product development (NPD), Maintain, Warranty and Archive. In figure 4, above phases are described more closely. According to Tolonen et al. (2015), pre-planned and strict length of product lifecycle are not planned in many case companies. Duration of lifecycle phases are discussed more in the later chapters.

Lifecycle phases can also consist of phases of Imagine, Define, Realize, Support & Service and Retire. The specific activities across the lifecycle depend on industry sector, however, activities can be mapped as five different lifecycle phases. In the imagination phase, the product is only as an idea in people's heads. In the realization phase, the product exists in its final form. In the last phase, the product is retired by the company and disposed by the customer. (Stark, 2015, p. 6). Sääksvuori & Immonen (2008, p. 192) divide lifecycle into six different phases: Planning, Introduction, Growth, Maturity, Decline and Retirement. According to Ameri & Dutta (2005), the product lifecycle can as well consist of Design, Build, Sell, Use and Recycle phases. Furthermore, Kiritsis et al. (as cited in Terzi et al., 2010) presented another product lifecycle model which can be defined by three main phases: Beginning of life (BOL), Middle-of-life (MOL) and End-of-life (EOL). BOL includes design and manufacturing, MOL includes distribution, use and support and the last one, EOL, is the phase where products are retired. Crnkovic et al. (as cited in Tolonen, 2016) divide lifecycle into six phases: the product business idea, requirements management, development, production, operations and maintenance and disposal of the product. In chapter 3, current state analysis, the best suitable lifecycle phase model is applied. However, Tolonen et al. (2014) PLM model is suitable when considering to horizontal and vertical portfolios in the next chapter. That model is applied during the thesis research.

NPD (New product development)	Maintain	Warranty	Archive
• New products being developed • Concept development • Engineering	• Active marketing • Sales • Delivery and Services processes • Ramp-down	• Active spare part business and repair operations process	• Obsoleted inactive product portfolio • No sales • Legally required information stored

Figure 4. Product lifecycle phases (retell, Tolonen et al., 2014).

2.3 Product portfolio management

According to Cooper et al. (1999), product portfolio management (PPM) is about making strategic choices concerning market, product, and technologies to invest in. It also considers, how to spend scarce engineering, research and development (R&D) and marketing resources. PPM focuses on which new product or development project to choose from the various opportunities. The purpose is to balance right numbers of projects to take, available resources and capabilities. Cooper et al. (2001) also describe that PPM is about balancing between risk versus return, maintenance versus growth and short-term versus long-term new product projects. Tolonen (2016) emphasizes that earlier literature about PPM have focused on the early phase of lifecycle, but extension of the PPM concept over all lifecycle phases and product structure level is running. PPM methods and tools can be classified into strategic and operational tools, which covers strategic, financial and portfolio balance viewpoints. According to Mustonen et al. (2020), the intent of PPM is to specify which products to develop, sell, deliver, maintain, and remove based on company's strategic targets and this is closely related to PLM, which manages the product lifecycle and the different phases of it. Productization is an essential topic when it comes to a profitable product portfolio. Lahtinen et al. (2021) state that maintaining product profitability over the lifecycle, it demands effective productization and product portfolio management practices supported by product structure considerations. Productization stands for the concept of product structure and relates to modeling of the offering according to a consistent product structure, both commercially and technically (Mämmelä et al., 2022). PPM compared to product management apart from the goals point of view. Product management targets to tactical goals and takes care of product project timetable and budget and manages products and stakeholders related to them. However, PPM focuses on strategic goals and balances with questions if a company is working on the right products or do the company have right resources to be competitive. (Mustonen & Härkönen, 2022). Lahtinen et al. (2021) also defines that product management focuses on managing an individual product or specific piece of business, whereas the PPM operates at a more holistic level and considers a set of products or projects.

In this thesis portfolio refers to a collection of tangible products, configure-to-order products, specifically valves. These products are grouped together to obtain effective management of product portfolio to meet strategic business objectives. Portfolio management determines, how the business should invest its R&D and new product resources. It is also a decision process, in which active new product projects are evaluated, selected, and prioritized. However, existing projects are accelerated, killed, or deprioritized. Resources to the active projects are constantly balanced. (Cooper et al., 1999).

Roussel et al. (1991) (as cited in Cooper et al.,1999) emphasize four essential functionalities of PPM:

1. Portfolio management is about making strategic choices and it enables operationalize business's strategy
2. Product and technology related choices, which determine the direction of company's portfolio and business activities
3. Resource allocation for R&D, engineering, marketing, and operations
4. Balancing available resources within portfolio

2.3.1 Product portfolio challenges

Current challenges of PPM are the explosion of product portfolio when sales revenue and profit is not created. Previous literatures have merely focused on new product creation and not the active PPM during the entire product lifecycle until the removal of products. Key challenges are product cannibalization, lack of overall understanding and the role of PPM and inadequate product portfolio management, which shows up as unclear responsibilities, criteria for project selection, and no overview of the portfolio. In addition, business impacts are faced too when having too wide and unprofitable product portfolio, such as unprofitable products, no planned product lifecycles, too slow product portfolio renewal and inadequate reporting capabilities on product portfolio and sub systems. Product portfolio of a company may expand or even explode rapidly due to simultaneous company mergers and acquisitions. (Mustonen & Härkönen, 2022; Tolonen, 2016). Vähäniitty (2006) lists problems which are caused by inadequate portfolio management. To mention few of them, inefficient resourcing, late decision-making, real causes of problems not recognized and inadequate process for portfolio management are the common problems. Hannila et al. (2019) characterize common challenges for PPM: there are no shared understanding of the company's product, no connection between commercial and technical product structures, corporate-level data governance is inadequate or totally missing, products are not classified into strategic, supportive, and non-strategic products. The last challenge is inadequate business IT support for data-driven PPM. Srinivasan et al., 2005 (as cited in Mustonen & Härkönen, 2022) define product cannibalization as the process in which a new product gains sales by diverting sales from an existing product in the portfolio. Cannibalization can be divided into four different scenarios: multi-product pack, combo-product, intra-product and inter-product cannibalization. Sources of cannibalization can be both internal and external. One internal factor is the introduction of new product. External factor is competition, which can derive from introduction of new products by the competition. Hannila et al. (2019) mention consequences of PPM challenges, which is that there is no relevant or reliable real-time information and no business IT support for PPM decision-making, therefore, the data model must be comprehensive. One of the preconditions for PPM is a holistic corporate-level data model. To understand these challenges and to avoid them, current state and preconditions for PPM must be well understood. In Figure 5, the explosion of product portfolio and PPM research scope is figured. Silvola et al. (2019) emphasize the importance of one product data to be under control. Uncontrollable product data reflects to everyday activities. One product data is needed to link business strategy and customer needs, which is not easy to operate because of deficient PDM and PPM practices in the company. Preconditions for one master data are presented later in this chapter.

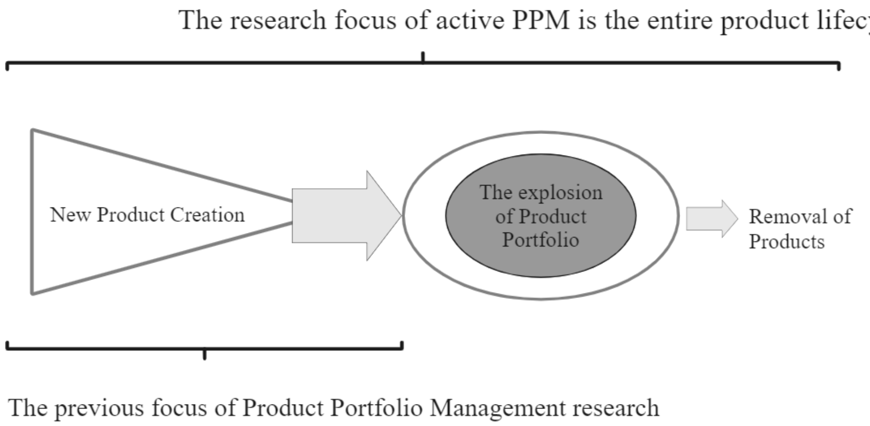


Figure 5. Explosion of the portfolio by the size (retell, Mustonen & Härkönen, 2022).

Tolonen et al. (2014) summarize generic challenges of PPM, which start on inadequate understanding of product portfolio management as a concept. In Table 3. (Tolonen et al., 2014), generic challenges in PPM are presented. In addition, in chapter 2.3.2, preconditions, and more specific PPM and one master data challenges (Silvola et al. 2019) are covered.

Table 3. Generic challenges in PPM (retell, Tolonen et al., 2014).

Generic challenges in PPM
➢ The explosion of the product portfolio as a size ➢ The idea and the role of PPM as higher-level analysis and decision-making process for the entire product portfolio including new and existing products is not thoroughly understood. ➢ The entire product portfolio and sub portfolios have been not clearly defined and agreed. ➢ Inadequate product portfolio clean-up activities. ➢ Too slow product portfolio renewal. ➢ The cannibalization within product families, and even outside them. Un-synchronized product ramp up and ramp down activities (phase in / phase out management). ➢ Lack of the product portfolio level business case thinking. ➢ The durations of product life cycles are seen not to be planned in original business plans for new products. ➢ Inadequate reporting capabilities on the product portfolio, sub portfolio and other product structure levels. ➢ Lack of clear ownership for PPM and product management decrease the capabilities to manage and communicate the change efficiently in co-operation with the main stakeholders such as R&D, sales, operations, and services.

2.3.2 Enablers and preconditions of product portfolio management

According to Tolonen et al. (2014), product portfolio management is seen as a challenge in researched case companies and preconditions of PPM are created based on faced challenges. A few examples of these specific challenges are gone through. Processes and tools related challenge is due the lack of implementation of process management concepts and descriptions for the entire PPM. An example of ownership and governance models related challenge is the inadequate clarity of responsibilities and expected responsibilities within an organization. The third challenge relates to target setting and performance measure, in which targets and measures are not set consistently, because of lack of understanding about PPM. The last challenge mentioned is data availability related, where targets of data have not been specified entirely. The preconditions for the PPM practices are connected to the fundamental main challenges.

Preconditions of PPM:

1. Identification of current challenges and preconditions in PPM
2. Creation of PPM strategic targets and KPIs → strategic fit, value maximization, portfolio balance and size
3. Creation of product portfolio and sub-portfolios
4. Creation of PPM ownership and governance models
5. Creation of PPM processes and tools over lifecycle
6. Creation of data availability and reporting capability
7. The result: Dynamic PPM implemented and connected to other business processes

(Tolonen et al., 2014)

Hannila et al. (2019) present another point of view to describe preconditions for product portfolio management, but more closely for data-driven and fact-based PPM. The following preconditions for data-driven and fact-based PPM are constructed based on the challenges mentioned before:

1. Clear productization
2. Creation of consistent commercial and technical product structure
3. Product classification in terms of strategic relevance
4. A holistic corporate-level data model for PPM
5. Organizing company business IT to support data-driven PPM

(Hannila et al., 2019)

Silvola et al. (2011) state the preconditions for one master data, which is prerequisite for efficient PPM and especially focusing on previous preconditions related to data model and data availability and reporting capability. Inadequate data model definitions are seen to cause problems when companies are trying to integrate data into one system. Preconditions for one master data:

1. Data model
2. Data ownership
3. Data quality
4. Culture

5. Roles and responsibilities
6. Organizational structure
7. Processes
8. Managerial support
9. Information systems

(Silvola et al., 2011)

Different viewpoints for preconditions are presented but to understand them thoroughly, one master data preconditions presented by Silvola et al. (2011) are researched more closely. This part of literature review is fundamental to consider current state analysis of the case company and make improvement propositions in the later point. Furthermore, the part in question helps to answer for RQ1 as well (See chapter 1.3).

Data model

The company needs to have a common definition on data model across the whole organization. To be able to integrate different data formats into one system, the company must define the one data model. The data model is created to support company's goals and to offer a framework to define one product data. In addition, data model unifies product terminology across a company.

Data ownership

The ownership of data relates to the cleansing, publishing, protecting, and sharing of data and all these should be done through common information systems. It is about taking responsibilities over data at the enterprise level. Definitions of data ownership is lacking or completely missing in companies. To tackle this problem, managerial support is needed, and the idea of data ownership must come from there. In addition, inadequate data ownership is also a common reason of poor data quality. The ownership of data should remain during the whole product lifecycle.

Data quality

The main challenge with data quality is that continuous practices are lacking. Data quality issues are due to data errors and inconsistencies, which can lead to mistakes, failed deliveries and invoicing problems. The quality of data should remain on excellent level over the whole lifecycle. It can be said that poor data quality is big challenge in the master data management. Usually, the increasing amount of data requires even more carefully maintained data quality. In addition, when data is transferred through integration between different application, the quality is usually decreased.

Company culture and responsibilities

To be able to execute one product data and use the data, company's culture must be according to that. Data ownerships must come from the higher managerial level, which also create organizational culture around the data. Culture, roles, clear processes, and responsibilities are needed for data owner network as well. Figure 6 combines the whole concept of one master data, including data, information systems and processes. Organization and the data owners are top of the figure, processes and places in the middle and content is the base for the concept. Parties is the most important entity as it is at the top. These three form a management framework for successful master data management implementation. All the cornerstones must be managed as a whole to implement one master data in the company.

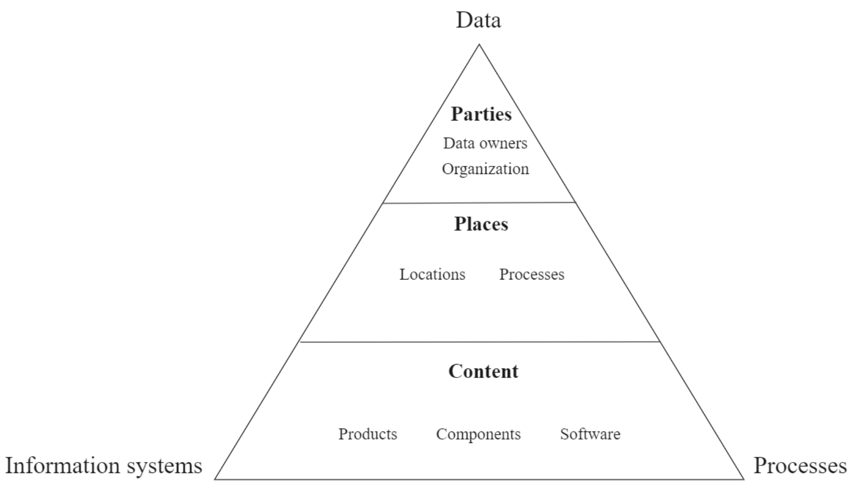


Figure 6. The concept of one master data (retell, Silvola et al., 2011).

Organizational structure and managerial support

The purpose of organizational structure is to support data processes, however, departments within the organization must not work in silos. Master data management projects need support from the higher management to the implementation of it. Managerial support shows the resources which are pointed to master data management projects.

Processes and information system

The idea of processes is to create a business case to gain managerial support and the definition for processes should be clear. Information systems includes applications and technologies to share and integrate the data. The most usual applications which handle the master data are for example PDM, ERP, PLM, and Customer relationship management (CRM) system. The idea of information systems is to work as integrated together and therefore to unify the data model.

Hannila (2019) compiles key business processes, information systems and corporate data assets for PPM in Figure 7. Business process layer consists of different key processes, such as PPM, PDM and sales and marketing. In these processes, product data and product-related business data is created, which are essential from the data-driven PPM point of view. Previously mentioned product master data is created at the early phase of product lifecycle, which is stored in PLM or PDM system. The product master data is transferred to other systems as well, which are presented in the same figure. Arrows between each system and master data, describe the transactions between them. These systems and key business processes are connected via master data, that require product master data and other product-related business process information.

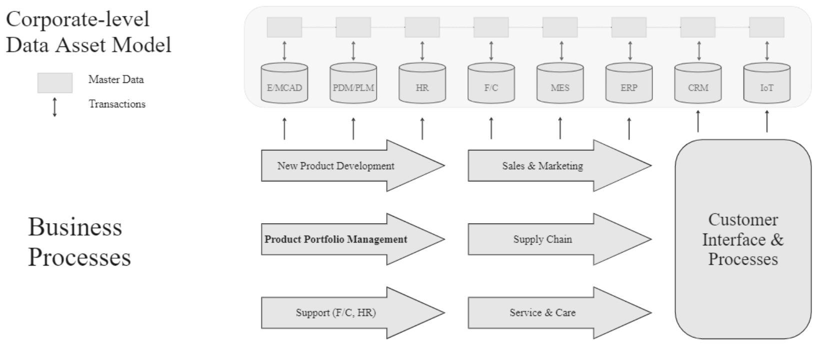


Figure 7. Key business processes, information system and data assets (retell, Hannila, 2019).

2.3.3 Product platform and product family

Product platform and product family are in a key role when considering modular and configurable products. One key problem is that companies design new products one product at a time, and this leads to a failure to embrace commonality, compatibility, standardization or modularization among different products and product lines. It can be said that product platform-based design is precondition for modularization and configuration as well. A product family can be described as a set of individual products that share common technology and address related market applications and this enables long-term success of enterprises. (Lehnerd & Meyer, 2011). Meyer & Lehnerd, 1997 (as cited in Simpson et al. 2010, p.3) describe product platform as “a set of common components, modules, or parts from which a stream of derivative product can be efficiently developed and launched”. According to Simpson et al. (2010), with product platforms, it is possible to reduce development time and system complexity, reduce development and production costs and improve ability to upgrade products. Companies are developing product platforms and designing product families based on platforms to provide competent variety for the market. Robertson & Ulrich, 1998 (as cited in Simpson et al. 2010, p. 3) describe platform benefits accordingly: “By sharing component and production processes across a platform of products, companies can develop differentiated products efficiently, increase the flexibility and responsiveness of their manufacturing processes and take market share away from competitors that develop only one product at a time”. Product platform and product family design provides cost-effective product variety and customization. (Simpson et al., 2010, pp. 2-3).

2.3.4 Commercial and technical portfolios over lifecycle

Tolonen et al. (2014) propose the product structure model, in which the portfolio is divided to commercial and technical product portfolio. The commercial side is more familiar with marketing, sales, product management and with customers. Technical side is more common in product development, engineering, manufacturing, testing, purchasing, logistics and suppliers. Both technical and commercial portfolios should be managed by product owners. On the vertical direction, the more complex or deep product structure is, the more unclear are ownerships within the portfolio. On the horizontally, products should be managed based on their lifecycle phases. Phases of lifecycle can vary depending on the size of company and its offering. In Figure 8, commercial and technical portfolios are described. Commercial side consists of solution, product family, product configuration and sales item layer. Technical side includes version item, main assembly, one or several sub-assemblies and single component. However, horizontal dimension manages the PPM practices over product portfolio lifecycle phases and the vertical dimension over product portfolio layers. Usually, SW, HW and service products have the same kind of commercial product structure, but there are differences in the technical side. (Tolonen et al., 2015). The highest level of product structure is the solution level, which can be a combination of several product families or configurations, or it can be a single sales item. Product family level include product configurations, which can share, for example, the same customers or same technical platform. Product configuration means the pre-designed sales items which are modules and components. By combining these items, a unique product for specific customer need can be done. As a result of product configuration, various of different kind of combinations can be created. Sales item is the lowest level in the commercial product portfolio, and it is something that can be sold, delivered, and invoiced. The sales item can be HW, SW, service, or documentation. On the technical side, version item is the first one, which is usually created to improve the existing product, sales item. Improvements are related to cost reductions or performance improvement. Main assembly level are the building block for the product, and they can consist of smaller sub-assemblies or components. These sub-assemblies are modules that consist of components. The lowest level of the product structure is component level, which are the smallest parts of a product. (Mustonen & Härkönen, 2022).

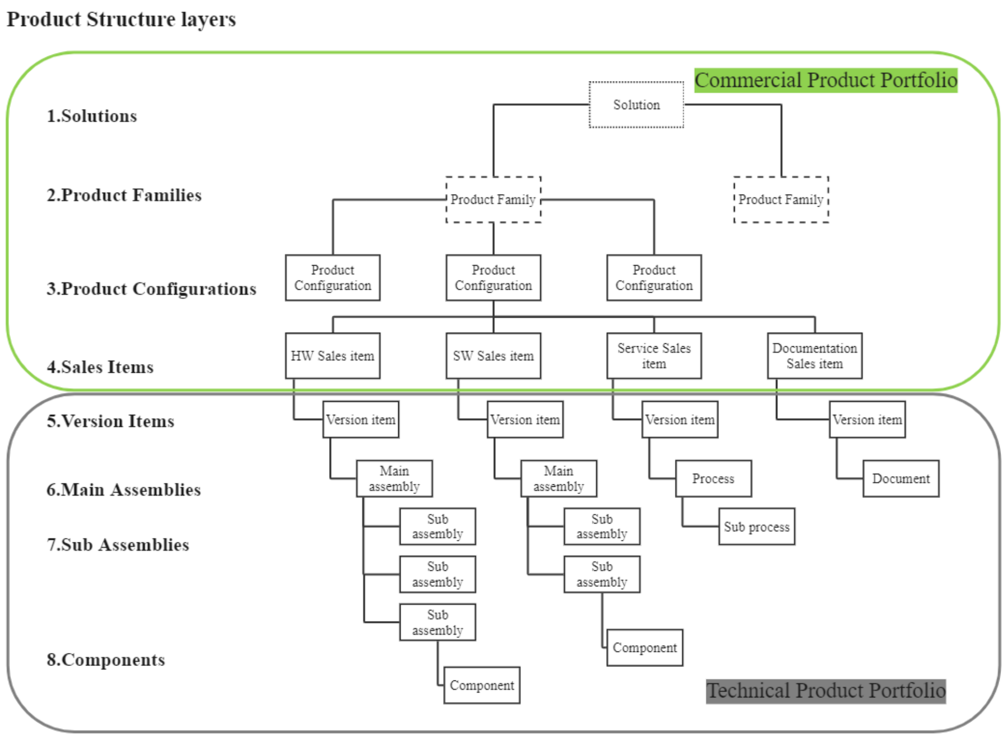


Figure 8. Commercial and Technical Product portfolios (retell, Tolonen et al., 2014).

Tolonen et al. (2014) propose a framework for PPM governance model, which aim at support the PPM’s main objectives. These objectives are strategic and cost-efficient renewal of product portfolio by adding, enhancing, modifying, and removing products. The target is to respond to the main challenge which is product portfolio size explosion on the different product structure levels and over the lifecycle phases within the company. In addition, PPM governance framework should not be dependent on the size of a company or its portfolio. The framework enables horizontal flow of products and items in all product structure levels from the early phase of the lifecycle to later phases. Four main enablers for developed framework are pointed out: vertical sub portfolios and their owners according to product structure levels, horizontal sub-portfolios, and their owners according to product lifecycle levels. The framework is in Figure 9, in which PPM board and PPM team are above these portfolios and are managing them with other portfolio-related managers. The PPM board consist of the executive level management covering sales, product management, operations, and R&D. The PPM team consists of product portfolio manager and vertical and horizontal sub-portfolio managers. The structure of the framework is closely related to previous Figure x.

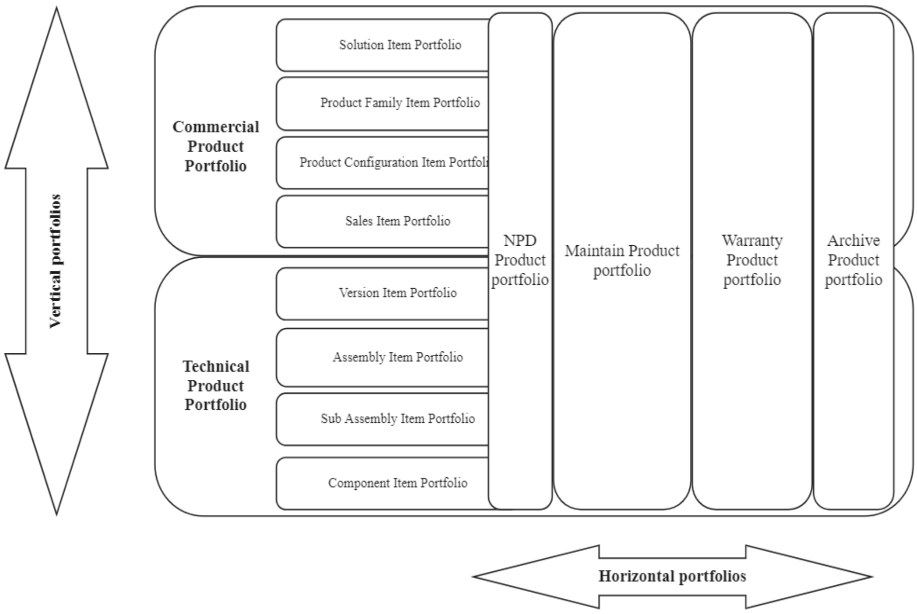


Figure 9. Framework for product portfolio management governance (retell, Tolonen et al., 2014).

Tolonen et al. (2014) consider if product portfolios can be more visualized both vertically and horizontally to increase understanding on the related PPM challenges. In addition, different kind of processes and tools should be considered for vertical and horizontal portfolio analysis and decision making. Certain product structure, configurability and modularity enables more efficient productization and renewal of the product portfolio. The following topics are considered in this thesis and the common challenges are reviewed.

2.3.5 Product portfolio management process as part of business processes

A new PPM process based on both horizontal and vertical dimensions is proposed by Tolonen et al. (2015). The new business process, PPM process, is proposed on the level of other traditional business processes. These processes are product process, support process, marketing and sales process, delivery process and care process. With the help of PPM process, decisions about what kind of products to develop, market, sold, deliver, maintain, and remove, can be analyzed, and produced. The other business processes have more operational role and relate to how the development, marketing or selling is performed. PPM processes and other business processes was presented in Figure 7. Tolonen et al. (2015) describe the roles of business processes as follows:

- Product portfolio management process determines how to renew product portfolio over horizontal and vertical portfolios along strategic PPM targets, KPIs and processes
- Product process: managing technology and product development over horizontal and vertical portfolios according to strategic PPM decisions
- Marketing and sales process: marketing, selling and contracting products on the customer interface
- Delivery process: purchasing, manufacturing, delivering and invoicing products
- Care process: installing, maintaining, supporting, and invoicing the products
- Support processes: managing investment and resources

2.4 Product portfolio management in product lifecycle management systems

A product lifecycle management system is an information processing system or set of IT-systems that integrates the functions of the whole company. To integrate functions, company's business processes are controlled, connected, and integrated with produced products by means of product data. PLM system has several capabilities, for example, workflow, program management and project control features. Systems can be easily connected globally inside the company and with external stakeholders such as suppliers or partners. The commonest ways to integrate systems are Transfer file integration, Database integration and Middleware integration. (Sääksvuori & Immonen, 2008, pp. 2, 13, 55). Batenburg et al. (2005) emphasize that PLM system implementation is a complex process, because it does not consist of one system but many systems that must be integrated with each other. The implementation of the PLM systems involves a detailed definition of various features of the business processes of the company. PLM systems are implemented for different reasons; however, it brings useful problem-solving tools and methods for product information PLM problems. (Sääksvuori & Immonen, 2008, pp.6, 24). As a precondition for PLM system, it is crucial to decide what kind of information will be updated in each system. The ownership of the information in each lifecycle phase should be clear. (Sääksvuori & Immonen, 2008, p. 53). To help understand what PLM system is, it can be necessary to compare it to other system, such as ERP. PLM system serves product data producers, whereas ERP system is for product data consumers. (Sääksvuori & Immonen, 2008, pp. 58-59). Figure 10 illustrates the relation between PLM and ERP. Terzi et al. (2010) describe PLM as a solution that must include all the product lifecycle phases and stakeholders related to products. Data exchange and information between different phases and stakeholders are critical element of PLM. CAD systems are two-dimensional (2D) or three-dimensional (3D) design SW and the information produced by CAD system is controlled by PLM system. For example, created documentation is directly saved into PLM without any excessive stages. PLM user interface can be integrated to CAD and the integration can include individual 3D-models, assemblies and sub-assemblies, items and structures and assembly drawings. Actual concurrent engineering is possible when different CAD systems used in a company can be integrated with the same PLM system. CE makes several teams and departments possible to work globally with the same CAD assemblies. (Sääksvuori & Immonen, 2008, pp. 60-61).

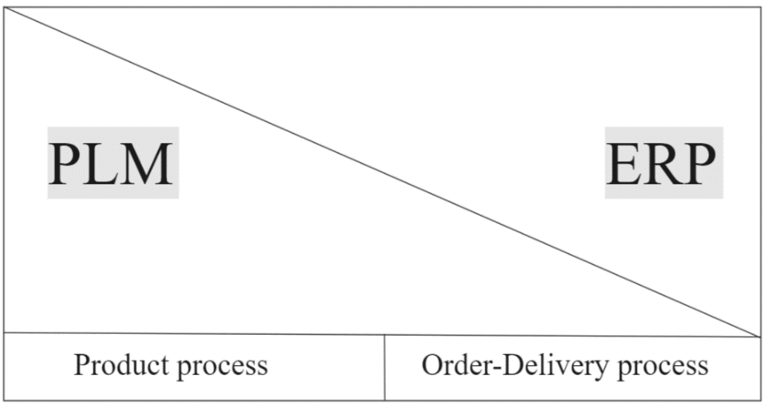


Figure 10. PLM and ERP in the business processes (retell, Sääksvuori & Immonen, 2008).

Stark (2015) sees product portfolio management as specific PLM application from the information system viewpoint. The application of PLM should enable review, analysis, simulation, and valuation of a company's product portfolio of existing products. The application should show sales estimation and effects of decisions such as new technology introduces or making acquisition. The application enables to track and analyze of product cost against target costs and profit. In addition, different kinds of charts and graphics should be provided by the application. Filter and information grouping options should be available as well. (Stark, 2015, p. 180)

2.5 Product portfolio management for future projects

According to Rothman (2009), project portfolio helps to make the right decisions to release valuable products constantly to fulfill customers' needs. With the help of project portfolio, it can be decided when to commit a project and when it is time to end a project and move to another one or when to transform a project. In addition, project portfolio management helps to discover what projects to do in the future as well. (Rothman, 2009, pp. 1-3). Oltmann (2008) describes the project portfolio management perspective of increasing business value by aligning projects with the company's strategic direction. Oltmann presents a funnel that starts from strategy and ideas, continues with regulations and portfolio management, and ends with projects coordinated. The idea is to connect both strategy and execution of projects. However, the idea of the funnel is to select only projects that meet certain criteria. (Oltmann, J., 2008). Kendall & Rollines (2003) state that the biggest problems in project portfolio are too many active projects ongoing or projects that are not linked to strategic goals which leads to unbalanced portfolio. The projects chosen and completed should meet the objective of organization. (Kendall & Rollins, 2003, pp. 207-208). Usually, the resources of companies are limited and therefore it is essential to identify potential projects, to target limited resources on the right projects. When the product comes to an end of its lifecycle, it should be replaced with the new one. However, the renewal process takes time and must be started in good time. Now, the lifecycle is not transparent and there are no way to predict when to start developing new replacing product. Project portfolio management should be taken into account when trying to see when to carry out projects and when to terminate them. When it comes to R&D project management, the process should start from the product specification, proceed to requirements defining, requirements follow-up, project plan and schedule creation, and project progress follow and reporting. The following process steps should be executed in new PLM system. In the improvement proposition chapter, a way to predict product development and R&D projects with the PLM system, is presented and proposed.

2.6 Synthesis of the literature review

Product lifecycle management and product portfolio management has mainly focused on the early stage of product lifecycle and besides, all vertical product structure levels are not fully covered. However, this challenge is covered in the PLM literature and in doctoral theses (e.g., Stark, 2015; Sääksvuori & Immonen, 2008; Tolonen, 2016). The current literature covers product data management comprehensively as well (e.g.Härkönen et al. 2019, Kropsu-Vehkaperä 2012; Martio 2015; Tolonen et al. 2014). The importance of product portfolio management as part of the company business processes and strategy have especially recognized by the research of Tolonen et al. (2014, 2015, 2016). Active product portfolio management is crucial for configurable products. Unstructured product portfolio, methods, processes, targets, KPIs, and governance models are the common challenges in PPM. (Tolonen et al. 2015). New products' and product variants' rapid time to market is important from a business perspective. However, the huge number of items in the product portfolio can lead to weakened gross revenue and increasing expenses. A holistic PPM for the entire product lifecycle is needed to avoid the following impacts in the product portfolio. (Tolonen et al. 2015). Preconditions for PPM are defined by Tolonen et al. (2014). Strategic targets include strategic fit, value maximization and portfolio balance and size. Targets should be based on company's strategy. To measure the targets, indicators are needed. After creation of targets, product portfolios and sub-portfolios need to be constructed. Product lifecycle phases and product structure levels must be recognized to form a product portfolio properly. The governance must be defined for vertical and horizontal portfolios to ensure the management of the portfolio. Processes and tools must be created to manage portfolio and data must be available and presented appropriately. (Tolonen et al. 2014).

PLM is a way to manage all the individual part and products as well as the entire product portfolio of the company. PLM gives visibility for the entire product portfolio during the whole lifecycle. PLM can be seen as a business solution which supports the flow of information about product and related processes through the whole lifecycle. PLM brings people, data, processes, and systems together to provide product information support and to manage the product portfolio the best possible way. (Stark, 2015; Ameri & Dutta, 2013;

Lim et al. 2020). The purpose of configuration of products is to react to customer requirements the best possible way by compiling a fixed set of pre-defined components. Configuration has cost savings while improving profitability in its entirety. (Kropsu-Vehkaperä et al., 2011 & Tiihonen, 1999). Company can proceed towards configurable product by two different paths. The first is to go from mass production, non-configurable standard products towards configurable products. The other way is to go from individually designed product to configurable products. (Peltonen, 2000). The case company applies the first option as individually designed products are rarely sold. Modularity of products offers customization and balances already broad product variety with rational production operating. In addition, the modularity enables proper configurability of products. (Tiihonen, 1999). The term productization is in fundamental role when it comes to product modularity and configurability. Productization can be seen to consist of commercial and technical sides of products, in which configurability is on the commercial side and modularity is on the technical side.

PPM requires data-driven activities in the company, which recognize and visualize product data in real-time and is fact-based. Data-driven PPM connects key business processes, IT systems and PLM together, to achieve holistic procedure in the company. (Hannila, 2019). Silvola et al. (2011) point out the importance of managing one master data and present preconditions for it. The one master data and master data management are to manage the increasing amount of data and the challenges that companies face. Product data management practices are in key role in today's companies, in which the lifecycle of product involves different phases, and each stage requires different data from the different sources. Information should be available at the right time and in right form for various stakeholders. One master data faces common challenges related to data, processes, and information systems. Difficulties are related to defining what the master data is and how to create one. In this thesis, literature review, current state analysis and improvement propositions are based on the several references, including dissertations, articles and books related to the PPM, PLM and PDM. Tolonen et al. PPM concepts, which are horizontal and vertical portfolios including lifecycle phases and product structures. Commercial and technical portfolios are considered as well. Project portfolio management and PLM are in central role when reviewing future R&D projects and how to make PLM system to support these functions. Silvola et al. provides the viewpoint of one master data within the company, which concentrates on business processes, data quality and standardization and integration of information systems.

3 CURRENT STATE ANALYSIS

Current state analysis chapter aims at to give a comprehensive view of the case company's status from the PPM and PLM point of views. In order to be able to understand current processes and procedures in the case company, internal interviews were held during the research process. Familiarization to the company's products and other common factors was done through discussion and internal materials.

3.1 Research process for current state analysis

The purpose of this section is to cover current PLM and PPM practices in the case company and analyze them. The current state analysis is executed by arranging internal interviews inside the case company. Interviewees are titled as Product Manager, Product Director, and Project Manager. Interviews were made after the literature review and questions are formed based on two main research questions (RQs) and observations are made during the literature review. Internal material has been shared as well, which has helped to comprise the general view of the current state of the case company and their products. In addition, participation to weekly meetings and vendor meetings have given a larger perspective for the current state of the practices used and current situation related to PLM process. Current IT systems are examined to form a viewpoint of current tools and systems used. These systems are PDM system, sales configurator, ERP system and data and documents about product typecodes. Typecode is given to a product, and it is formed by using different numbers and alphabets according to document that specifies the features of the product. An example of typecoding is shown later in Figure 13. The current state analysis precedes improvement propositions, to form a holistic perception of current challenges and way of acting. Current state analysis articulates current PPM-related challenges in the case company as well. Current state analysis consists of short introduction to case company background and current state, interview questions and going through internal interviews, PLM maturity level assessment, the current state of the PDM system and sales configurator and PPM and PLM practices. Current practices are compared with the help of the theory presented in the literature review. The structure of this chapter is to present the current state of the company from the PPM point of view and closely related topics are reviewed as well. After the current state analysis, state of the art is analyzed based on external interviews and case study literature in chapter 4. Finally, current state analysis and state-of-the-art differences are compared and introduced as well. All interview questions can be found as Appendixes 1,2 and 3 in the end of the thesis. The data gathered for this section has been constructed during the spring of 2023.

3.2 Overall current state in the case company

Valmet Flow Control has a PLM vision to transform daily work from fragmented working into entirety consisting of one product data surrounded by people, processes, tools and systems connected without gaps. The benefits seen in the business side are digitalized customer experience, shorter lead times from quotation to product delivery, shorter time to market for new products from R&D and secured business continuity and product data. The major change in the current state is to proceed from current PDM system to a new PLM system with its new ways of working. A new PLM system is under functionality validation at this moment. PLM process scope covers customer order engineering, factory services, spare part management, PMD management, projects, product management, product compliance, offering and configuration management, manufacturing, quality, R&D project management and many others. In this thesis, PLM process is considered mainly from the product management point of view and especially focusing on configure-to-order valve products. Current PDM system and future PLM system are examined later, and it is performed by using a few different kind of valve types. Advantages and disadvantages of functionalities and examined in the PDM and new features are presented in future PLM.

The case company has no clear view of lifecycle status of their products in the current systems. On the component level, the status is visible in the current PDM system, and it is showing whether the component is acknowledged or in phase out stage. The role of product manager and the whole product center is to manage the product offering by seeing demand for new and to obsolete the old ones. However, support from other stakeholders is needed as well. Product managers should be able to find customers' demands directly from customers and from the sales. In addition, an ability to look in the future and take productional and procurement issues into account. Product managers are closely related to development work and launching of products as well as supporting sales, maintaining product capabilities including competitiveness, updating the products and modernization of them. It is emphasized that this kind of business, valve industry business line, is a conservative in a way that obsoleting products is very infrequent process. Valves are high quality, highly engineered products which means that they are often maintained, supported, and serviced and not obsoleted lightly. At present, items are managed in PDM system and product offering is managed in sales configurator system, which shows variants of products that are available. However, a tool for tracking phase of products and processes for PLM does not exist at the moment. It is seen in the case company that the valve products do not have clear product lifecycle duration and it is not seen as necessary compared to consumer product.

Definition of product varies between interviewees, but in this thesis, the product is a tangible sellable item, more specifically valve, actuator, or valve controller itself. In addition, HW product includes documentation, which consist of certificates and standards needed for tangible products. In Figure 11, the basic combination of products is presented as assembly. The assembly in question, proceeding from top, consists of Neles™ NDX valve controller, Neles™ pneumatic cylinder B series actuator and Neles™ modular ball valve series M. The valve cannot be operated without actuator or manual handle, nevertheless, valve is a product as well and can be sold by oneself.

Figure 11. Neles™ modular ball valve, series M. (Valmet).

PLM maturity level models were presented earlier in Tables 1 and 2. The purpose of PLM maturity assessment is to show a company its position on the progression path towards complete PLM. PLM maturity models consist of different stages, which describe the knowledge and capability level of PLM maturity to reach complete PLM process. (Kärkkäinen et al. 2014). Based on the interviews, the case company’s PLM maturity level can be placed on level 3, which stands for defined, according to Sääksvuori &

Immonen (2008) model. There is no PLM process support tool, and the work is mainly made manually from the process point of view. According to Helms et al. (2006) model, PLM maturity is on level 1, which stands for silo-oriented PLM. The need for PLM processes and tools is noticed, but only on the departmental level at the moment. The aim is to provide propositions to improve the company's PLM maturity level and consequently PPM practices to achieve a stronger understanding of PPM and make PPM more manageable in the case company. The achievable PLM maturity level in the future will be presented in the results section based on the improvement propositions. Neither PLM nor PPM are transparent throughout the current systems and employees have no clear and common understanding of the products' lifecycle status. The current state of PPM is presented in Table 4. Tolonen et al. (2014) have presented preconditions for PPM and these preconditions are the basis for the figure below. It consists of six preconditions and description of company's current situation according to preconditions. However, this thesis especially focuses on stage five and six. On the stage 5, processes and tools for PPM are created and the focus of this thesis leans on this stage. In current state analysis chapter, current PDM system and tools are examined more deeply by showing features of the system and general PPM practices are presented. PMD, item codes, typecodes and configuration rules and current IT system arrangement are presented in this chapter.

Table 4. Current state of product portfolio management in the case company.

	Precondition	Current status in the case company
1	Identification of current challenges and preconditions in PPM	Product portfolio management is known as a concept and the importance of it is understood. The need for PLM system implementation is identified.
2	Creation of PPM strategic targets and KPIs	Some PPM-related indicators have been set but they are mainly focused on sales revenues and quantities in the early lifecycle phase.
3	Creation of product portfolio and sub-portfolios	Hierarchical product structure exists, but it is not clear and not visible in the systems.
4	Creation of PPM ownership and governance models	Ownerships are defined based on product centers.
5	Creation of PPM processes and tools over lifecycle	Tools for product data management and for sales are in use but process and tool for product lifecycle management does not exist yet.
6	Creation of data availability and reporting capability	Several PDM systems are in use but not integrated. PowerBI is used in reporting. One transparent system is needed.

3.3 Current product portfolio management practices

This chapter includes an analysis of PPM current state of the case company. Background, current state, and future targets of the company are addressed. The interview questions cover topics related to the product, product lifecycle, product portfolio, customer requirements, technical and commercial dependencies as well as tools and targets for product portfolio management. The topics can be divided into commercial product portfolio to cover configurability of the product and configure, price, quote (CPQ) system and to technical product portfolio to cover modularity of the products, which makes configuration of products possible. Horizontal product portfolio covers the product lifecycle viewpoint and lastly processes, and tools are reviewed to complete this chapter. One noticeable thing is that product portfolio renewal in the case company is not made regularly. When new versions come in, old ones are not obsoleted at the same pace, and this leads to product portfolio explosion. However, this phenomenon is recognized in the case company. One factor for the product portfolio explosion are mergers and acquisitions of the companies. However, in this case company, merger and acquisition did not affect to the product portfolio in a negative way. The reason is that the company, which was acquired had different kinds of products, which means that the case company broadened its offering and did not cannibalize it. The merger with other company did not affect either since the case company formed a new business line.

In general, valve industry is a kind of conservative industry which means that customers want the same products to replace old ones. The product can be, for example, 40 years old but changing to a completely different or new product version would require excessive work from customer due to different certificates and standards concerning valves. Product portfolio is managed by following cost-effectiveness and sales of the products and by receiving feedback from the sales organization and customers. Generally, it can be said that more concrete customer needs and requirements have become from the performance point of view. Salient requirements are related to the valve's inner sealing, better operational endurance, reliability, and better usability. Nowadays, emission restriction is one key performance factor. In addition, valves for more complex and laborious processes are considered from material-technical and coating requirement viewpoint. Product compliance plays an important role in valve industry. Product compliance refers to different requirements by marketing and customer, standards, applications (including sizing or materials), product qualifications and application approvals. In other words, product compliance is what product must meet to ensure that it is compliant with regulations.

Customers' behavior is followed up by the industry management team which follows different market segments such as oil & gas and pulp & paper industries. Product centers create product roadmap based on feedback from industry management and sales organizations. The feedback is related what should be developed and what kind of requirements are needed in the future. However, R&D projects are not high-speed way of acting which lead to slow changes that appear later in the future. Therefore, it is important to have an ability to predict future demands and interests as well, which can be seen as Project Portfolio Management or Product Lifecycle Planning. Fully constructed and workable product management and data management integrations between product data are not carried out. During PLM project, it has been revealed that the company needs one centralized PLM system which produces cultured data and data that can be clearly analyzed. This enables that the information and data must not be searched from the several different sources but enables to gather them as one construed data. PPM supposed to focus on what should be done now and in the future. The case company is basically quarterly based business, which means focusing on the year in question in three months periods, even though it is common knowledge that the product portfolio must be managed in upcoming years as well. This quarterly based business might lead to short-sightedness and managing the future operations is partly dismissed. Valmet Flow Control Oy aims to bring transparency and effectiveness to their daily product management tasks by means of PLM system. In that case, product data is centralized to one place and is available for everyone in the organization and easy to reach due to transparent system.

3.3.1 Commercial product portfolio and configurability

This chapter focuses on the commercial product portfolio and the next one on the technical product portfolio. Both commercial and technical portfolios are reviewed and explained in chapters 3.3.1 and 3.3.2. Commercial product portfolio of company's products become from the sales configurator. Based on the interview, the model of product portfolio can be seen as a hierarchy as in Figure 12. The highest level of it, is valve type which can be ball, butterfly, segment, globe, or pinch valve. The brand of the product is under the valve type. The hierarchy is determined in the systems, but it is not up to date and clear view for the whole product portfolio does not exist currently. In the field of valve industry, valve brands are fundamental for customers. Customers know the specific brands and want that specific one, even if the same functionality can be achieved through another brand or solution. It can be said that some valves are competing due to same functionalities and applications. Different valve types have overlaps even if each of them has some unique feature that separates it from other valve types. However, it is currently challenging to keep track on overlaps and to compare if two different types of valves have same performance. The company is aware of the overlaps, but they don't know the quantity of them and don't have a proper system to identify such situations. Therefore, a proper PLM system could reveal these kinds of overlaps and offer overall transparency.

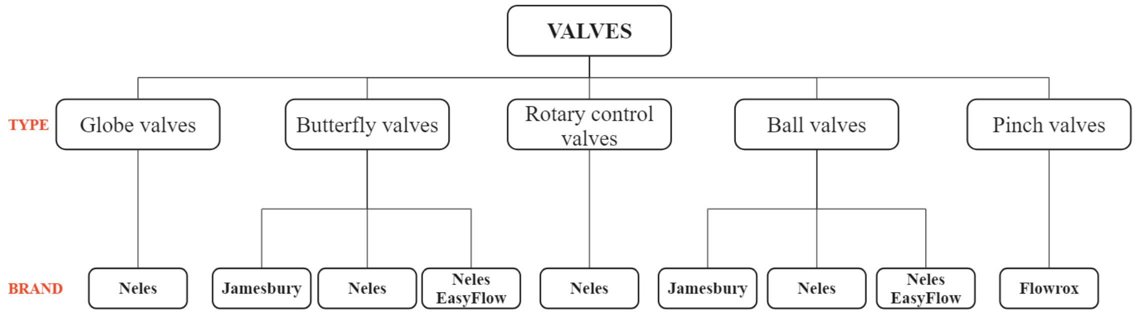


Figure 12. Product hierarchy for valves.

The product can be defined in many ways. It was seen as assembly of the valve and an actuator or valve connected to positioner or just a single valve. However, it was emphasized that valve can't operate itself and it needs some external source of power to achieve the torque in the shaft to change position. The other viewpoint for product was that it is not only manufacture of high-quality product but also the solution for customer's need. Along with HW product, the essential part of the whole product is expertise for the product selection for the customer. Operational environment of the customers site must be considered when choosing adequate solution. However, it is challenging to make clear and uniform understanding of the product as concept in the company. As mentioned before, in this thesis, a product is a tangible sellable item, more specifically valve, actuator or valve controller. This thesis focuses on configurable valve products.

The current commercial product portfolio of the case company is formed in CPQ which is sales configurator system. Dividual product configuration system does not exist, but the current configurator system covers both sales and product viewpoints. Company has no clear view of the product structure model, but the CPQ divides products based on their typecodes and related information and rules. These include information about the product and determine its features, functionalities, and dependencies. An example of typecode document is presented in Figure 13, in which the content of features are shown, and available alternatives are listed, however only five features are listed, the rest are figured as Appendix 4. The below example is for LW type of butterfly valve which stands for wafer type of valve. The quantity of features available depends on the valve type and model. CPQ makes configurations based on typecode documentations and configuration rules made in Excel. Excels are created and maintained by specific employees and they are managed manually. It is clear, that manually maintained excels are easily prone to mistakes done by a human. In addition, massive excels are challenging to manage and maintain. In Figure 14, the same thing is configured through CPQ. The configurator shows only available and allowed choices. For example, if valve type is ”butterfly”, then only possible choices for valve series are shown and series ”XH” is not valid for the reason that it is a ball valve series. The other example is related to size and valve body pressure rating which have an effect on mounting parts. In addition, specific body pressure rating matches with specific valve sizes. The sales configurator offers the newest possible version of the product selected but more clear data is needed when it comes to product versions. As a result of configurator, following typecode was created for LW valve, which is LW6KBA200AAAATD. Descriptions of alphabetical and numerical symbols are explained in the figures below.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
_	LW	6	K	B	A	200	A	A	A	A	T	D	_

1. sign	Flow balancing construction
_	Standard construction
Q	Flow balancing trim, Q-disc

2. sign	Product series/design
LW	Wafer type
LG	Lug type
L6	Double flange type

3. sign	Face to face
	LW & LG
6	EN558-part 1, basic series 20
7	En 558-part 1, basic series 25
8	En 558-part 1, basic series 16
5	API 609 category B class 300
	L6
4	API 609 category B double-flnaged

4. sign	Pressure rating & drilling
C	ASME 150
D	ASME 300
J	PN 10
K	PN 16
L	PN 25
M	PN 40

5. sign	Valve-actuator connection and shaft construction
B	Drive shaft + trunnion with two keyways/ bracket Neles standard
A	Through shaft with two keyways/bracket Neles standard
D	Drive shaft + trunnion with square drive/ bracket Neles standard

Figure 13. Typecoding for LW, LG, L6 butterfly valve example.

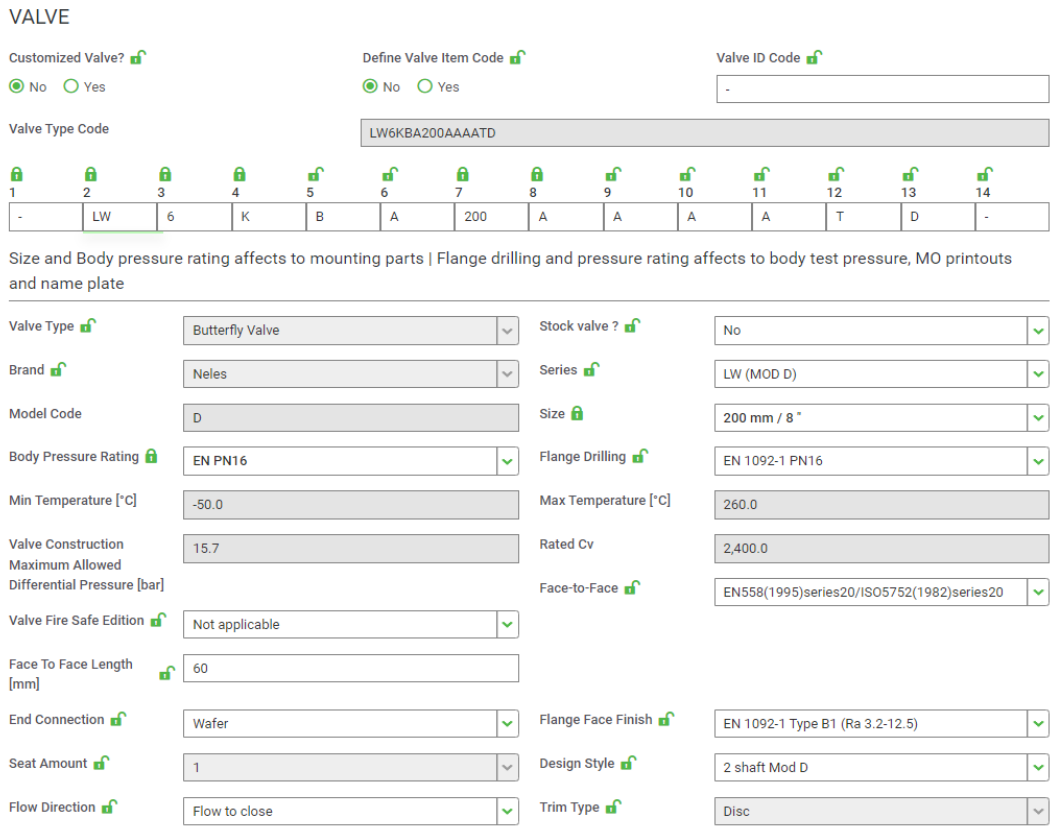


Figure 14. CPQ view of LW type of valve configuration.

3.3.2 Technical product portfolio and modularity

The case company's technical product portfolio is in PDM system in which bill of materials (BOM) is created. BOM includes assemblies and subassemblies. The lowest level of technical product portfolio is component level. However, BOM and production times and all related data are managed in Enterprise Resource Planning (ERP) system. Configurable valves have been required an effective modularity of product. The more modularity is applied, the more savings can be achieved through larger purchase quantities. It also makes data mass managing easier. One key problem is that several items are created locally for the same component in the PDM system. The new PLM system should enable a feature to have visibility for item management. The same item could be applied globally instead of only locally with several items for the same component. Modularity enables to use same structures and components that can be applied to different product series. The current state of modularity is that it is not clearly visible in the current PDM system. Different types of valve modules are bearing module, body module, body associated module, bolting module, soft sealing module, shaft module, shaft associated module, seat module, name plate module and trim module. However, it cannot be viewed which modules belong to which product series through current PDM system. There is no appropriate view of the product series level object, what it contains and what things are related to that certain product series object. Apart from the commercial product portfolio, the technical product portfolio should not be visible to customers but currently the technical product portfolio is not fully visible for the company's employees either. Therefore, product designers have no complete view how the engineering change impacts to current modules and products and what products are impacted. Usually, product managers give command to make redesign or other changes to the product and only the product manager have fair understanding what products are affected when some part is changed. Currently, product managers are mainly managing the product with multiple excels and outside of the PDM system. The information about impacts is mainly in someone's head and in different locations, therefore, reliable, and comprehensive description of the impacts are not visible. The PLM system in the future should cover that feature and give explicit perspective for the product series and modules as well.

3.3.3 Horizontal product portfolio

In order to understand horizontal and vertical product portfolios, they are earlier reviewed in literature review part (see chapters 2.2.2 & 2.3.4). In previous chapters, product portfolio was considered vertically, whereas in this chapter product portfolio is seen as horizontally which stands for product lifecycle phases. The product lifecycle status of product or valve series is not visible in the current PDM system. There is only an item level lifecycle management, in which items in use are shown as well as items that are under development or are not in use anymore. In addition, there is no view which product version is under support phase, meaning that there is still spare parts available. It requires training and guidance to inform about product lifecycle status change because of lack of suitable PLM system. The lifecycle of the valve starts from the product center's decision to renew the current product portfolio by creating something new to meet customer requirements and competitive performance level. The early phases focus on ideation and concept design of the product before the realization and the actual design phase. During the design phase, the product is designed, built, verified, and tested before the new product launch. Lifecycle phases of valves are seen as growth, maturity and decline phases. During decline phase it must be decided whether to update the existing product or to create new one, which means the obsoleting of the old version. However, valves are rarely obsoleted because of they have long lifecycles and customers might want old versions even if there is newer version in the market. Based on the interviews, it can be said that the length of product lifecycles are not determined beforehand during the early phase. Nevertheless, valves have typically a long lifecycle which means 30-40 years and they are supported by selling maintenance and repair work to customers. From the sales and marketing point of view, it is difficult to predict how long the product will be profitable and how long it has marketing potential. The new PLM should have a feature to help to predict product's supposed lifecycle length and including the sales aspect. In addition, project portfolio management is not covered in current systems. Product lifecycle planning and especially R&D projects should be figured somehow to have a clear perspective in which lifecycle phase a certain product is. This means that active product, outdated active product and new R&D projects should be visible, presented on timeline. Currently the case company have started to prepare new product launches but in fact, they should have been started a bit earlier. Project portfolio view would give a transparent perception of company's products phases and an information when to start preparing a new product design. The new design requires not only new design and manufacturing but also a new supply chain. All these kinds of factors must be considered when starting a new R&D project and that is why predictability is necessary to make it at the right time.

3.3.4 Processes and tools

Company's product management related tools and integration between them are covered in this chapter. Relations between different systems used are presented in Figure 15. This thesis focuses mainly on the PDM, typecode and CPQ applications, therefore ERP is only presented on general level to formulate a general view of commonly used systems. Proceeding from the left to right, firstly when the customer order has become, CPQ handles the incoming order. In the case of configurable valve, the product is configured in the CPQ according to customer's requirements and needs. Each valve series product has typecode document related to it. This document includes all the technical variations for the valve as the previously presented Figure 13 shows. Configuration rules are defined and structured in excel and each valve series has its own excel. Some of these excels can be very large, including hundreds of columns and many thousands of rows, which are plainly very prone to mistakes, and they are not easy to maintain. Typecode information is also in PDM system because all the technical options are also in PDM. Configurations has earlier made in PDM and nowadays it is done in CPQ for most of the products. An ideal situation is that all the configuration related operation could be in one PLM system to have consistency with requirements, to ensure accuracy of meeting targets and maintain performance throughout the product's whole lifecycle. However, it is long-term target and have significant cost impacts. Information between CPQ and PDM is bidirectional. Product data, which is in PDM, proceed from the PDM to ERP, in which the data is enriched. For example, if designer creates a new version of some part or make other changes to the item, the change proceeds to the Aton, but it must be approved by Item data management, before the data updates to the ERP. Furthermore, customer order moves forward from CPQ to ERP, and in case of customer order engineer (COE) product, customer order goes to Aton PDM as well. The ERP is used in production related operations and all the material data and schedule for manufacturing is in there. There are many challenges related to all these systems and the one main challenge is that both systems and people around them are siloed and the information flow is not smooth. The other challenge is that the company has view only for single component, for example valve, and the whole valve-actuator-positioner assembly is not managed. Current PDM system is not suitable for that, which means that PLM system is needed to get people to work around one system and to reach the available data easily. The flow of right data should be ensured with the PLM.

Clearly defined PPM-related targets are not set, however, KPIs are strongly related to the product lifecycle phase in question. In addition, sales related KPIs and targets are set for quantity of sold products and comparison between new and old version sold. Other target is related to schedule for product launch, in which new product version must be released by the specific date. In the ealy phase of product lifecycle, targets are mainly focused on quantities to gain adequate sales volume for the product. On the contrary, during the end of the lifecycle, targets are focusing on cost-effectiveness to try to press all profit out of it. Based on the internal interviews, portfolio balance, strategic and non-strategic balance related targets are not clearly connected to R&D or product management. Renewal of the product portfolio is quite slow in the valve industry, therefore, targets and KPIs must be set taking that viewpoint into account. According to interviews, incorrect decision are made as well by misleading target. Targets and KPIs must be set by taking technical perspectives into account as well without harming financial targets and vice versa. Therefore, target setting must be done as any other PPM related process to endorse the big picture of product portfolio.

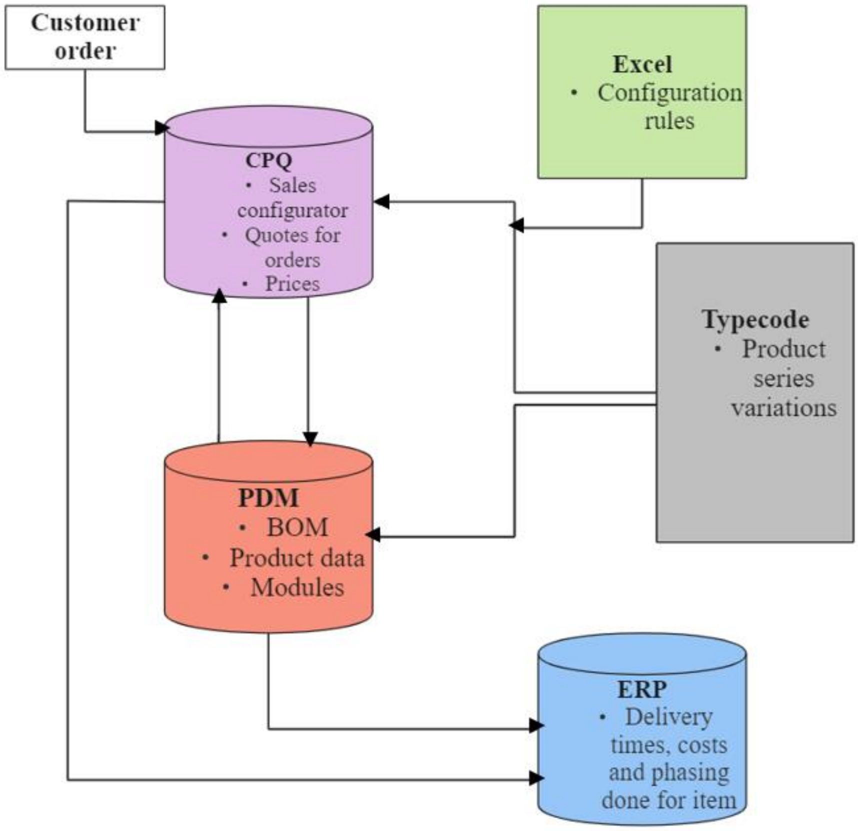


Figure 15. Fundamental systems and relations between them from product management viewpoint.

3.4 Current product data management system

Valmet Flow Control's current product data management system in use is Aton PDM by formerly designated Modultek. Aton PDM has been put to use in 1999 and data was imported already during 1998, which means that Aton has a long history in the case company. The Aton system has been developed through these years; however, the case company has not been updated their version of Aton for years, and therefore all the newest functionalities are not used by the case company. This has led to the situation that the case company must renew their PDM systems. In this chapter, PDM system and its functionalities are familiarized more closely. In addition, to understand the features and shortage of the currents system's features, few different typecodes are examined. In other words, the current PDM system's functions, strengths and weaknesses are reviewed in this chapter. This chapter reveals the requirements of the upcoming PLM system and supports improvement propositions. Aton is used approximately by over 800 employees of Valmet Flow Control Oy. However, most of them use Aton for searching by item codes to find item related CAD drawings and attributes or searching by drawing code to find the specific drawing. Anyway, only a part of the users search by using typecodes. This is a result of a huge amount of different typecodes and only few of them are known by each employee. The designers know the typecodes that they are usually working with, for example, a specific type of valves' typecodes. On the other hand, it refers that typecodes are not in common use in the company. Aton is a typical PDM system in which items and documents are preserved and users can search them. It requires quite of knowledge about products and their typecode rules to be able to find specific products at this moment.

3.4.1 Main functions of current product data management system

Aton PDM has nine different workspaces in the main information window. The most used in the case company are Document, Item and Rules workspaces. A general view of Aton PDM main window is shown in Figure 16. Document workspace includes CAD drawings, 3D models, word documents and engineering change notices (ECN) which are transferred to the document workspace by the creator of the file. Rules workspace is where configuration rules are determined, however, only actuators and positioners are configured in Aton. Configuration of valve products is done in Tacton CPQ with the help of Excel, besides, not all valve products are configurable. Valve configuration used to be in Aton before moving to Tacton CPQ. Rules enable to determine what modules belong to different product series and how the individual product variants are created via configuration. It is possible to form so-called spiderweb of the configurable actuators and positioners modules. Product option would allow to view all levels of the product, but this feature is not applied in the case company and this a significant problem at the moment, because a clear view of product series levels is not available.

Item workspace is probably the most used in the case company's daily work. Item feature refers to the documents, for example, a 3D model is created for axle which is transferred to the Document workspace as a file, which has a specific document code. In addition, CAD drawings have drawing codes as well. After the model and drawing is done, an item is created to the Item workspace, where documents are referenced. In general, product data is searched from the Item side, because the information is easier to find rather than from Document side. Items, modules or configured product structures are able to search through the Item workspace. Item workspace includes tabs which are description, data/user, attributes, relationships, alternative parts, components, permissions, and history. The description tab represents the item in question and its item number, item type, typecode and additional information. Data/user informs the creator and modifier of the item and date of the changes made. Attributes offer technical information about the item such as pressure ratings, materials used, diameters, measures, weight, temperatures, and other values. In addition, it is possible to limit search by defining attributes, for example by setting valve body pressure rating as ASME Class 300 or valve seat type as metal seated. However, this feature is not agile, since there are many attributes available, and the value must be known beforehand. New documents can be created to the relationship tab. History tab shows the user history with date, time, operation made and status of item.

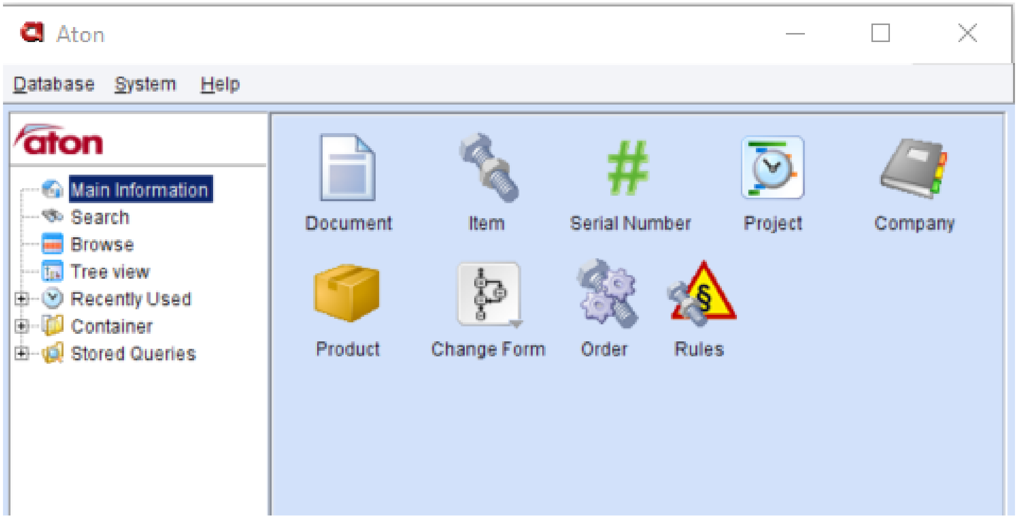


Figure 16. Aton main information window.

3.4.2 Weaknesses of the current product data management system

The case company's version of Aton does not show products as product series, instead they are presented as an individual items and modules. In the other words, there is no view available where, for example, Neles X series modular ball valves are shown, and modules and items related to each X series model is clearly shown. The other general problem in Aton is that it is challenging to know exactly, in which products a certain module is related to. For example, if product manager wants to make changes to the module, it is hard to find out which products the module changes affect. Third challenge relates to the module structure and the part number and part quantity information in the attribute tab, from which the module consists of. The same information is shown in module structure attribute information and in Item structure menu as well. Changes made to the attribute list does not affect to Item structure quantity and part numbering automatically. This adds probability to mistakes with data management; therefore, the same information should not be kept up in several places. The fourth fundamental weakness with current PDM system is that there can be several same items for the same purpose by chance. One example of this kind of situation is related to search features in the PDM. The search features are such weak in the current PDM version, that two separate items are done with exactly similar geometric features, in which other one is older while the other has been created even if the item already exists. Practically it means that vendor notices that new item has been created and it needs a proper tool for manufacturing and therefore the vendor starts to manufacture the item that already exists. In this case, the problem was faced with several valve sizes, which could have led to unnecessary investments and have financial disadvantages. There is the difference to manufacture 10 pieces per year with two similar items and two similar tools or with only one item but 20 pieces per year and with one tool. It is obvious that the latter is more economical. Above challenge is due to lack of effective information retrieval in Aton and result in mistakes. An error-free system is infeasible; however, search features must be enhanced in the future PLM system to avoid these kinds of mistakes. Product series level lifecycle status is not available in the current PDM and therefore predictability of product series renewal is not visible. Currently all this information is in people's heads and all over the place in different excels and other locations. In addition, a clear view of product manager or other responsible person of the valve series should exist. Currently the information about responsible person is in the logging history mainly. There should also be an illustration of the valve available, which can be a 3D model view or a picture of valve. Desired features and functionalities of PLM system are examined more closely in improvement proposition in chapter 4.

3.4.3 Example with specific typecode

Searching a specific product from Aton with typecode gives exactly the desired option, but it requires good know-how of the products. One example of typecode search is presented here. The given example is a butterfly valve with the following typecode LW6KBA200AAJAT. In Figure 17, an example of that specific typecode in Aton is presented by using the typecode. The description view, as rounded in figure, is the main view on the item level. It contains an information about item code, typecode, creation and modifying dates and classification information about the item. Data/user menu points out the information about creator and modifier of the item. Attribute menu includes the detailed data about item's attributes such as size, material, weight, pressure, usage temperature or flow capacity rates. As mentioned before, it is possible to search items through attributes, however, it is challenging and requires very specific knowledge. When using attributes search, the value must be known in advance, because there are not ready options offered automatically and the values must be typed manually. Documents related to the item, such as an assembly drawing or 3D file, can be found under the Relationships menu. Even in this example, the typecode was known in advance, which eased the searching, but this indicates the property of the PDM system being challenging. Currently, even the searching in PDM requires excessively effort from the user, which does not support the case company's future PLM related ambitions and vision.

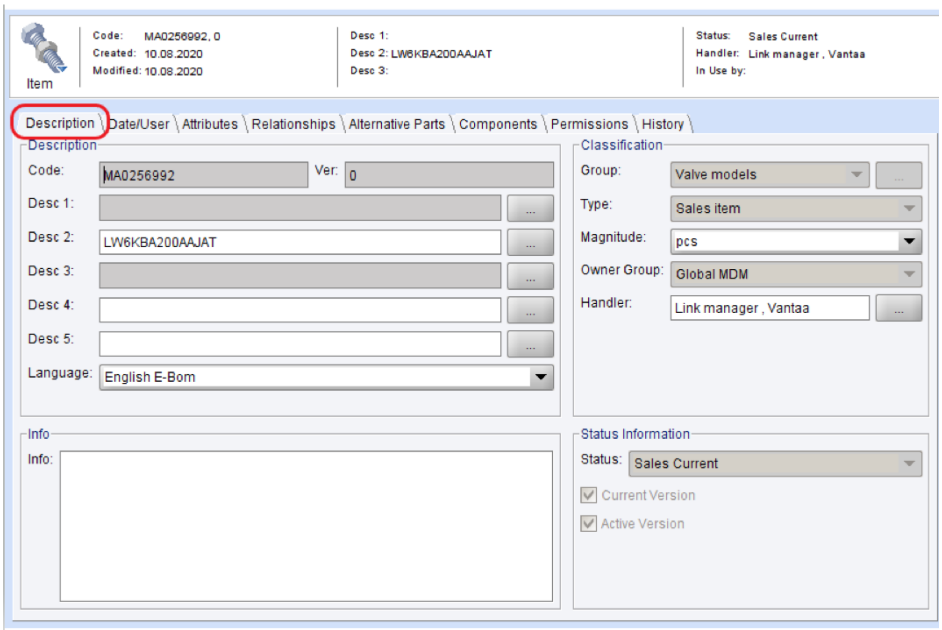


Figure 17. Aton PDM Item workspace with specific typecode.

3.5 Conclusion of current state analysis

Conclusion of the current state analysis part compiles Valmet Flow Control Oy's most considerable development areas from the viewpoint of current PDM system, PPM and PLM practices and the overall current state of the case company. Presented development areas in this part conduct to the next chapter to make improvement propositions. The most prominent development areas in Valmet Flow Control Oy's PLM practices are the following:

- Product management is mainly carried out outside of PDM system by using Excel and other separated tools. Data should be centralized in one PLM system so every authorized user has access to the system to manage products and reach the data easily.

- Modules, items, product series, documents and the whole lifecycle of the product should be managed in one PLM system.
- A tool for tracking PLM phases of products does not exist and there is no clear definition of the whole product lifecycle duration.
- Modularity is not visible in current PDM, and item and design reuse is not applied at the best level. Product configuration is done outside of PDM and there is no both sales and product configurator.
- There is no tool for project portfolio management and therefore no visible predictability of upcoming projects in R&D, product management or sales.
- Traceability and dependencies between product are not visible which lead to product portfolio explosion and overlaps.
- Product series object does not exist in the current PDM which contains all the relevant information about products series.
- Product compliance viewpoint is not managed in the PDM. Product compliance offers critical information about requirements or certificates about the product.

4 IMPROVEMENT PROPOSITIONS

After the literature review and current state analysis are reviewed, the improvement propositions can be formed and presented. The propositions are divided into three different parts on how to deal with existing and new data. Some propositions are examined with demo version of real PLM system environment. The aim of this part is to disclose the main improvement opportunities leaning on the current literature, interviews, and state-of-the-art position around the topic. The state of the art is examined in this chapter to give support for the improvement propositions part and by comparing the as-is status of the case company with state-of-the-art.

4.1 State of the art

State of the art stands for the most recent ideas and methods in the specific field and in this thesis, state of the art is reviewed from the product portfolio management and product lifecycle management viewpoints. State of the art indicates what is known about the theme and what is the most advanced state for now. State of the art is executed by interviewing external companies' representatives and their vision about PPM and PLM in general and related challenges of PPM practices in the company they represent. Case studies and state of the art related articles are also reviewed to gain a holistic understanding of the current state. This chapter focuses mainly on the large global Finnish companies and their applications in the PPM and PLM fields hence Valmet Flow Control is a large global Finnish company as well. The purpose of overviewing the state-of-the-art level is to understand the desirable level of PPM and PLM by comparing the case company's current state to the best practices and see the optimal targets to set. Improvement propositions are aiming to achieve that optimal level. Interviewees are titled as product center director, product manager, PLM solution owner, solution manager and a highly experienced person in the field of product management. Previously presented PLM maturity level matrixes (see chapter 2.2) function as a base for the case company's PPM and PLM related evaluations. The aim is to raise the maturity level from the starting level by using state of the art, literature, and interviews and to compare them to the current state of the company.

4.1.1 State of the art more closely

According to Hayat et al. (2022), one key challenge is that most of the existing PLM systems do not contain all the required features, which leads companies to integrate different softwares together to create full-fledged PLM system, which in turn, leads to overall system efficiency descending. Required features of PLM system are change management, design management, document management, project management, PDM, requirements management, quality and compliance management, and supplier management. The current PDM system in the case company covers only a fraction of those. When it comes to PLM system, data should be transparent and auditable, and every stakeholder should have an access and permission to make changes to data in it. However, permission to make changes can be limited so that the critical data will not change by accident. Haya et al. propose a blockchain-based innovative solution, which is a digital and immutable ledger maintained by different computer nodes that leads the process of recording transactions and tracking assets in a business network. The blockchain solution increases the overall system efficiency as well and provides secure and connected infrastructure for data management, processing, and storage at different stages of the product lifecycle. All the data is visible and accessible to every stakeholder around the product which provided a collaborative decision-making environment in product development. (Hayat et al., 2022).

Kulkarni et al. 2021 emphasize that globalization, eco friendship, energy economy and cost efficiency are the key aspects that must be considered when setting a PLM system. It is necessary to understand which are the operations, who is operating and how are they operating in the company. One of the steps in establishing and implementing PLM is to know the as – is maturity model and develop the model to suite the as – is model. (Kulkarni et al., 2021). Silva dos Santos et al. (2020) enlist following necessary steps when implementing PLM system in the company: drive the goal of 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, implement software solution, and train employees. However, implementation of PLM strategy is long-period investment and benefits are visible in the long run. Mustonen & Härkönen (2022) state that companies should seek cost reductions by means of reuse of designs and the standardization of assemblies and components. The one key challenge in reuse of existing designs is that it requires mechanism from a company and to succeed, knowledge and experience of designers is required

According to reference company 1, PPM consists of many factors and levels. The minimum level is the basis of PPM. A company must know, what they are going to do concerning PPM. There are a lot of companies around, that do not know their core act. PDM gives good starting point for managing items. It can be said that if data management and information handling take more time than the manufacturing phase, then PPM is not controlled. This can be a result of a shortage of given information about the product for retailer. As mentioned, the company must know what they are doing, and it is a minimum level to achieve a proper PPM level. The next question is how to proceed to next level which requires more actions, and it is a complex process. Based on interviews held during research, the following factors were listed when discussing about PPM: development project management, product platforms, product families, product revisions, product releases, product technology management, product modulation, product configuration, product feedback management and product portfolio models. There is no company that covers all the PPM-related factors and in the case company, only a few of the above are carried out currently. Those factors are product revisions, product releases, product technology management, product modulation and product configuration. In addition, the current processes and tools do not support the company to execute all the mentioned factors properly. Therefore, the management of the previous factors is not centralized to one system and the data related to them are mainly copied and transferred from one place to another.

It was emphasized that PPM should meet the company's challenges which require the company to identify its challenges. For example, technology management refers to that a company must find the key technologies to focus on. According to internal interviews held in Valmet Flow Control, that technology is related to valve sealing and its improvement. Product platforms are essential in PPM, it defines what are the products, how are they related to each other, what platforms there are and what products are in them. However, this requires a common understanding about product platform. Product portfolio covers products that are planned to do, what are produced now and what have been produced, which means delivered products. By understanding PLM, it is possible to manage the product from an idea to the maintenance and disposal of the product. Difference between configurable product portfolio management and other products is seen clear. Configurable products' portfolio management requires product platforms, which defines what is done. A clear product portfolio platform and model is precondition for complete PPM. In general, it can be pointed out that companies that have deployed PLM system and practices, have always improved their product management, data availability and communication within an organization.

In the reference company 2, there have been created data instances which are divided in to engineering and design base, configuration, and maintenance environments. The following instances include a huge mass of data and users around them. As for data management, reference company also utilize data platforms and configurations as mentioned. Developed components and product platforms by R&D are created by gathering these components. In reference company 3, products can be divided into capital, services, and consumables product organization structures. Capital standard products can be divided into several lower-level products which have its own service and consume side product offering. Capital standard products have their own configurations, and they are kept up with product updates, which affects to product specification and structure. It can be said that only the name of the product remains the same from the beginning of the lifecycle to the end of it. Several product updates occur during the first year of the product's lifecycle, which can be related to safety, supply chain or material availability and they are effective only for a certain period. When it is a question of standard product, it stands for the product that does not require tailoring to manufacture it. The product can be sold by predetermined configurations without separate engineering. The product portfolio is strictly defined, whereas product specification from the sales viewpoint is problematic. From the product management viewpoint, it is essential to get everyone around the same systems and perform tasks in the same way. Configuration happens in the separate system, apart from the PLM system, which means that there are a lot of documentation outside of the PLM. In addition, there is no integration between sales system called Saleshub and PLM system, as sales and marketing perform their tasks mainly in the Saleshub. With the help of PLM system, challenges are detected more easily, pictures of products are shared, product offering have grown, maturity matrix was created and change management features have gathered people around the common PLM system, even the marketing, which have had its own tools. Minimum level for maturity is predefined and development paths lead what is done on the product level. With minor changes to the product, it is gained an improvement to sales revenue as well. One aspect for product manager was that there should be two or more product managers for the product. For example, service should have its own and supply chain part its own, so the ownership or governance of the product would be divided among several people in the different lifecycle phases. This prevents the information to be dependent on one employee only.

4.1.2 Difference between state of the art and the case company as-is status

This chapter compares the case company current state to state-of-the-art in PPM and PLM. The chapter also compares the difference in which level the case company is operating and what is the level to strive for. Required features for PLM were listed in the previous chapter and all the features are managed in different places in the case company because there is no single and centralized PLM system. It was also emphasized that by understanding PLM, it is possible to manage the product from the idea to the disposal of the product, however, the case company has mainly focused on the early stages of the product lifecycle and not on the removal of products from the portfolio. The other essential factor is that it is important to get all people to do the same way from the product management viewpoint. That is why a PLM system is necessary to achieve that target. A maturity matrix was used in one interviewee company and the minimum level of every state was defined. After defining the maturity level, a development path was created. In the case company, the maturity level was not assessed and defined before. The governance of the specific type of product is typically done by one product manager regardless of the lifecycle phase. The blockchain-based platform was introduced previously by the literature to meet all the requirements and features in a single system. This platform is not applied in the case company. However, the same article illustrated several PLM softwares and their features. In the case company, future PLM software is under assessment, and improvement propositions are presented by using that software later in this chapter. The PLM system in question is one that has all required feature that company need. An essential case was revealed during the interviews. Product management was carried out on the product level in the reference companies, whereas in the case company, management of products was based on item management. Individual parts and documents are managed in the current PDM system and not the whole product series. Furthermore, the existing PDM system emphasizes assembly drawings, and serves primarily as data repository, rather than utilizing the data.

4.2 Overview of improvement propositions

The fourth part of the research presents improvement propositions of PPM for CTO products by means of PLM in the case company. Improvement propositions are based on the literature review addressed and the most prominent development areas are discovered in the current state analysis. As mentioned before, the thesis considers configurable valve products in the Valmet Flow Control Oy, therefore, improvement propositions and examples are presented in respect to that. Interviews, both internal and external, act as an essential source of information for current state analysis and in that way for improvement propositions. The improvement propositions made in this thesis, correspond to two main RQs (presented in Chapter 1.3) as well. Future PLM system decisions are not made during the research work. However, all the PLM system-related proposals are based on the test version of PLM system, which is under assessment in the company. The aim of this chapter is to provide propositions to achieve a stronger understanding and visibility of PPM and PLM in the case company.

Improvement propositions can be distributed into three main areas:

1. Visibility of the data
2. Traceability of the data
3. Utilization of the data

The first area concentrates on the visibility of the data and how to adduce the data. In addition, this part contains product series objects which include modules, product series documents and product lifecycle phases related improvement proposition. The second area represents the traceability viewpoint, to understand dependencies between products and what modules are common on the product series level. The third are includes utilization of the data and to be able to do that, the first two parts must be perceived properly. The purpose is to understand item and design reuse ability, better specification of configuration, and take advantage of lifecycle-related information in different stages of the product lifecycle. The three main parts are closely interrelated and proceed in chronological order. To make propositions more concrete, the required features are demonstrated in the future PLM system.

4.3 Visibility – Bring the data into sight

In this part, vertical and horizontal product portfolios (see literature, chapters 2.2.2 & 2.3.4) are in a central role to understand the whole product portfolio and product structures. A horizontal product portfolio brings the product lifecycle viewpoint. Both vertical and horizontal portfolios are presented here and explained, how to indicate them in the new PLM system. In addition, the product series -level is in a crucial role when perceiving the product portfolio. Product series is located at a high level of product offering hierarchy in each product types. Each product series steer main features of products under the certain series. Product series specifies, what kind of features these products have and what makes them special. Therefore, the product series -level must be more observable in the case company's everyday operations and visible in the PLM system. In the current PDM system version, all the products under the product series cannot be viewed at a time. Each product series have its own typecode document, which defines the available variables of that certain product series. However, these typecodes are currently separately from PDM and other common softwares. Typecodes documents are in an internal web location, and they are also maintained in there. Technical bulletin and installation, maintenance and operating instructions are currently outside of PDM as well. These kind of product series related documents should be attached with the certain product series in PLM system. This allows to all internal stakeholders and product-associated people to achieve benefits of common PLM in the case company. The benefits are easy access to common documents by any stakeholder such as marketing, sales or other stakeholders who uses product-related commercial material. In addition, stakeholders that are not that familiar with typecodes, benefits from typecode documents, which offers critical information about product series. Therefore, the documents are easily available. Product series consist of different kind of modules, and depending on the series type, modules can vary. In addition, different valve series types can share the same modules, however, it is impossible to trace reliably in the current PDM system. In other words, valve module types are not properly visible in the current PDM, for example, a view of specific product series and modules related to it, is not possible to view. The other way around, a certain module and valve series related to it is also infeasible to see. The main point in any kind of PLM system is that all the visible data is relevant, because excessive information leads to confusion, and relevant data get lost in a huge volume of information. PLM users have various intents and demands when it comes to the PLM system. Therefore, all the data and information within the PLM must be informative and explicit in order to serve different kinds of users. Features described in this chapter are examined with PLM system more closely later in this part.

4.3.1 Vertical product portfolio and product structure

According to Tolonen et al. (2014 & 2015), product portfolio can be presented in a horizontal and vertical directions. When it comes to CTO product, it is essential to have a product structure that supports configurable products' variations. The product structure model proposed for the case company is in Figure 18. It is a base for the product structure in the PLM system. When product series are figured as a hierarchical model, it is apparently more efficient and clear way to manage the whole product portfolio in the company. Moreover, more benefits are reached by visualizing the product structure in the PLM software for user. When the product portfolio is concerned from both vertical and horizontal directions, the PPM is comprehensive, and it not only focus on single product or the early phase of the focus. By understanding the product portfolio in its entirety, it can be managed thoroughly, and the ownership of sub-portfolios can be defined as well.

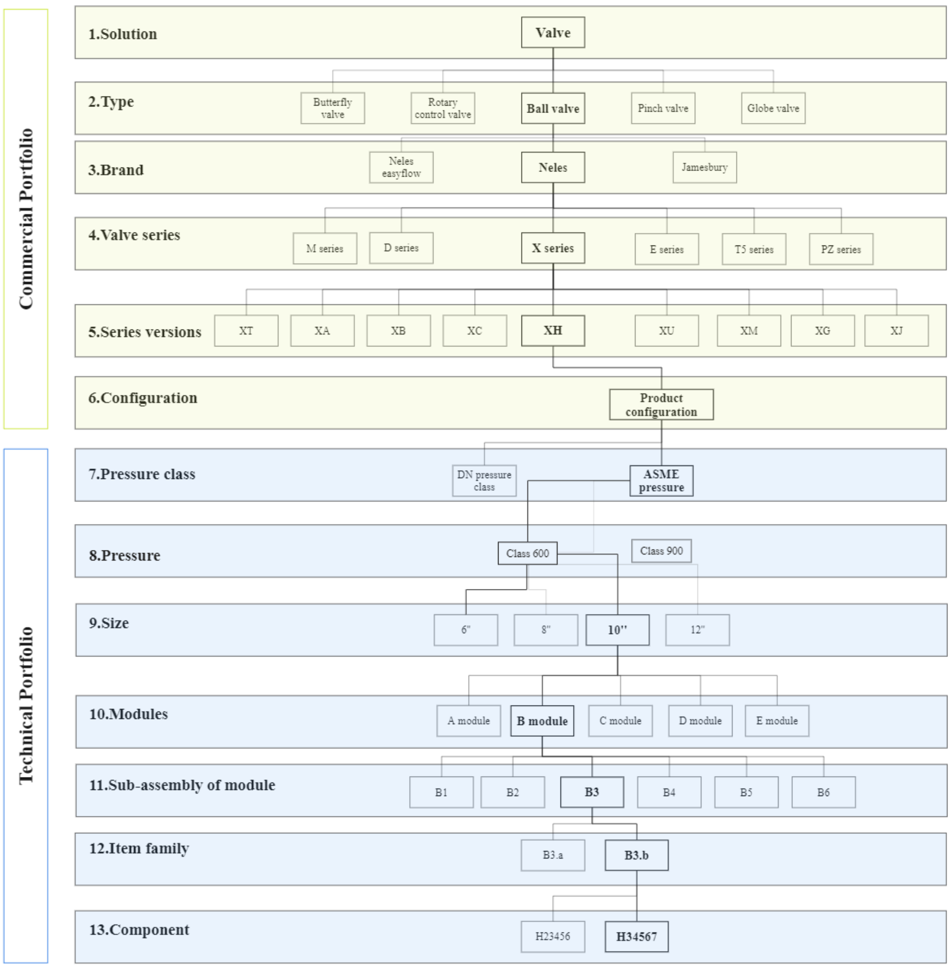


Figure 18. Proposed product structure model for valve.

The suggested product structure model consists of 13 different levels in which the first six levels from the top are commercial portfolio and the rest seven levels are technical portfolio. The model has been structured based on typecode documents, sales configurator, product part lists and the model presented earlier in the literature (Tolonen et al. 2015). Commercial portfolio includes solution, product type, brand, series, series versions and configuration levels and it is mainly a tool for sales. In this thesis, the solution is considered as valve. Type level describes the valve by its type. The next selection is brand, which is essential for customers and for the company as well. Under each type and brand, there are different valve series and series versions. Valve types have different kinds of characteristic features, anyway, they also have common features. Usually, a valve type selection depends on the application it is used in and customer's industry. In the valve industry, customers know different brands for their good reputation and therefore the brand level is on the high.

The technical portfolio is the viewpoint of R&D and production. It consists of pressure class, valve size, modules and sub-assembly modules, item family, and component levels. Technical portfolio includes modules that are characteristic for each valve series, however, the same modules can be applied to different valves as well and this is one improvement target to recognize these kinds of opportunities. The modules consist of sub-assemblies and components. Both pressure class and the size are directive factors in valve selection. The lowest level is the component level which is the smallest part of the whole product.

4.3.2 Horizontal product portfolio and product lifecycles

It is essential to manage both vertical and horizontal product portfolios to reach the maximal benefits of PPM. PLM brings transparency to products and more effective product management in its entirety. Product lifecycle phases are not managed on product level in the case company, but only on the single item level. Figure 19 presents proposed model of product lifecycle phases. Suggested product lifecycle phases are on the product series level and should emerge from the future PLM software. Product lifecycle phases are managed by product managers, and it shows the way of R&D projects and how to maintain products and when to update or obsolete them. In addition, lifecycle phases instruct sales, services, marketing, production, and logistics to operate in a particular way. Product lifecycle phases address all stakeholders regarding what products are under development, in active and service sales, and what products are ramped down and finally obsoleted. Product lifecycle phases' lengths are not predefined and therefore they are not visible in any system. Valves have quite long lifecycles, and they are rarely obsoleted. In this suggestion, product lifecycle phases are defined, and approximated length is defined as well. However, the focus of this proposal is on the lifecycle phases and what they encase. The proposed horizontal model is based on product managers' interviews and Tolonen et al. (2015,2016) research. New product development phase starts with input given from product management team. The input can also be based on feedback from the sales or customers; however, product management make the last decision about starting new product development. Before the realization of the product, ideation, and concept design must be done. After the concept design, an actual development phase starts, in which the product is designed, tested, verified, and manufactured. In the end, the product is ready for the product launch from where it goes to the markets and customers. When the product is launched, maintain phase has started. During that phase, ramp-up, sales, delivery and ramp-down are executed. After sales phase follows maintain phase in the lifecycle, in which maintenance, repair and operations (MRO) and service are handled. When proceeding to decline phase, the decision about product continuity must be done. The one option is to make product updates, which means the development of the existing product. The other option is to obsolete the product, which means the end of the lifecycle and no sales are carried out during that phase. Based on the internal interviews, approximate lifecycle length of the valve is from 30 to 40 years, however, it can be longer or significantly shorter as well. As mentioned before, customers want the exact product after 40 years and do not want the latest version of the valve in some cases. The case company do not want to let the customers to ask substitutive valves from the competitor's side. Therefore, valves are obsoleted very rarely, and they remain in the after sales -phase a quite long period of time.

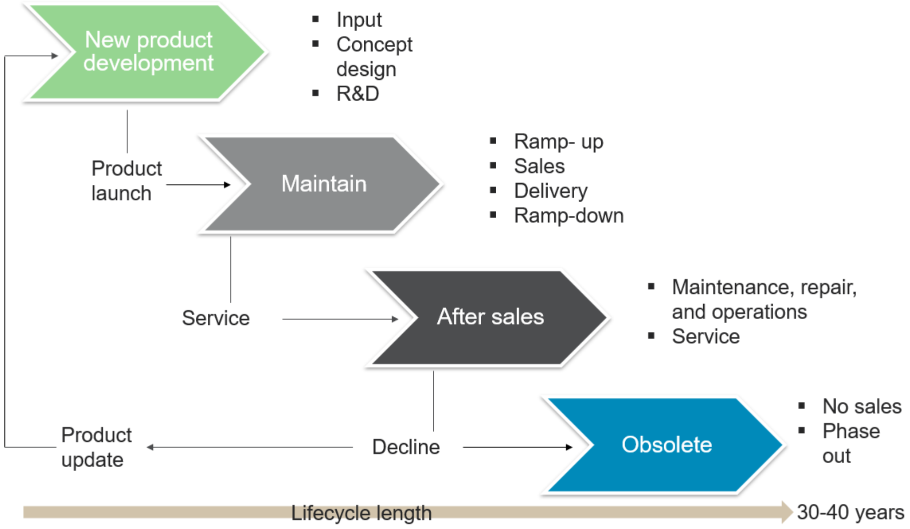


Figure 19. Proposed horizontal product portfolio, product lifecycle phases.

4.3.3 Demo in PLM system

PLM demo version is built by PLM architect and figures showed in this part are from the specific PLM system. However, all the suggestions and modifications on top of demo version are made by the thesis author. The PLM acts as a platform for improvement propositions and it provides visual view of PLM implementation. To figure all desired PLM features, some of suggestions are visualized outside the system. The PLM system contents can be divided into different sections such as Change management, Design, Documents, Portfolio, Process, Sourcing and Variant management. In the examples of this thesis, Design section is used mostly, which includes parts and series groups. Parts group is similar to Item group in Aton PDM. Series group would be a new feature in the case company; however, valves are understood as valve series and this feature supports that. In this thesis, PLM is mostly considered from the series point of view.

Figure 20 shows a proposition of different kind of product series in the future PLM system. It must be taken into account that normally the" Ball valve" dropdown menu would open the series under the menu, however, to save space, X series is located on the right side of the figure. The classification column indicates the product type, which can be a valve, actuator, or valve controller. This thesis still focuses on the valve series group. In the valve group, detailed product type indicates the valve type, which can be a ball, butterfly, rotary control, pinch, or gate valve. Under the ball valve menu, all ball valve series types are shown. The XH series is examined more closely, as in previous examples. In the horizontal direction, the series number indicates the given number of the product series. The description column describes the product more closely, such as the valve type, series type and construction of it. One important column is the brand column, which points out the brand of the valve and is in a central role when considering valves. In addition, the brand is important from the customer point of view as well. Revision column indicates how many revisions have been made for a certain product series. The phase column indicates the lifecycle status of the product series. For example, if the XH ball valve series is under development, the state would be ”Development” from where it proceeds to “Maintain” phase and finally to ”After sales” and ”Obsolete”. The following phases are according to the phases presented in Figure 19 and they are based on literature review. In addition, modules and items have their own lifecycles as well and the names of the phases are the same as with product series. The XH series can be selected by clicking the row and next part will explain more closely, what a certain valve series encases.

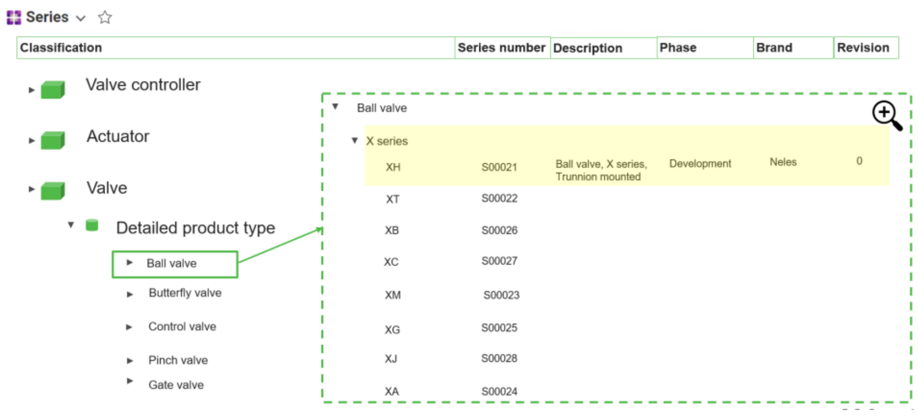


Figure 20. Proposed view of series level on the PLM system.

Next, a proposition of XH series level view is conceived. The Figure 21 shows a proposed perspective of how certain product series should be presented in the PLM system. To proceed from the left to right, the first section includes close to the same information as the previous Figure 20. The first section from left is to bring forth the most essential information of the valve series. ”Info” is free text box in which the product can be described more closely. The next section includes an information about valve’s technical data. It also includes partly the same information as the ”Series” level view. Difference is that it also contains information about available ASME pressure classes and the size range. To make valve series search easier and more effective, it is suggested that ASME pressure class and size range columns are defined as well. Both pressure class and size of the valve are in critical part when choosing the right valve for certain application, therefore, these attributes are seen as crucial. This section is important; however, it is more detailed information and not all PLM users need it daily and therefore it is in a different section. The third section includes the information about the governance of the valve series. The ”Product manager” stands for the daily owner of the product, and there can be several of them. Product manager is responsible for the lifecycle of the product series and is the main contact of product management-related cases. It helps the user to find the responsible of the certain series and reach the person or the department. The last section ”Preview” includes a 3D model figure of the XH valve. Visualization of the product gives the user a real experience around the product, and it also gives the system a more professional appearance. As Figure 21 shows, a valve series includes a lower menu as well. It includes modules, breakdown structure, document, main dimensions, compliance, variability item, configured item and fixed BOMs options. The following options are presented more closely in the Traceability chapter. The main idea of this proposition is to make product series level object visible to all stakeholders in the case company. The future PLM system must serve everyone and be easily accessible to avoid silo-thinking between different stakeholders in different departments and countries.

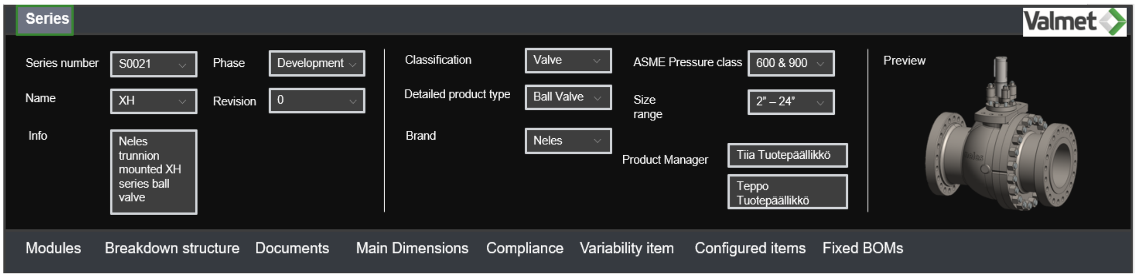


Figure 21. Proposed series level object of XH series ball valve.

4.4 Traceability – Understand dependencies between the products

This part focuses on the traceability of the existing data in the future PLM system. After the data is visualized and structured, it should be applicable for different product management purposes and offer relevant information for all stakeholders. In that way, the data should be easily discovered and applied. In the current PDM system, traceability of different modules and product series is challenging or even impossible. Tracing the relevant data in PDM requires extensive knowledge of products and therefore it does not serve most of the internal stakeholders and causes errors. Furthermore, lack of visibility and traceability of existing data in current PDM system can lead to ignorance and overlaps in product development, which leads to excessive expenses in the case company.

Transparency of modules and product series in the future PLM system gives possible cost savings and it saves time in a daily work. A fundamental question is about different product series and common modules between them and how to discover that information. A view of specific module and all series that uses it is a crucial information when it comes to traceability of data. In addition, information about modules used in a certain product series gives essential information about that product series. During the product's lifecycle, it will meet several changes and updates. Therefore, when proceeding from one product lifecycle phase to another, it is important to know all affected modules, parts, and other factors. Dependencies and differences between different product series and modules is necessary to identify and take into account. Holistic product management through the whole lifecycle is achievable by applying the PLM system.

4.4.1 Product series level traceability

According to Figure 22, valve series XH includes different kinds of additional information related to it. Firstly, Modules-menu is looked more closely. There are all available modules for that certain valve series. The number column indicates the number of certain module and is one way to sort out different modules. Revision column tells the quantity of revisions done for the modules. The name column describes the name of the module and tells what kind of module is in question. Usage condition column describes the conditions of the module. For example, SM0001847 module is applicable only if valve size is DN100, NPS4 or NPS6. These conditions must be entered for each module. Condition defines what modules are applicable in which valve application. Apart from present PDM system, PLM shows all the modules for the product series and there can be hundreds of modules for one product series. As mentioned before, modules have their own lifecycle phases as well, such as maintain phase as in figure below. The modules menu allows to view all affected modules if any changes are done on the XH series level.

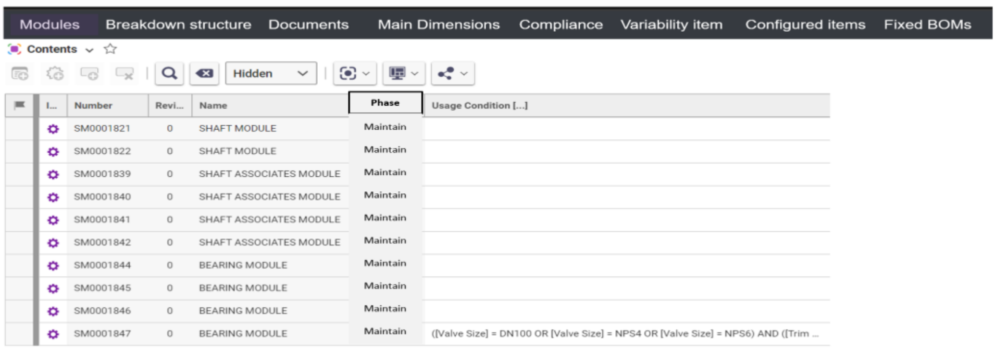


Figure 22. Modules menu on the product series level.

From the breakdown structure menu, the whole structure of the product series can be viewed, including the structures of modules. Figure 23 shows a proposition how module's structure would be in the PLM. Phase of each module and part is visible as well as revision number. A shaft module consists of the shaft and round bar, which is machined in the manufacturing for the ready shaft module for the valve. Documents-menu includes all the related documents according to XH valve series. The document types are typecode documents, installation, maintenance, and operating instructions (IMO) and technical bulleting document. All the documents are relevant and essential for the product, and they must be easily accessible. Documents are in crucial part of product portfolio and the product lifecycle. Each document has its own document number, revision number and lifecycle phase. In addition, the information about the creation and modifications made for a single file is left visible. This functionality is important when it comes to the traceability of information in one centralized PLM system. Figure 24 shows how the following documents are gathered under the valve series.

Modules | Breakdown structure | Documents | Main Dimensions | Compliance | Variability item | Configured items | Fixed BOMs

Number	Revision	Name	Phase	Quantity
SM0001821	0	SHAFT MODULE	Preliminary	1
1172880	0	SHAFT	Preliminary	1
203616	0	ROUND BAR	Preliminary	1

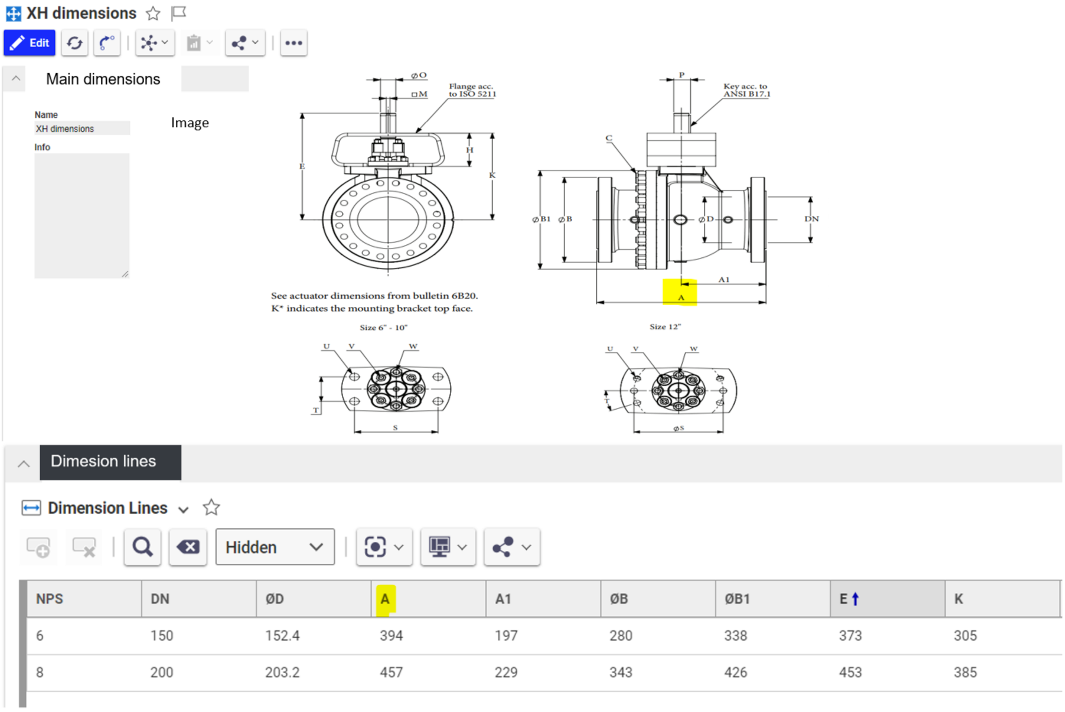
Figure 23. Breakdown structure menu and module.

Modules | Breakdown structure | Documents | Main Dimensions | Compliance | Variability item | Configured items | Fixed BOMs

Document N...	Revi...	Name	Created ...	State	Authoring Tool	Created by	Modified by
41387025	0	IMO-xh-en.pdf	5/4/2023...	Preliminary	PDF	Kiia Kokko	Kiia Kokko
43572591	0	fc-s389-4858-en.pdf	5/4/2023...	Preliminary	PDF	Kiia Kokko	Kiia Kokko
46318097	0	Technicalbulletin-xh-en.pdf	5/4/2023...	Preliminary	PDF	Kiia Kokko	Kiia Kokko

Figure 24. Documents related to XH series valve.

Main dimensions menu includes the main dimensions of used for installation, maintenance, and operating instructions of valve series in question. All dimensions are marked with alphabetical symbols, which can be found from the attached picture as well, to be able to view the dimensions easier. All dimensions are dependent on the valve size class, which means that from example, dimension ”A” can be 394mm or 457mm depending on the size of the valve. In the Figure 25, there are two sizes, NPS 6 and NPS 8, in which NPS stands for Nominal Pipe Size standard size for pipes.



NPS	DN	ØD	A	A1	ØB	ØB1	E	K
6	150	152.4	394	197	280	338	373	305
8	200	203.2	457	229	343	426	453	385

Figure 25. Main dimensions of XH valve with image.

Product compliance consist of marketing area and end user requirements, standards, application (including sizing or materials), product qualifications and application approvals. Product compliance is what product must meet to ensure that it is compliant with regulations. Compliance menu includes all the compliance-related information about the product. It would include information about required certifications and standards concerning that specific valve series. Standards and certifications are related to design, testing, quality, emission, fire safe or ATEX directive, which refers to safety requirements for equipment used in explosive environment. Product compliance must be in future PLM system to be able to find it from the single source system. The PLM system brings the product compliance and qualifications capabilities into one system, to match customers, local sales area, and other regulatory requirements and to manage them in one system.

PLM system includes configurator as well. In the case company, the configurator in future PLM will only be applied to valve controllers and actuators, not for valves. Configuration of valves will remain in currently used Tacton CPQ. However, the configuration feature is introduced in this chapter. As in the main product series level in Figure 21, variability item refers to the XH valve’s ability to be variable. Features can be, for example, valve series, valve size, flow direction or trunnion plate material. On the item level, variability items are trim, seat, valve body, stem, bearing, gasket, flange et cetera. The idea of variability items is to show if the valve is a configurable valve and what items, and features are configurable. Options of different features come from the configuration rules made in PLM. The selection of valve should be easy to make. If a certain size is selected, then all other size-related features should be dependent on the selection and all impossible options should be automatically unselected to not to make mistakes in valve selection. The menu option Configured items, in Figure 21, includes all the part-level valves that are already configured and attached under the certain valve series type. A view of all valves under certain valve series type is essential for viewing, tracing, and utilizing the data in the PLM. The PLM system offers a potential to have a holistic view of all products, items, and variants of different valve series. The last menu option, Fixed BOMs menu includes all the fixed options of single valves under the certain valve series object. Fixed BOM stands for not configured valves but manually structured ones.

4.4.2 Part level traceability

Previous chapter dealt with valve series level traceability, whereas, in this chapter, part level traceability is addressed. Figure 26 shows an example of one body module used in XH valve. From the dropdown menu, it is possible to select ”Where used” to see all the valve series that can apply this specific module with item number SM0002363. This view gives information about the affected product series if changes are done for the module and is therefore necessary feature in the PLM. Due to the demo version of the PLM system, current product series in the Figure 26 are set for the test purposes. However, it shows how the series in question appear. The other crucial information is where a certain valve series is used.

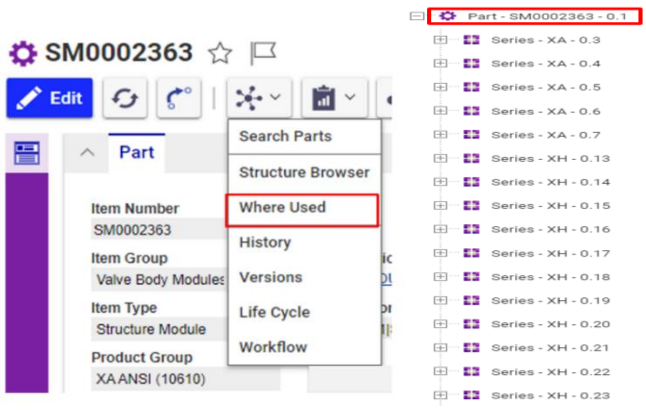


Figure 26. Example of body module and where it is used.

Figure 27 shows an example of XH ball valve on the series level and associated valves. For example, if product management is planning to make product update or lifecycle related changes on XH series valves, this information about affected valves and their quantity is necessary. Where used -function in the PLM is beneficial when tracing the data and finding dependencies between different products in the product portfolio.

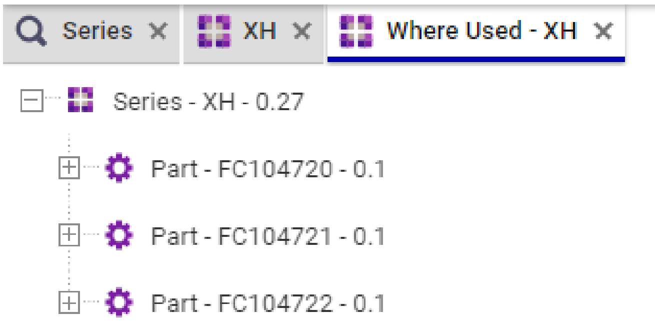


Figure 27. XH series ball valves and associated valves.

Figure 28 shows a specific type of item which is used in following parts, which are different kind of valves. If part H073236 is planned to be obsoleted in someday, here can be seen all the affected valves. In addition, the same part can be applied in the future designs as well. The term "part" in the used PLM system refers to item or single product such as valve.

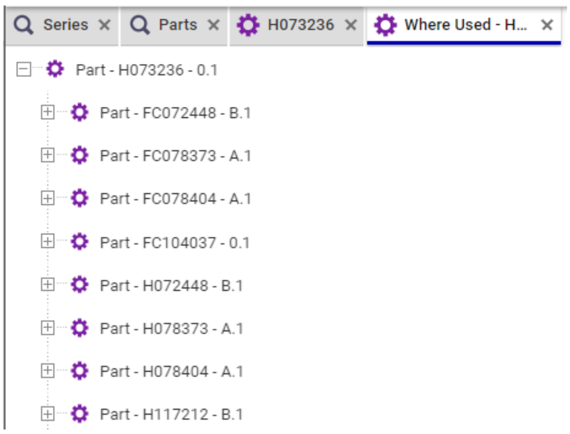


Figure 28. A specific item used in several different valves.

Figure 29 shows an example of XH series ball valve on the parts level. Part level gives more detailed information about the product rather than series level. Typecode is presented as well as picture of that certain valve to offer more information about the product. This feature is especially great because it gives clear understanding of the product, and no special knowledge is needed to trace products in the PLM. Part level includes very detailed technical information, which is divided into different groups of parts. Trim, body, seat, flange, stem, bearing, and other parts related detailed information is presented, such as material and size. As in series level (see Figure 21), the lower menu should contain Compliance menu, which shows all the requirements according to this specific valve. BOM and BOM structure are included to the lower menu as well. BOM indicates the whole structure of a single valve. BOM structure shows modules and what each module encases. Product-related documents, CAD documents, and Engineering Change Order (ECO) documents are also attached under part level. The difference between series and part is that part level refers to specific valve and therefore includes more detailed information than series. However, series offers comprehensive information about product series and related modules. When the whole product portfolio of a company must be managed, the series level is especially suitable for that. When it comes to revision, all the previous versions and information related to them are available in the PLM. In addition, Item history shows all the changes made for the part and the type of action is defined. Detail about edit maker and date remains in the item history as well.

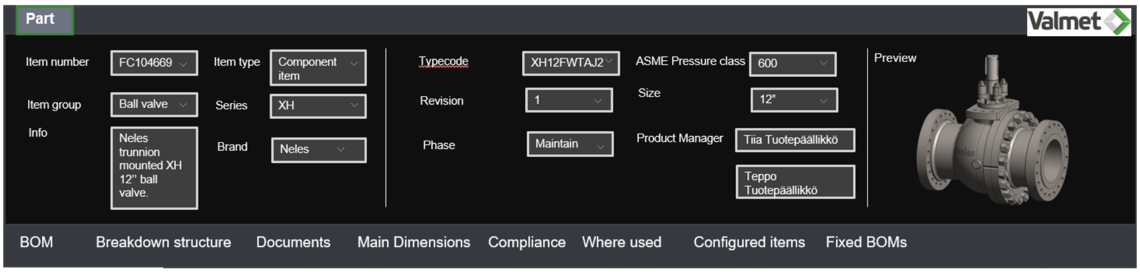


Figure 29. Proposed part level view of XH series ball valve.

4.4.3 Lifecycle phase in PLM

Proposed horizontal product portfolio was presented earlier in this chapter. The same proposal is presented in here, however, it is adjusted for the future PLM system. Lifecycle status of the part, product or product series can be viewed from the previously mentioned dropdown-menu in Figure 26. The suggestion is that the chart would figure the whole lifecycle of the selected item as in Figure 30. For example, if new valve series is being released, the current lifecycle phase is on the new product development (NPD) phase, briefly “Development”. The proposition is that bolded circle points out the lifecycle status in the chart. From the after sales phase, the product can proceed either to obsolete phase or to product update and NPD phase again. The decision about lifecycle changes is made by product manager. However, product's lifecycle should be defined beforehand and decisions about changes are done based on the product portfolio and product lifecycle plan. When the decision about obsoleting the product comes, the lifecycle status is changed through the PLM system in use. Below the PLM chart, the expected length of each phase can be defined in the PLM system. The period of each phase is predefined by the product management team. The lifecycle phase tracking tool enables different stakeholders to forecast the product's status in the future. For example, by anticipating a product's lifecycle, new product development and product launch can be commenced precisely right time. In addition, the information about lifecycle decreases overlaps and mistakes in design, production, logistics, and in every division by providing crucial information about how to proceed with the product.

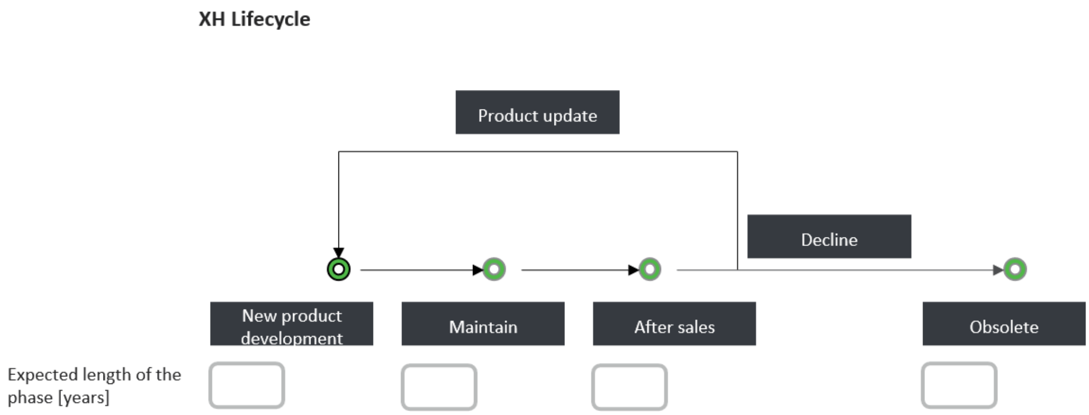


Figure 30. Proposition of product lifecycle phases in the PLM.

4.5 Data utilization – How new data can be utilized wisely?

This chapter focuses on how to utilize new data wisely. Previous chapters introduced how to bring the data visible and how it can be traced in the PLM. Data utilization can be divided into three smaller improvement proposition entities. The first one describes how to reutilize existing items and design, in the other words, how item and design reuse is made possible and how it should be carried out. Currently, the configuration of valve products is executed in separate CPQ system. The second part suggests how both product structure configuration and sales configuration should be executed to obtain easier specification of product configuration. In order to achieve the best possible benefit of lifecycle data in different areas in the case company, exploitation of that data should be examined more closely. The third part focuses on product lifecycle data in R&D project planning, product management, and sales. In addition, ownership of the product in different lifecycle phases is taken into account as well. Data utilization in future PLM allows organization to share information related to products. Future PLM should be applied consistently despite of the business type, geographical location, or other difference factor. The idea is to integrate the operations around the products and to get rid of silo-thinking.

State of the art level could be achieved by utilizing the existing and new data wisely, but it also requires the eco friendship and energy economy viewpoint to be considered (Kulkarni et al., 2021). In addition, to succeed in achieving state of the art level in the case company, necessary steps should be done when implementing PLM system. Silva dos Santos et al. (2020) enlist actions that should be done to succeed in implementation process. One example is to identify company maturity level (as-is-process), specify requirements for system selection, select software solution, define the evolution path, implement software solution, and train employees and key users and keep doing that continuously. The whole state of the art part can be found from chapter 4.1.

4.5.1 Reutilization of existing items and design

Reutilization of existing items and design of the product portfolio is necessary. When aiming to maximize the benefits of PPM to avoid redundant work and to reduce product-related costs by focusing on material costs in the early phase of the product lifecycle. The reuse of designs and standardization of assemblies and components is a way to do that. In order to discover possibilities to reuse items and design, a tool for comparison of existing products, items, and product series must be achievable. However, comparing existing products and their features is very challenging with the current Aton PDM system version in the case company. Browsing of relevant data is made possible in the future PLM. Series and part level analysis is possible by tracking the details of products and dependencies between them. Overlaps in the design phase can be prevented by having a suitable PLM system for PPM to enable the reuse of existing items and design. The view of a specific item and the Where used -function together offer a great advantage to view which valves are dependent on that item. This information helps to observe if the same item can be utilized for future designs as well or if there are two similar items with minor differences, but they could be the same item. A view like that has not been available in the case company. Accessibility of data has been dependent on strong product knowledge. Reuse of existing items and design have an impact on supply chain as well. When the company has a lot of common items used in their products, it naturally decreases the purchasing costs by allowing to order items in greater quantities. In addition, when the design is reused, it is more unified and therefore eases the manufacturing and machining as well by enabling to simplify production streams. From the product management viewpoint, reuse reduces the growth of product portfolio and therefore makes product management more controllable.

4.5.2 Easier specification of product configuration

Currently, the sales configuration is done in a separate configuration system. The purpose is to retain the configuration in the separate system, outside the PLM, in the future as well. However, the visibility of configuration rules should be in the PLM. The idea is to show different modules and how they are associated with the configuration. Configuration works through modules. Figure 31 shows a proposition, how different variations of modules are expressed in the configurator. The example is simplified and defective version to disclose the main point of configuration. On the left side of the figure, product type is selected to be a valve. Under the valve sign, different valve modules are grouped including trim, seat, and valve body. In the middle of figure, modules' technical attributes are defined, and different options are presented. Green borders stand for selections made. When there are multiple options available, the configurator should work consistently, which means that only viable options are left, and all the invalid options are deleted when selecting an option. The selection does not have to happen in any specific order. On the right side of the figure, a configurator creates the summary of the selected options. After the selections are made, by selecting "Resolve" -button, all the possible alternatives of configured products are presented. Consistency between modules and configuration in the PLM system, give user a clear and convenient figure of products. In the current PDM system, modules are not grouped and therefore they are not easily visible. In an ideal situation, there are separate sales and product configurator, however, they should correlate each other. The proposition is that sales configuration is done in current CPQ system, but base of product configurator can be viewed form the PLM.

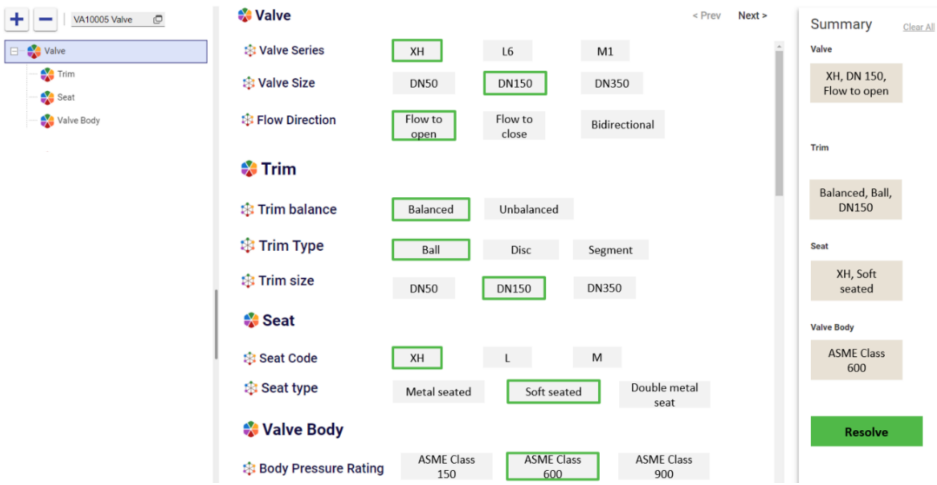


Figure 31. Proposition of product configurator in PLM.

4.5.3 Exploitation of lifecycle data in different areas

This chapter deals with exploitation of lifecycle data in different functions during the product’s lifecycle. These functions in question are R&D project planning, product management and after sales, which stands for maintenance, repair, and operations (MRO) and Services. The ownership of product series in different lifecycle phases should be shared and every phase requires different kind of monitoring. In order to be able to share the data between different functions, a common and one centralized PLM system is needed. In addition, suitable information must be achievable in the system. The PLM system should contain different partitions to offer all functions relevant data they need and in a right form, so that the data can be utilized accordingly. In R&D and product management departments, new products and solutions are developed continuously and existing products are managed during their lifecycle. Generally, R&D focuses on the early phase of lifecycle, including discovery and innovation, new product planning and the introduction of the product.

Figure 30 proposed a way to express the lifecycle timeline in the PLM, by showing expected lengths of each phase. By providing information about lifecycle durations, R&D related planning can be done properly. For example, a certain product series model is designed 30 years ago, and it is predicted to be active for another ten years. However, this is the point where new R&D project should be started, to make it early enough to replace the older design. PLM system should show an updated timeline, whereby product management and R&D teams can make decisions and act according to it. The lifecycle data is most important to the product management team who is responsible of the whole specific product center they have. They have the main responsibility of certain product types during the whole lifecycle. Nevertheless, product management needs support from various stakeholders during the lifecycle and therefore, it is necessary to have a common system that all can apply. During the After-sales phase, MRO and Service have a central role in managing the existing products. Lifecycle data is essential when considering, when to start after-sales actions and how long it should keep on. This gives an opportunity to plan and forecast future sales strategies. In addition, future PLM system not only makes early phase product management possible, but it also enables later lifecycle phase product management. Overall transparency in PLM system creates methods and predictability around the product. Visibility, traceability, and utilization of current data are covered in the future PLM and the useability of the system is considered to be in a central role.

5 RESULTS AND DISCUSSION

The previous chapters comprise the literature of PPM and PLM related challenges and processes, the current state of the case company and improvement propositions made for the company. This chapter introduces the key results and findings discovered in the thesis, discuss about the whole research, and reviews the main RQs of the thesis. The purpose of this chapter is to combine the scope of the thesis.

The main research questions in the thesis are presented below and the results for the questions are addressed after the results are reviewed. This research is constructive research, and it utilizes qualitative research methods by executing a study in the case company. In order to answer to the RQs, current state analysis of the case company was done by interviewing several employees from the company and by attending various meetings. Furthermore, both internal and external materials and documents was used to acquire holistic understanding of current practices and the current challenges in the case company. Daily discussions with supervisor and the key people from the R&D and product management afforded essential information about the details and the big picture as well. The results of the thesis can be divided into three parts according to division of improvement propositions. Next, the key results are reviewed one at a time. Main research questions are the following:

1. How to improve Valmet Flow Control Oy's PPM by means of PLM?
2. What are the expected benefits if Valmet utilizes the latest PPM capabilities in PLM?

The first result is regarding to visibility of the data, which stands for bringing the existing data into sight. In order to bring the data visible, the format of the data should be considered carefully. Product portfolio of the case company is large and therefore it requires appropriate management. The current systems the case company has, do not fully support the idea of portfolio management, therefore, the management has mainly focused on the item level and not on the product or product portfolio level. In addition, items are managed through the PDM system. Vertical and horizontal product portfolios are proposed for the case company PPM in the future. Vertical portfolio considers the product structure levels, which consist of commercial and technical portfolio, totally thirteen levels. Especially in the case of CTO products, product structure plays essential role to support configurable products' variations. Commercial side is mainly considered from the sales viewpoint to manage the strategic value offering for customers. Technical portfolio management analyses and develops modular solutions and structures to gain efficiency in product creation, sourcing, manufacturing and in other operations. Horizontal portfolio includes the product lifecycle perspective, which considers the different lifecycle phases and the length of the phases. The information about product series, product and item level lifecycle phases are proposed to be visible in the future PLM. The PLM system handles the whole product portfolio of the company, and it follows both vertical and horizontal portfolio structures. The key result of the data visibility is the product series object, which was structured to be in the PLM system (see Figure 21). The case company understands their products on series level, but they don't have a proper IT system for that. As the PLM system is aimed to bring to bear in the company, it improves the PLM maturity level of the case company. Maturity level tables were presented earlier (see Tables 1 and 2) in the literature review. In the current state analysis, the maturity assessment was done (see chapter 3.2). The starting level of the PLM maturity in the case company was on level 3, which stands for defined, according to Sääksvuori & Immonen (2008) model. Whereas the maturity is on level 1 according to Helms et al. (2006) model, which stands for silo-oriented PLM. If the data visibility is applied, achievable maturity level within the company will be on the interorganizational level (level 3) according to Helms et al. model, and on the managed and measurable level (level 4) in Sääksvuori & Immonen model. The first one stands for the interorganizational level in which PLM is seen as a business problem that extends through the whole lifecycle including the supply chain. In addition, PLM systems are integrated with suppliers to enable collaboration. Product data across the whole product lifecycle is stored in a central system and therefore it makes the product lifecycle more transparent and enables decision-making about the product. On the second model, the level 4 stands for the level in which IT systems support PLM processes well and processes are under constant improvement and provide bests practices.

The second result is according to the traceability of the data and how to present dependencies between the products in PLM. Traceability can be considered on the part, product, and product series level. Different features for tracing data on each level are the main results of this part. Presenting the product lifecycle status in the PLM is one of the key results as it gives predictability for the product and for future R&D and product management projects. This thesis proposed a model how to show the lifecycle phase of certain product series (see Figure 30). The other key feature is the planned length of each phase, so that the whole product lifecycle length can be seen. In the current PDM system, traceability of modules and product series is very challenging, and the management has mainly happened on the item level instead of managing the whole portfolio. In addition, traceability of the data has required deep knowledge about products and therefore the use has been limited only minor part of the stakeholders. Configurable products consist of modules, which enable the configuration and variability of products, whereas modules consist of different parts. In the future PLM, these modules can be viewed, and the structure of each module can be viewed as well. The difference between current PDM version is that these modules are more accessible when they can be viewed from the product series level. The other crucial information is that on the part or product level, all modules it includes, is listed below the product. On the product series level, there are hundreds of different modules that are applicable for that certain series type. This gives an opportunity to examine all the modules and when any modifications occur on the product series level, affected modules can be traced. Product series object was presented in Figure 21 including essential product data and specific information about that and dependencies between other products and modules. In addition, several other critical product data is located under the main view of the product series. Documents related to product series are in a key role and therefore they are placed under the product series. These documents are specially to support sales, marketing, and product management. Main dimensions of valve can also be found very easily in the PLM. Part level traceability is possible in PLM with Where used -function, which shows all products that use that specific part. For example, if replacing part is considered, it is possible to view how many different products are affected and is it profitable to do so from the supply chain viewpoint as well.

The third part is about data utilization including how to reuse the existing design and items, how to view product configurator easier and how the lifecycle data should be utilized in different lifecycle phases and by different sections in the company. One key result is that there are a lot of different items in the product portfolio and some of these items are the same with different item numbers. To avoid this kind of working, items should be easily accessible and viewed. In the future PLM, it is possible to view items and where these items are used. In addition, the transparency of items prevents overlaps in the product portfolio. Unifying the design and modules have an impact on R&D and product management but many other stakeholders such as supply chain management, resourcing, and services. By reusing items and design, time and cost savings can be achieved, and it increases conformity to the everyday operations. The case company can offer products more efficiently and reliable when they have solid product portfolio. As this thesis focuses on configurable products, one key result is that there should be a configurator in the PLM system as well, however, sales configuration is still done in CPQ system outside the PLM. The idea is that there a view for product configurator in the PLM as well to see the base of configurator. The lifecycle data have not been utilized wisely before and the lifecycle data has only been visible on item level, not on the product series level or even single product level. In addition, the data has not been continuously updated. The product proceeds through different stakeholders within the company during its lifecycle. It is necessary to have a proper PLM system to trace where the product is and who is responsible of it in each phase. Product lifecycle related data is necessary for each stakeholder as it provides information about lifecycle phases' lengths and therefore offers predictability for the product's lifecycle. The lifecycle related is most crucial for the R&D project planning, in which future projects are planned and the product management must continuously evaluate when new products should be developed and launched, or the existing product updated. The product management makes decision about obsoleting the product and that decision should be predicted early enough to have time to react for new product development. For example, if the company knows that one of their products has been 30 years in the market, which indicates them that new R&D project should be started soon, so that there will be new model when the old one must be obsoleted. Currently there have not been a one centralized system that indicated the whole product series' lifecycle status. This information has mainly been in different kind of sources and in product manager's head. The idea of all results is to bring the case company more transparency to their portfolio and bring all people around the same data instead of copying the same data into different systems around the company.

The main RQs were presented earlier in this chapter and the aim of this chapter is to answer these questions directly and briefly. The first question is about how to improve the case company's PPM by means of PLM. The main results for the first question is previously discussed in this chapter 5. All in all, the availability, traceability and finally the utilization of new data are the key factors to improve the PPM with PLM in the case company. The second question is about how the company can benefit from these propositions made in the thesis. If the case company utilizes the latest capabilities in PPM and PLM, they can achieve transparency to the whole product portfolio and can prevent overlaps within the portfolio. The PLM enables to predict future projects, lifecycle status and see the size of the portfolio and trace the wanted data. Through these capabilities, the company has a chance to make cost and time savings, to focus more on the product management with proper tool and to improve their internal communication around the products through one system. The proper tool for the PPM is crucial for the company to manage the whole product portfolio and make their everyday business even more efficient and profitable.

This research aims to answer two research questions. The research method is qualitative and is a study to the case company. Internal and external interviews were applied during the research to gain a comprehensive understanding of current state of the company and to study PPM and PLM state-of-the-art. The main limitation is related to the limited number of interviews made and a predefined schedule during the research. The research focus was on the configurable products and specially on valve products. In the future research, there could be broader interviews done and the focus could be on the whole product portfolio of some company instead of limited to certain type of solution in the portfolio. Previous literature has covered the whole lifecycle of products well and have taken all product levels into account. Therefore, the aim of this research was to utilize existing literature of PPM and PLM and to apply those findings to the case company situation. To achieve future PLM vision in the case company, common objectives must be clear and new systems must be put to use.

6 CONCLUSION

The thesis consists of three main parts which are the literature review as theoretical part, current state analysis as empirical part and improvement propositions as constructive part. Introduction is preceding part, which introduces the topic of the thesis, introduces the case company, and presents the limitations. Literature review addresses the main preconditions and challenges of PPM, capabilities of PLM and defines the product. Furthermore, configurability and modularity of products were studied as well to cover the whole topic. The current state analysis is based on the internal interviews done during the thesis project. In addition, daily discussions, familiarization to the systems and introduction to the products and procedures have all supported the current state analysis writing process. All the sources are gathered as one matrix in Appendix 5.

The main objective of the thesis was to study PPM and PLM related practices from the configurable product viewpoint and make improvement propositions for the case company according to that. The main research questions were presented at the beginning of the study (see chapter 1.3), which this thesis presents answers. To improve the current state of the case company's PPM practices, the common PLM system must be utilized, and the product series object must be defined and implemented to the PLM system. The new and existing data must be easily accessible, visible and to be able to trace through the PLM system. To manage the whole product portfolio, the portfolio must be managed both horizontally and vertically, which stand for managing the portfolio on every product structure level and through the whole lifecycle. The possible benefits by utilizing the latest PPM capabilities in PLM gives transparency to the whole product portfolio, prevent overlaps within the portfolio and the PLM enables to predict future R&D projects by offering information about lifecycle status. In that way, the company has a change to make cost savings to achieve even more profitable product portfolio and to focus more on the product management with proper PLM system. The key benefit is achieved by implementing the PLM system in the future according to Valmet Flow Control's PLM vision of transforming daily work from fragmented working into entirety.

The main findings of the study are done from the case company's viewpoint to offer solutions to improve their state of PPM and PLM. This study is not applicable in all circumstances and is mainly customized for the Valmet Flow Control Oy needs. However, literature review covers PPM and PLM on the general level. To ensure the validity of the research, both internal and external interviews were invested in by gathering as many interviewees as possible during the limited period of time. In addition, by selecting high quality resources enough ensures the validity of the research. The reality that the study was performed by one person's perspective and during limited time, must be taken into account when considering reliability of the study. State of the art level is achievable by using recommendations done in this thesis, but it also requires the eco friendship and energy economy viewpoint presented by Kulkarni et al. (2021).

Potential topic for further research could be related to Life Cycle assessment (LCA) viewpoint in the case company. LCA stands for sustainability assessment methodology that measures the environmental impact of products, processes, or services through the entire lifecycle from the raw materials to disposal of products (Omodara, 2022). As the environmental and sustainability related questions, such as circular economy, are in a central role in the companies, the LCA is very current topic and should be researched even more. For example, when considering product portfolio and the future R&D projects in the case company, the LCA could be involved in everyday work. The other future research could consider the whole product portfolio of the company or focus on other solution in the company. In addition, the valve portfolio could be studied from the ETO perspective as well.

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Appendix 1. Questionnaire for product lifecycle/ product portfolio management practices in the case company.

Interview session

- Name of interviewer:
- Date and locations:
- Company:
- Name of the interviewee(s), current position, and experience in the company, and what is your relationship to PPM:

Questions

1) What do you think our product is?
2) What kind of lifecycle valves have?
   a. Phases
   b. Length of the phases
3) How are valves divided in the product portfolio? Do they have some hierarchical model?
4) What kind of demands our customers have regarding of valves? Do these demands affect R&D to react and develop new products or enhancements to existing products?
5) How is the product portfolio managed now, processes and tools?
6) How do we follow customers' needs and behavior? How much is customers' voice heard during different lifecycle phases?
7) What are the dependencies between products?
   a. Commercial
   b. Technical
8) Does Valmet Flow Control have target setting or KPI for Product Portfolio management? What are the KPIs in Valmet and in which level they are measured?
9) The merger of Valmet Oyj and Neles Corporation came into effect on 1. April 2022. Has it affected product portfolio management or product lifecycle management? How about Neles' acquisition of the valve and pump businesses of Flowrox?

Appendix 2. Questionnaire for product lifecycle/ product portfolio management practices in reference companies 1 & 2.

Interview session

- Name of interviewer:
- Date and locations:
- Company:
- Name of the interviewee(s), current position, and experience in the company, and what is your relationship to PPM:

Questions

1) How do you determine your product?
2) What kind of product portfolio you have in your company?
3) How is the product portfolio managed in your company? For example, by launching new products to portfolio, removing old ones, or moving existing product to the next lifecycle phase.
4) Do your products have some special feature, which must be taken into account in product portfolio management?
5) What kind of lifecycle the products have in your company? Phases and length of the phases.
6) What kind of requirements customers set for products and R&D? How much is customers' voice heard during different lifecycle phases?
7) Does Metso Outotec have target setting or KPI for product portfolio management? What kind of things are measured?
8) Have you managed to enhance the current state with the help of product portfolio/product lifecycle management? How?

Appendix 3. Questionnaire for product lifecycle/ product portfolio management practices in reference company 3.

Interview session

- Name of interviewer:
- Date and locations:
- Company:
- Name of the interviewee(s), current position, and experience in the company, and what is your relationship to PPM:

Questions

1) Why should product portfolio be managed?
2) What kind of things should be taken into account in product portfolio management?
3) How does product portfolio management of configurable products differ from other products?
4) How the development of the product portfolio has been done with product lifecycle management?
5) What are the benefits that company can achieve with the help of
    a. Product portfolio management
    b. Product lifecycle management?
6) How do you see the level of state-of-the-art of
    a. Product portfolio management
    b. Product lifecycle management in the technology industry?
7) Example cases, in which product portfolio management has been challenging and the problem was solved by means of product lifecycle management?
8) Finally, general notices or tips, how the product portfolio should be managed?

Appendix 4. Typecoding example for series LW butterfly valve.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
_	LW	6	K	B	A	200	A	A	A	A	T	D	_

1. sign	Flow balancing construction
_	Standard construction
Q	Flow balancing trim, Q-disc

2. sign	Product series/design
LW	Wafer type
LG	Lug type
L6	Double flange type

3. sign	Face to face
LW & LG	
6	EN558-part 1, basic series 20 API 609 category B class 150
7	En 558-part 1, basic series 25
8	En 558-part 1, basic series 16
5	API 609 category B class 300
L6	
4	API 609 category B double-flnaged

4. sign	Pressure rating & drilling
C	ASME 150
D	ASME 300
J	PN 10
K	PN 16
L	PN 25
M	PN 40

5. sign	Valve-actuator connection and shaft construction
B	Drive shaft + trunnion with two keyways/ bracket Neles standard
A	Through shaft with two keyways/bracket neles standard
D	Drive shaft + trunnion with square drive/ bracket Neles standard

6. sign	Construction
A	Standard max. +260°C
N/N1	Extended service max. +425°C
H/H1	High temperature service max. +600°C
B	Bearing protection max. +260°C
1B	Bearing protection for extended service max. +425°C
Z	Oxygen service max. +200°C
1A	Graphite free max. +260°C

7. sign	Size (inches/mm)
ASME	03, 04, 06, 08, 10, 12
PN	080, 100, 150, 200, 250, 300

8. sign	Body
9.sign	Disc
10. sign	Shaft & pins

11. sign	Seat
A	Hard chrome plated T=-200°C...+500°C
H	Hard chrome plated T=-200°C...+650°C
K	T=-200°C...+600°C

12. sign	Shaft seal options
T	Standard live loaded PTFE V-ring packing
G	Standard live loaded graphite packing
T1	High performance live loaded PTFE V-ring pakcing
G1	High performance live loaded graphite pakcing

13. sign	Model code
D	Mod D, modular butterfly valve platform

14. sign	Standard flange finish
_	

Appendix 5. All the references for thesis as a matrix.

	Internal material	External material	Communication
1	Product portfolio	Case company website	Weekly meetings
2	Current PDM system	Reference company materials	Interviews
3	Documents	Articles & doctoral theses	E-mails
4	Power points	Course materials from University of Oulu	Vendor demos and meetings
5	Other IT systems in use	Related books	Reference companies