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MANAGEMENT OF PROCURED COMPONENTS

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Master of Science Thesis
April 2020

ABSTRACT

Niko Liiri: MANAGEMENT OF PROCURED COMPONENTS
Master of Science Thesis
Tampere University
Master's Degree Programme in Automation Engineering
April 2020

Many companies produce custom products by combining own manufactured and subcontracted components. Knowledge of the used components is required to be able to provide product life cycle management for these products. This thesis aimed to find a solution for managing the subcontracted components and develop an example solution as proof of concept.

The research was conducted as a case study on a company designing and manufacturing products conducted of own manufactured and subcontracted components. The case study was performed by interviewing the personnel of the company. The aim of these interviews was to find the requirements that the company has for the component management solution. The interviews were conducted as unstructured interviews. The results of the interviews were reflected against the existing research to identify the best practices.

As a result of the interviews it was identified that the company uses two different methods for procurement of the components. For example, the selection of the suitable manual valves is set as suppliers' responsibility. Some of the challenges found were the supplier's reluctance to provide detailed information of the components. One of the reasons behind this is that suppliers are often only retailers of the components and thus try to prevent their customer from buying directly from the manufacturer in the future.

A solution based on the identified aspects was developed as the second result of the research. The solution is based on two different types of items. The first type is based on the properties defined by the engineer. This item type could be utilized in the procurement of the manual valves and piping components. With manual valves the items should however be replaced with manufacturer type specific components.

Keywords: Itemization, component management

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TIIVISTELMÄ

Niko Liiri: Alihankittavien komponenttien hallinta
Diplomityö
Tampereen yliopisto
Automaatiotekniikan diplmi-insinöörin tutkinto-ohjelma
Huhtikuu 2020

Nykypäivänä monet yritykset valmistavat tuotteita, jotka on koottu itsevalmistetuista ja alihankituista komponenteista. On tärkeää kerätä tietoa näistä komponenteista, jotta tuottetta voidaan hallita koko sen elinkaaren ajan. Alihankittavien komponenttien tuntemus mahdollistaa myös toimittajien kilpailuttamisen. Tämän tutkielman tavoitteena on selvittää komponenttien hallinnan kannalta oleelliset asiat, sekä kehittää niiden pohjalta esimerkkiratkaisu.

Tutkimus suoritettiin tapaustutkimuksena yrityksessä, joka valmistaa tuotteensa omavalmisteisista ja alihankituista komponenteista. Tutkittaviksi komponenttityypeiksi valittiin käsiventtiilit, putkikomponentteja ja automaatiossa käytettäviä komponentteja. Tapaustutkimuksessa yrityksen työntekijöitä haastateltiin yrityksen toiminnan kannalta olleellisten ja komponenttien hallintaa koskevien vaatimusten löytämiseksi. Haastattelut suoritettiin avoimina haastatteluina. Haastatteluiden tuloksia peilattiin aikaisempiin tutkimuksiin.

Tutkimuksen tuloksena havaittiin, että yrityksen sisällä on erilaisia tapoja komponenttien hankintaan. Tutkimuksessa havaittiin myös toimintatavoista johtuva epätasapaino nimikkeistön potentiaalisissa hyödyissä. Esimerkki löydetyistä haasteista on toimittajien haluttomuus antaa tarkkaa tietoa toimittamistaan komponenteista. Syynä tähän on se, että toimittajat toimittavat usein omien alihankkijoidensa valmistamia komponentteja. Tarkkojen tuotekohtaisten tietojen salaamisella pyritään estämään mahdollisuus kiertää toimittaja tilattaessa komponentteja myöhemmin uudelleen.

Toisena tuloksena tutkimuksessa kehitettiin malli nimikkeistön hallintaan. Ratkaisu hyödyntää kahdenlaisia nimikkeitä. Ensimmäinen nimiketyyppi perustuu suunnittelijan määrittämiin vaatimuksiin. Toinen nimiketyyppi perustuu valmistajan tyyppikoodiin. Ratkaisu luo myös nimikkeille kuvaavan koodin niiden tärkeimpien ominaisuuksien perusteella. Ominaisuuksiin perustuvien nimikkeiden havaittiin soveltuvan käsiventtiileille tarjouskyselyvaiheeseen. Ne tulee kuitenkin korvata tarkoilla valmistajan tyyppikoodiin pohjautuvilla nimikkeillä kun toimittaja on valittu. Putkikomponenteilla ominaisuuksiin perustuvia nimikkeitä havaittiin pystyttävän hyödyntämään laajemmin.

Tutkimus suorite
Avainsanat: Tiivistelmä-tekstin jälkeen

Tämän julkaisun alkuperäisyys on tarkastettu Turnitin OriginalityCheck –ohjelmalla.

PREFACE

This thesis was created as part of my studies in Tampere University on Automation Engineering program. I am thankful that I got to work on such an interesting topic. I learned a lot during the process.

I want to thank everyone who supported me in this process. I could not have done this without you. Special thanks to Olavi Kleine, Olli Hannula and Sami Remes who supported me with case study in Valmet Technologies Oy. I also want to thank all the interviewees who contributed their time for the research. I am also grateful to Professor Jose Lastra and Wael Mohammed who provided me guidance during the research process.

A special thanks goes to my girlfriend who supported me during the whole time and kept me mentally sane. I would have lost it without you.

Tampere, 29 April 2020

Author

Niko Liiri

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LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

API	Application Programing Interface
ASME	American Society of Mechanical Engineers
DLL	Dynamic-Link Library
EN	European Norms
ERP	Enterprise Resource Planning (software)
ETIM	European Technical Information Model
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
PDM	Product Data Management
PI	Piping and Instrumentation
PLM	Product Lifecycle Management
PO	Purchase Order
RFQ	Request For Quotation
SQL	Structured Query Language
TC	Technical Committee
UNSPSC	United Nations Standard Products and Services Code
URL	Uniform Resource Locator

1. INTRODUCTION

This thesis aims to find a solution to a problem of managing procurement of components from suppliers based on the properties defined by the end system that the components are required for. This problem is common in industries the business on designing systems based on given requirements and using sub contracted components to implement the system. The problem becomes more crucial when the products are unique and thus prevent the reusage of the designs.

In the first chapter the problem is introduced in more detail and the frames for the requirements of the solution are set. The second chapter introduces other work related to the solving similar issues. The third chapter describes different possible solutions and compares their strengths and weaknesses. The fourth chapter introduces an example implementation of the solution. The last chapter aims to reflect the proposed solution against the requirements set by the first chapter. The last chapter also proposes possibilities for further research.

1.1 Description of the problem

The goal of this thesis is to find a solution to a procurement problem faced by many industries working on custom products composed of subcontracted components. Although products share similarities in design, the specific implementation varies. This variation is required as specific requirements for the product vary. This means that the exact components can be chosen only during the design process even if the general model of the product is known earlier.

The definition of requirements phase the designer defines the boundaries or requirements for the desired component. The design process might be a multidimensional process with multiple parameters effecting the requirements. Often the design of the product is done by using software specialized for the design of the specific product type. The solution should provide an interface to enable communication with the design software. The specific design process itself is outside the scope of this thesis and is only considered as the source of the requirements of the components.

In many cases multiple different components from multiple different suppliers could fill the requirements. Finding the cheapest option filling the requirements from the different suppliers' catalogs is however often cumbersome. The information about the components the suppliers also varies widely. Some suppliers have full e-store catalogs with property-based description of the components and other smaller companies only provide printed catalogs with varying descriptions of the components. Some components are always custom designed and thus the supplier might not even provide a catalog, but instead always quotes on the requested components directly based on the requirements.

Many companies use Enterprise Resource Planning software (ERP) to follow and manage many resources of the company, including the procurement process. The solution should be seen as a part of a wider business intelligence environment and consider different functionalities and requirements of possible linked systems. One of the functionalities required beneficiary to the ERP systems in general is the ability to analyze the data. This should be considered in the solution.

1.2 Objectives and research questions

The first objective of this thesis is to find aspects related to the item management of subcontracted components. The subcontracted components mean components purchased from suppliers and utilized to assemble the final product. These aspects are considered in the scope of a company engineering and manufacturing power boilers. The scope is limited further by selecting specific component types to be studied further and for example components related to the buildings are not considered.

The second objective is to find a suitable solution based on the found aspects. This solution is considered as a suggestion, as there can be multiple valid solutions to this problem. Based on these objectives, the following research questions (RQ) are formed:

RQ1*: What aspects should be considered when creating component management solution?*

RQ2: *What kind of solution could be used to meet these aspects?*

This thesis considers the aspects related to the topic from point of view of business processes, stake holders and component types. The general categories of the selected component types are manual valves, piping components and automation instrumentation. The solution is to be considered based on the known best practices and the specific needs of the company.

1.3 Challenges and limitations

This study is conducted in conducted in collaboration with a company, later referred to as “the case company”. The business processes and practices exercised by the case company will have great effect on the found aspects and thus the final solution. This effect is to be minimized by reflecting the found aspects to the best practices in literature.

Another limitation is the amount of considered component types. The scope of the thesis is limited to few types of components. The aspects found based on these components might not cover all the aspects of subcontracted component management. Furthermore, these same component types could be own designed and manufactured in other comparable companies.

1.4 Structure of the thesis

This thesis is divided into six chapters. This first chapter acts as an introduction to the goals and the scope of the research. In the second part the concepts found in existing research and literature are introduced. The sources were used to gain understanding of the existing best practices and solutions related to the topic. The found concepts are later reflected to the aspects identified in the interviews.

The third chapter of the thesis introduces the methodology utilized in the research. It also introduces the selected research approach. The fourth chapter focuses on the reasoning behind the selected solution. The made choices are discussed in the perspective of the aspects in the literature review and the requirements of the case company.

The results of the research presented in the fifth chapter. This includes the case identified case company specific aspects as stakeholders, business process specific needs and component specific aspects. Additionally the suggested solution is introduced. In the last chapter the results of research are discussed and the validity is evaluated. Lastly the further research topics are suggested.

2. THEORETICAL BACKGROUND

This chapter introduces existing work related to the issue. It also introduces technologies and principles that could be beneficial to the implementation of the solution. Suitability of the existing work and technologies is then analyzed in more detail in the chapter 4.

2.1 Example case

An example of this kind of product in question is a power boiler used in power plants. The power plants commonly convert fuel to electricity. This happens by burning the fuel in the boiler and utilizing the heat created by it to heat steam. The hot steam then creates flow used to run the generator. The power boiler is used to heat this steam.

All power boilers share similarities in the design. They need fuel feeding system, pressure piping for the steam, cooling system, combustion air system et cetera. These subunits then consist of components of varying types. For example, pressure piping uses pipes, valves and gauges. Fuel feeding might utilize conveyors and motors and Cooling water system utilizes pumps and combustion air system requires fans and ducts. An example illustration of a power boiler is shown in figure 1.

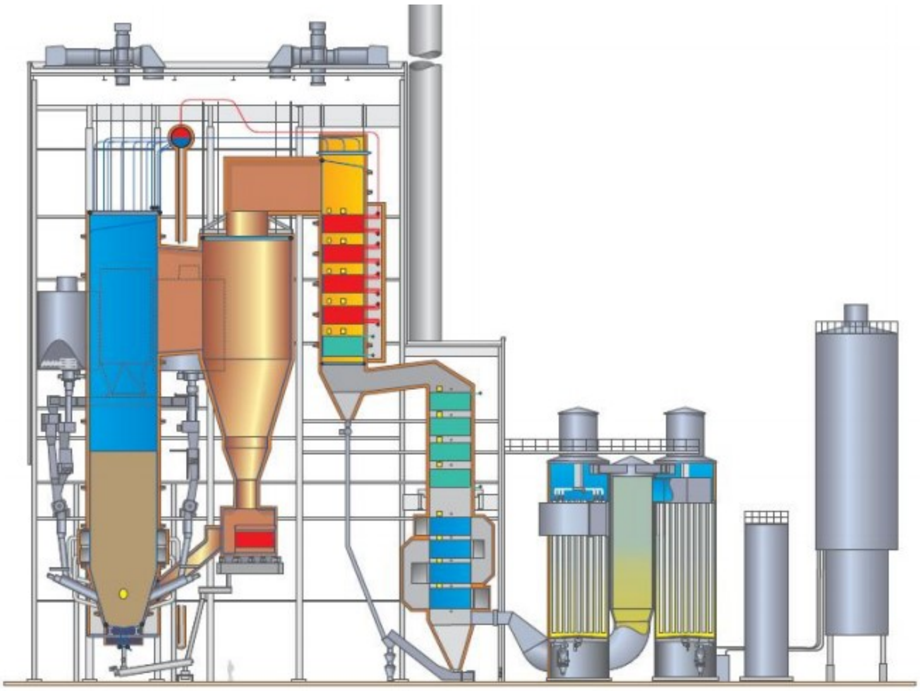

Figure 1. *A Cymic Power boiler illustration by Valmet Technologies [1]*

The differences originate from the external requirements. For example, the type of desired fuel, allowed emission levels and special features effect on what functionalities the power plant must fill and thus required systems. In addition to these for example the required power output and standards set by the customer or local law effect the exact design of the systems.

According to these boundaries and decisions made during the design process, varying requirements are set to the final components used to build the power plant. Operating pressure, temperature, flow speed, and type of fluid effect the required wall thickness, material and diameter of each pipe. Another example of varying set of component requirements is sealing materials, type and connection types of valves.

The design and manufacturing of many of the components is often better to outsource as the company producing the power boiler focuses the knowhow and effort to the overall design of the power boiler. Managing the suitable components for each case is a challenge as there are many different suppliers providing similar valves with varying properties. This is even harder as many suppliers do provide full specification for their components. Reusability of these components is very poor as they are not comparable with each other after the purchase.

2.2 Streamlined management philosophy

Lean is a management philosophy derived from Toyota Production Systems. The goal of Lean is to minimize the losses and inefficiencies of a production system and by doing so optimize cost, delivery and quality while still improving safety. One of the key categories causing loss is waste. [2, 3]

Waste can be defined as anything in process that increases costs but does not add value to the customer. Seven types of waste are overproduction, waiting, transportation, over-processing, inventory, motion and rework. An additional eight category is inability to utilize people's skills in improving of the business process.

Overproduction means that there are more products manufactured than required. This increases the storages and thus adds costs. This could also affect workers motivation to improve process efficiency as there are always final products waiting to be shipped.

Waiting is one of the main causes of loss as it means phase of process where the product is not processed and thus the value is not added. This is caused by bottlenecks in process where resources are forced to wait for other resources. These can be for example overloaded processing machines, personnel or subprocesses. Some of the possible solutions to these problems are increasing capacity of the bottlenecks and automating possible unnecessary manual work.

Unnecessary transportation can be caused by long distances between working stations and storages and thus cause extra work and time used to moving the products and components. This can be minimized with careful layout and process planning.

Over-processing means processing the product further than what is required by customer, in other words adding irrelevant value to the product. This adds the costs while not adding any actual value.

Inventories mid process cause extra costs on storing the unfinished products and might hide process bottlenecks. There might also be faulty components in the storages which in turn might delay the detection of faults and so lengthen the reaction time to problems. Minimizing mid-process storages also helps on minimizing the lead time of products.

Motion count as waste means any extra movement made by worker. This could be for example need to move away from working station to retrieve required tools. Organizing working stations and minimizing distances are some of solutions to minimize motion.

Rework is caused by faulty products. These in turn can be caused for example by undertrained personnel, misfunctioning machines and miscommunication.

Ineffective enabling of People's skills and ideas is the eight commonly added category of waste. Personnel working in the process often know the process well and might have useful improvement ideas. Failure to acknowledge these ideas is a waste of skills and unnecessarily slows the process improvement.[2, 4, 5]

2.3 Industry 4.0

Industry 4.0 (I4.0) is often referred to as the fourth industrial revolution. The first industrial revolution means mechanization and steam power. Second revolution refers to mass production and electricity and the third one to the computers and automation. The fourth revolution refers to the revolution of information. The idea of industry 4.0 originated from German industry has afterwards been adopted by other nations in European Union, India, China and other countries in Asia. [6, 7]

The term industry 4.0 includes multiple different concepts. Some of these are smart factory, cyber-physical systems and new systems in distribution and procurement. Industrial Internet Of Things or IIOT is also closely related to I4.0.

The core idea of industry 4.0 is the digitalization of flow of information. This means flow of information horizontally between different departments of an enterprise but also vertically through the whole value chain from company to company. Better business decisions can be made and processes enhanced by having more accurate information available for each step. This however requires that the information can be utilized.

2.4 Enterprise Resource Planning

Enterprise Resource Planning (ERP) is management of the enterprises' core business processes. The term usually refers to a software or combination of software used for this purpose. Some of the business areas commonly associated with ERP systems are accounting, sales, corporate performance governance and procurement. [8 p.3-5]

One of the key benefits gained by using ERP is the ability to instantly share information between departments. This is crucial as the operations of departments often depend on the other departments. Well informed decisions can be made when actual real time or almost real time information from other departments is available. This also helps to for a bigger picture of the status of the whole enterprise. For example, sales department can use the information about the load of manufacturing department when considering the promised delivery times. Information about the sales and inventory can then be used by the procurement department to gain better picture of required materials and components. Combined information of these and other departments can then be used to make decisions about possible required investments or preparations to enable the enterprise to meet the changing demand.[8 p.2-31]

ERP system is commonly a massive investment of resources and time for any enterprise. As the goal of an ERP is to integrate different departments it often requires the business processes to be unified to some extent. This might be a considerable challenge for big enterprises with widely heterogenous processes. A successful utilization of an ERP however commonly leads to great benefits. [9]

2.5 Product Data Management

Nowadays enterprises produce vast amounts of information related to their products. This could be for example 3D-models, drawings and required materials. Managing and using this information in an efficient way is a great challenge. The Product Data Management (PDM) aims to solve this. [11 p.21-27, 12 p.9-11]

Product Data Management is a systematic method or a principal of managing information to products. It is however often also used to refer to Product Data Management system which is a software or group of software used for this purpose. The main purpose of PDM is to bring the information related to product available of all the parties requiring it. [11 p 18-19, 12 p.12-13]

Some important responsibilities of a PDM systems are item manage, product structure management, user rights management, document management, change management, configuration management and information search functions. [11 p.21-22]

The item management is in the core of PDM system and enables it to identify different entities.[11 p.19-20, 12 p.15-46] Items will be discussed in more detail in chapter 2.7. However, it should be noted that if PDM is commonly the master of items if it is used in the enterprise.

The product structure management can refer to few different things. Firstly, it can mean the general categorization of the products. The logic used to categorize the products depends on the company’s needs. Secondly the product structure may refer to actual structure of the product. This could be a hierarchical structure composing of items and further their subcomponents. In this thesis the product structure is used to refer to this concept. Having a product structure and items enables the engineering to understand where certain items are used and what would possible changes to a certain item influence. It also makes it easier for example for spare part sales engineers to identify the spare parts for certain product. [11 p. 49-58, 12 p.59-67]

According to Sääksivuori and Immonen the PDM is also responsible for the management of the documents related to products. These documents could be for example manufacturing drawings, specifications and standards. Management of the documents mean that PDM system has the knowledge of where the documents are found. [11 p.22]

The change management includes version and revision management of items, product structure and documents. The versioning should contain information about made changes and who made them. The change management should also ensure that the information about changes reaches all significant parties. [11 p.22, 12 p.71-77]

The configuration management means management of possible configurations for configurable products. The configurable products are discussed in more detail in chapter 2.6 with items. In short, the PDM system should hold the information off all possible configurations and the tools for managing them. [11 p.52-56, 12 p.79-92]

2.6 Product Lifecycle Management

Product lifecycle management (PLM) is a systematic plan for product life cycle management at the corporate level, in specific business or product area. The goal of PLM is to provide control to creation and management of product related information from the design of the product to the after sales and possibly to decommissioning. [10 p.11-17]

The PLM and PDM share many responsibilities and it can be said that PLM includes PDM. Where PDM is focused on the structure and definition of the product, PLM adds the process and focus on development and after sales of the product. This however almost always requires the understanding of the product itself. Sääksvuori and Immonen define the typical features PLM system to include the same features as PDM system.[10 p.21-22, 11 p.15-16]

2.7 Itemization principles

Items provide a systematic way of identifying products, parts of products and services. A single item can be for example the whole product, a module, a single component, software or a service. The exact definition of the item depends on the needs of each company.[10 p.19] The concept of an item can be generalized as an entity in the product structure. They play a crucial role in most PDM, PLM and ERP systems.

According to Peltonen, Martio and Sulonen there are five views that successful item management system should support. These are structure view, categorization view, translation view, state view and lifecycle view. The structure view describes provides a view on how items consist of each other. The categorization view helps to identify similar items. The translation view provides translations of item descriptions so that they can be used in multilanguage environments. State view describes the usability of the items and which items as still drafts or expired. The lifecycle view shows and manages the change history of items. [12 p.45-46]

Items are the basic piece of the product structure management. Each entity in the product structure can be identified by an item. The item links together the documents and metadata related to this entity, for example a component. This can mean for example manufacturing drawings, standards, material documentation et cetera. Especially items higher in the product structure hierarchy can contain a Bill Of Material (BOM) which contains the items composing the higher level item. The BOM can be multileveled or flattened depending on the needs of the company. [11 p.27, 12 p.44-45]

The items should be divided in to different categories or a hierarchy. This hierarchy can be based on the company's specific needs or a wider used standard. For example, valves could be one category with ball valves, butterfly valves and gate valves as subcategories. The categorization of the items eases the management of the items. However too detailed categorization might make the item management more difficult as the correct category might not always be clear. [10]

Commonly items identify identical components as same item. This can mean for example all the components manufactured from same materials and based on the same manufacturing drawing. Each of these components is an instance of the same item. The parameters determining the uniqueness of an item also depend on the needs of the company. In some cases, for example different color variations could be defined as the same component, but they could also be defined as separate items.

2.7.1 Item version control

Item version control is commonly a responsibility of PDM system. Having version control makes it possible to keep track of changes in components and decreases the need for new items and each change in component does not necessarily require creation of a new item. Key terms related to item version control are version, revision and variant. Definition of these terms however varies depending on the person using them. [12 p.32]

Term revision is commonly used to describe changes made to a component. Usually revisions follow each other on the time axis, meaning that new revision is based on the previous revision. Revisions are usually backward compatible, meaning that newer revisions can be used to replace older ones, but older ones might not be compatible as replacement of the newer ones. In practice the compatibility means that the newer revision should function and fit the same as the previous revision. New item should be created if changes made to item make it incompatible with older revisions. [12 p.32-34]

Terms revision and version are often used about similar changes. It is common that the major and minor changes are followed separately and marked with running numbers separated by dot. For example, 2.4. Depending on the source the revision could mean a major change and version a minor change, but they can sometimes be used the other way around too. Minor change can be for example an addition of a missing measurement to drawing and a major change could be a change of the actual measurement. [12 p.32-37]

Versions and revisions can also contain information of the validity of the item. This could be linked to date or serial number information. This way it can be known when the revision of version of component can be used and on the other hand the version history can be followed in relation to time. [12 p.32-37]

Variants are used to identify different variations of the same component. This could mean for example different sizes of the same component. This component could be defined on single drawing with actual measurements collected to a table defining the different variations. Different variations can be identified for example with an alphabet in the end of the item code. [12 p.36-37]

Using revisions, version and variants at the same time can provide additional challenges to item version control. Simple solution is to use the revision as master to variations, so that each variation belongs to certain revision. This could be the case for drawing and the variations described by the drawing. This is described in figure 2. Each revision of the drawing defines the variations related to the revision. [12 p.32-40]

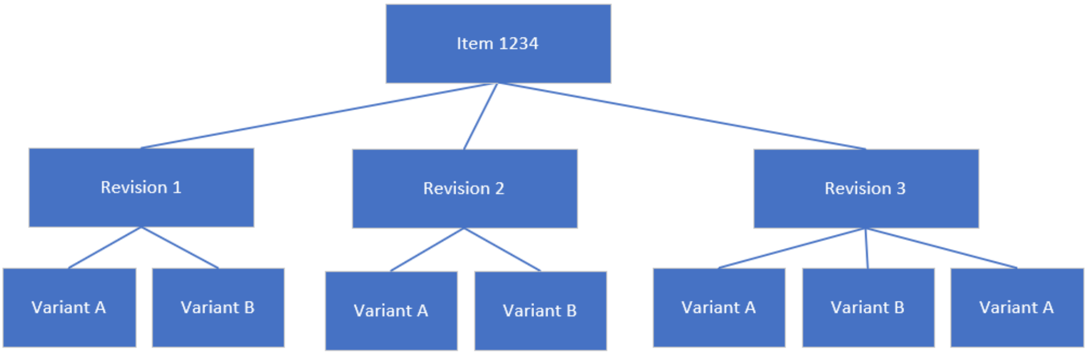

Figure 2. *Variations by revision [12 p.38]*

However, the case could be more complicated if the item is a document and different translations are the variations of the document. In this case each translation could have its own change history for example for spelling errors. These could be managed with variant specific versions. The bigger content specific changes could be managed with revisions common to all translations as described in figure 3. [12 p.37-40]

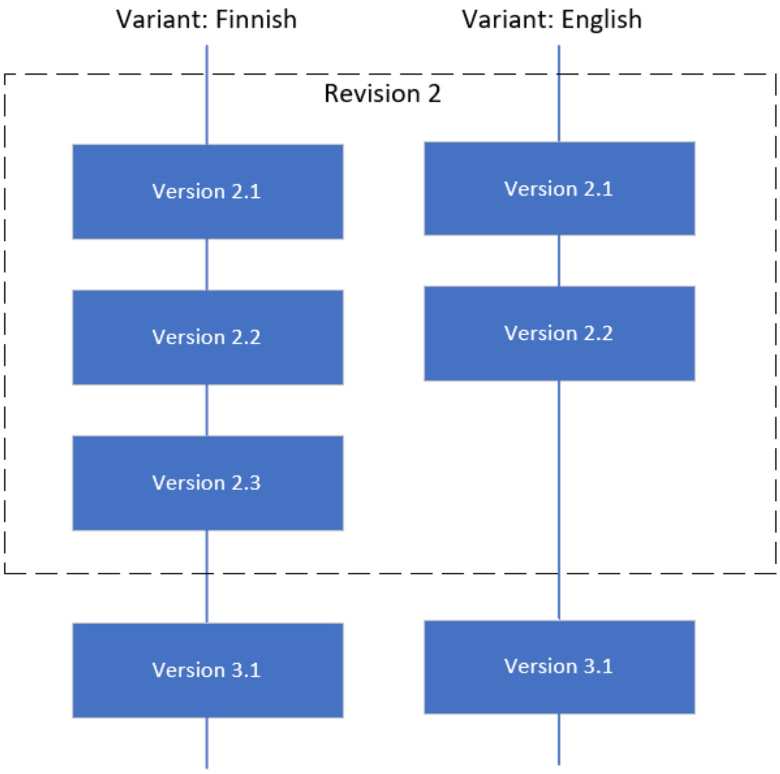

Figure 3. *Versioning for variations [12 p.39]*

In figure 3 each vertical row is a translation variant and the dashed box describes a revision common to all translations. The blue boxes describe smaller version changes on the document.

2.7.2 Items connecting PDM and ERP

Items are used in PDM systems to identify components and resources required for manufacturing and upkeep of the products. In ERP systems the items are used to keep track of the resources. Each item represents a resource. By keeping track of quantity of each item in the warehouses the need for ordering more can be determined. The items can also be used to identify the components provided by multiple suppliers. [9,11,12]

When same items are used in PDM and ERP systems they provide a common language for engineering and resource management to keep track of what is needed to manufacture given products and whether company has the required resources. They also connect the product structure to own manufactured and suppliers' components and thus provide a way for procurement to know what components they are required to purchase. [9, 11, 12]

2.7.3 Purchased item management

Managing items of components provided by suppliers require special consideration in comparison to own manufactured components. One aspect is that multiple different suppliers might provide the exact same component with their specific identifiers. This makes it difficult to identify which components are same. This can be avoided by acquiring the original manufacturers identifier for the component.[12 p.41]

Many manufacturers might also supply components that are interchangeable with each other. For binding these components together company should have their own item. This generic item should have relations to the suppliers specific items filling its specifications.[12 p.43]

The company might have policies for testing the supplier's components before accepting them to be used in their own products. The item management solution should be able to manage this information for each suppliers components.[12 p.43]

The relations between suppliers' components and compony specific items can be managed by utilizing possibly existing suppliers item databases. There are existing standards for description of components to help integration between different companies' item databases. Some of these standards will be introduced in chapter 2.8. [13, 20]

Peltonen, Martio and Salonen introduce a data model for describing the information related to purchased items. This data model is visualized in figure 4. The model is described with UML-terminology and principals. [12 p.42-44]

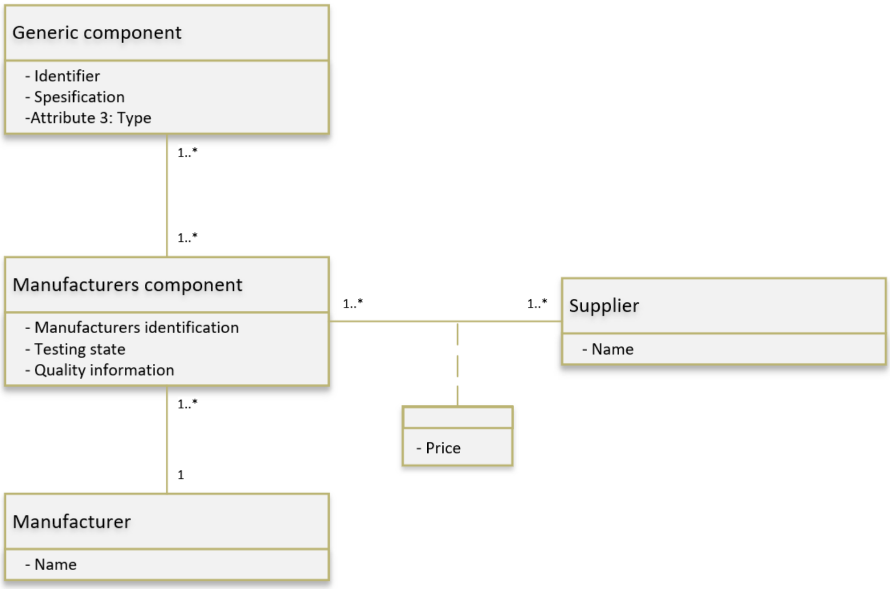

Figure 4. *Components, manufacturers and suppliers[12 p.43]*

2.8 Itemization and Classification Standards

Items and components can be classified in multiple different ways. Many companies might have their own ways to accomplish this but there are also multiple international standards for this purpose. Some of them are introduced in this chapter.

Term "classification" is used in this thesis to describe any logical way of organizing components. This is further divided into two sub organizing logics defined in ISO 13584-42: categorization and characterization [39]. Categorization is a logic of organizing the components by specific purpose. This could mean for example division to pumps, valves etcetera. This groups could then be divided by more specific types to sub groups.

Characterization means description of the products by its properties. In this principle the products are grouped by their common properties. This logic provides a way of describing the component in a detailed level.

2.8.1 Related international standards

International Organization of Standardization (ISO) is nongovernmental independent international organization with members of 164 national standards bodies. It governs the international standards related to almost every industry. ISO also works in co-operation with International Electrotechnical Commission (IEC) on matters concerning electrotechnical standardization. [13, 14]

ISO 13584 provides a standard for generalized structure of a part library. It includes standardized methodology and necessary mechanisms and definitions for library data to be exchangeable, useable and updatable. It does not provide full implementation of a part library but instead a standards enabling compatible implementations being interchangeable.[13]

The different parts and thus general view of content of the standard is listed below:

- 1: Overview and fundamental principles
- 10: Conceptual description: Conceptual model of parts library
- 20: Logical resource: Logical model of expressions
- 24: Logical resource: Logical model of supplier library
- 26: Logical resource: Information supplier identification
- 31: Implementation resource: Geometric programming interface
- 42: Description methodology: Methodology for structuring part families
- 101: View exchange protocol: Geometric view exchange protocol by parametric program
- 102: View exchange protocol: View exchange protocol by ISO 10303 conforming specification

Another closely related standard is IEC 61360. This standard specifies in detail a classification scheme for electric components. IEC 61360 has is divided to six parts of which parts 3, 4 and 5 are withdrawn. ISO 13584 references for example data structures defined in IEC 61360. ISO 10303 standard also known as Standard for the Exchange of Product model data (STEP)

There are also many component type specific standards. For example, EN 10253-4 used in Europe defines butt-welding pipe fittings such as reducers and pipe bends [15]. Similar standard for seamless steel tubes is EN 10216-5 [16]. Both standards are approved as Finnish national standards. Another organization managing standards used for same purposes is The American Society of Mechanical Engineers (ASME). For example, an ASME standard covering dimensions, tolerances and ratings related to butt-welding fittings is B16.9 -2018 [17].

2.8.2 European Technical Information Model

European Technical Information Model (ETIM) is a free international standard used in classification of products and components developed and maintained by ETIM International standardization committee. ETIM provides a standardized way for describing products. It is not an item management system itself. ETIM International is a non-profit association formed by partnership of national ETIM organizations. Its first and main sector is electrical components, but it is nowadays also active in other sectors. [18]

The association has three formal bodies: The General Assembly, the Executive Board and the Technical Committee (TC). The General Assembly is the highest formal body in the organization and is formed by the member countries. Decisions are made by voting and each country has a single vote. The General Assembly elects the Executive board which performs operational tasks. The standardization process and supervision of the ETIM model are concluded by the TC. Each member country designates one technical expert as member of TC. [18]

ETIM classification system is a two-level model based on five main entities. The entities are: Product group, product class, features, values and units. In addition to these, the model includes synonyms, which are key words helping with finding correct class. The two levels categorizing products in the system are groups and classes. The structure of the classification system is visualized in figure 7. [18]

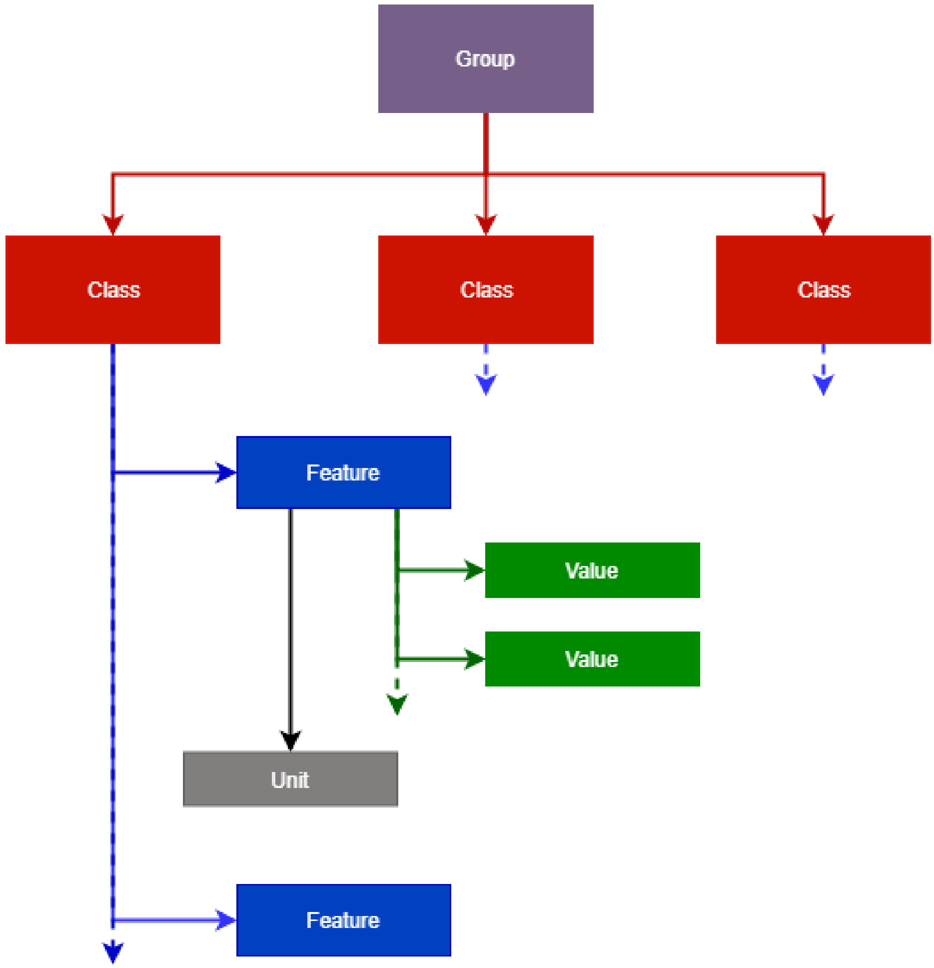

Figure 5. *ETIM Classification model structure [19]*

Groups are highest level category of the model. They are meant for convenient grouping and management of the classes. Each group might contain multiple classes, but each class only belongs to one group. An example of a group is group Valves/taps/controls. The classes are the key component of the ETIM classifications system. They describe similar products and define features that are essential for this type of product. An example of an ETIM class is a butterfly valve. [18]

Another essential entity to the model is feature. Classes define key features for this type of item. Multiple different classes can use same features and this helps in identifying similar and possibly compatible products. An example of a feature is “Nominal inner diameter”. Each feature is defined by description, possible unit and one of following types: [18]

- A – alphanumeric, list of possible values
- L – logic, yes or no question
- N – numeric, one numeric value
- R – range, two numeric values that limit a range of values

All alphanumeric feature has list of allowed values. These lists are defined by feature class combination, so the same feature might have different allowed values in different classes. The numeric features define the unit in which the value should be provided. Exception to this rule are features that define number of something. [18]

Groups, classes, features, values and units have a language independent code which uniquely identifies them. This makes it possible to have translations for different languages without compromising the integrity of the model. All codes have two parts, the two-letter prefix and six-digit number. For example code for class ball valve is EC011343.[18]

2.8.3 Component characterization standard ECl@ss

ECl@ss is a widely used product characterization and classification standard. It is compatible with ISO 13584. It provides a property and class-based approach to product characterization and four leveled structure for product classification. [20]

There are two different “versions” available of ECl@ss: basic and advanced. Both versions provide property-value based characterization but the advanced also enables more advanced methods. These include for example property structuration as “blocks”. Block is a structure which in turn may contain multiple different properties. This allow hierarchal description of products. [21]

ECl@ss for basic standard is available in two different formats: .csv and .xml but the advanced only in xml. This is because of more complicated structure of advanced standard. The standards require a paid license to use. The price depends on the size of the acquiring company and desired products. By purchasing the license for eCl@ss one gains the right to use the standard access to a tool for browsing the standard. The actual implementation of the item management and describing the items with the standard is the utilizers responsibility. It is utilized for example by Siemens’ Teamcenter[22]

2.8.4 United Nations Standard Products and Services Code

United Nations Standard Products and Services Code (UNSPSC) product and service categorization standard. The focus of UNSCPSC is in classifying commodities across industries in a wide but general scope. The standard includes commodities from different kind of apples to globe valves and street cleaning services. However, it does not provide a way to differentiate different globe valves from each other or a structure to describe different features of the commodities.[23]

UNSPSC classification is based on for levels which form a tree structure. Each of the lower level categories belong to one of the upper lever categories, which in turn belong to a category above this level. The levels of the hierarchy are

- Segment
- Family
- Class
- Commodity

The UNSPSC code consists of eight digits and each level set two of those digits. This way the hierarchal path of a product can be read from the code. An example of coding in case of Globe valves is shown in Figure 8.[23]

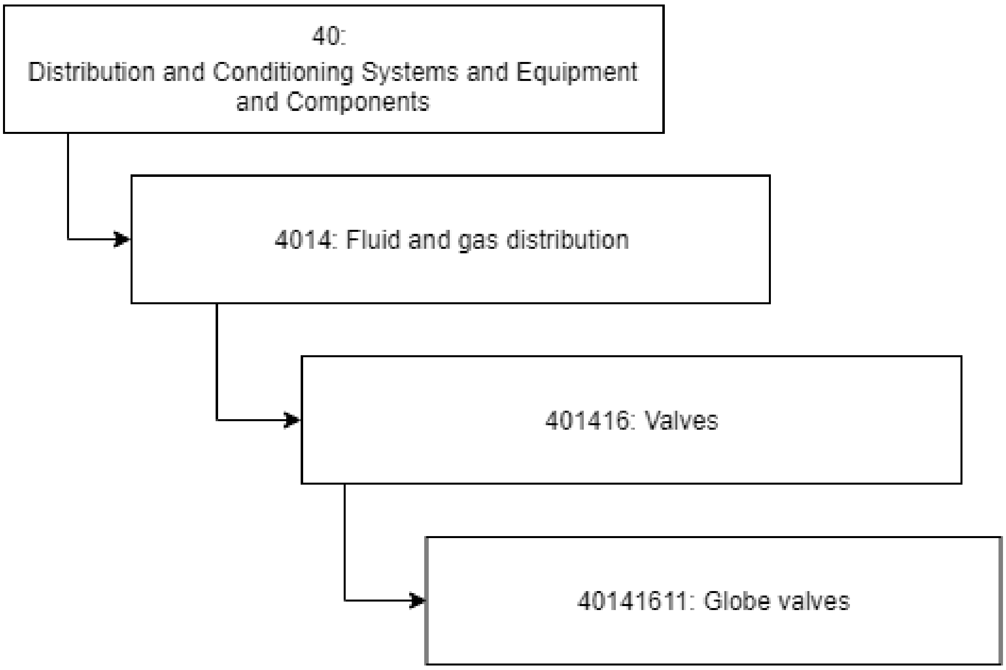

Figure 6. *UNSPSC classification example Globe valves*

An additional optional level to the hierarchy is Business function. This level describes how the commodity or service is used. The values can be for example rental or lease, maintenances or repair et cetera. This level also adds two digits to the end of the code.

UNSPSC is a global free to use and owned by United Nations Development Programme (UNDP). It is funded by members of the association whom in return reserve additional benefits. The current version of the standard is always available for everyone, but only members have access to the past versions. Members are also able to request changes to the standard and thus develop it further to suit their needs. [24]

2.8.5 Other commodity classification standards

There exist multiple standards used in classifying commodities for the purpose of customs and international trade. Some of these are for example Standard International Trade Classification (SITC) published by United Nations and Combined Nomenclature (CN) managed by European Union. These standards classify commodities based on hierarchy and varying rules. The logic of the hierarchy is similar to UNSPSC but the rules vary.[25, 26]

Automating assignment of these standards is challenging. They are only available as spread sheets and text files but there has been effort to automatically translate them to OWL format. [27] The CN standard is updated every year but the SITC standard in more stable. This enables this enables analyzability over longer periods of time. There are also several other standards used for example by Finish customs but these are discussed no further in this thesis.[28]

2.9 Procurement

Procurement is a process of finding and purchasing desired materials and components from suppliers. The procurement costs of enterprises are often 60% of the total funds. In some industries the procurement can account even for 90% of costs. [29]

According to Jiang the common procurement management systems used by enterprises are of three different types:

- Centralized
- Decentralized
- Hybrid

In centralized system the procurement of all main resources is done by a specialized professional procurement team. Centralizing the procurement bring multiple advantages. Some of these are for example possible centralized inventory and increased orders sizes as result of combining different batches. This in turn brings advantages in negotiations with suppliers. On the other hand, the disadvantages include extra effort in communication between procurement unit and the units using it and prolonged response times to demand changes. The hierarchy of different departments and inventories is visualized in figure 5. [29]

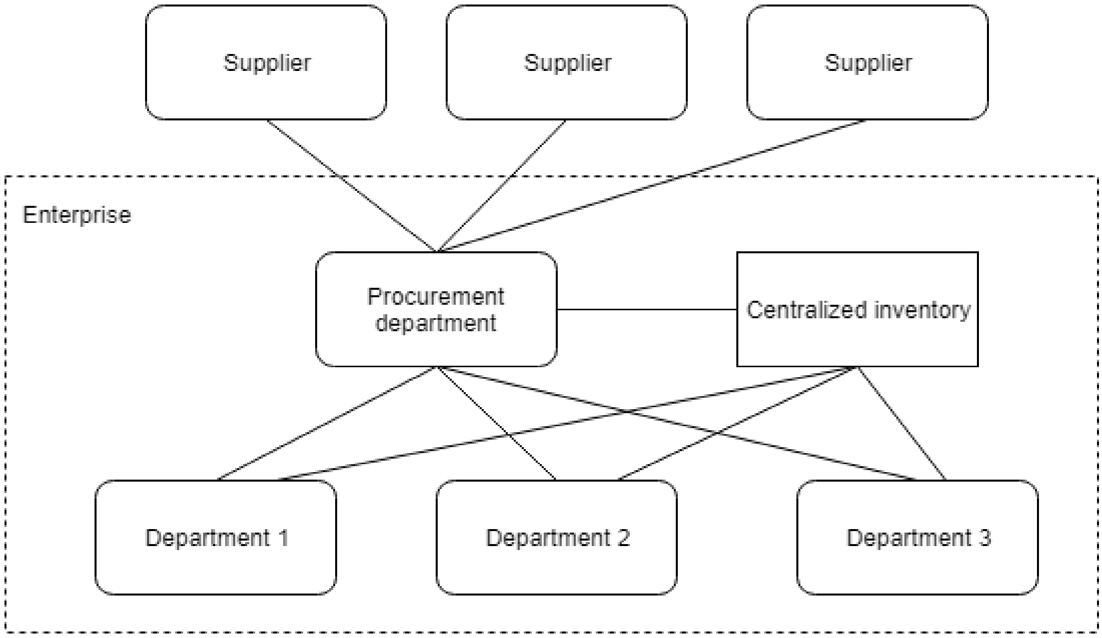

Figure 7. *Centralized procurement model*

Decentralized model is in many cases opposite to the centralized one. In this model each department handles the procurement of its own demands. This model does not require the extra communication step between the procurement team and department with demand. This makes reacting to the changes faster and simplifies the procurement. However, the total efficiency of the enterprise level procurement is usually worse than with the centralized systems. Decentralized model also often includes decentralized inventory, which effects the utilizability of the resources. This in turn causes increased storage costs. The Decentralized procurement model is visualized in figure 6. [29]

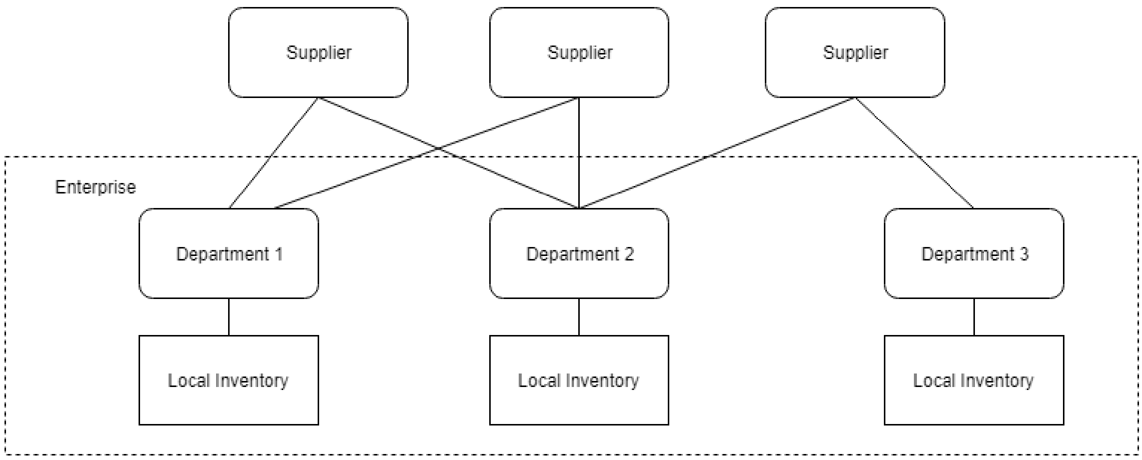

Figure 8. *Decentralized Procurement model*

The third model is combination of the previously introduced ones, a hybrid model. In this model the centralized department handles the procurement of the main materials and bigger equipment. These are also managed in centralized inventory. The less frequent demand is handled by each department separately. [29]

2.9.1 E-procurement

E-procurement is procurement of products or services by utilizing internet and other information and networking services. The meaning of the term includes multiple sub concepts such as e-informing, e-tendering, e-auctioning and e-purchasing. The goal of e-procurement is to make the procurement process more efficient and to help the procurer to find the best deals for the desired products or services.

A much-researched part of e-procurement is e-auctioning. This means usually an electrically conducted reverse auction. In practice this means that suppliers bid on varying rules on the sale to the customer. Some of the common forms of reverse auctioning are English auction, Dutch auction and Sealed bid auction. For example, in English auction the bidders improve their bid until only one bidder is left. In Dutch auction the required bid is determined by the auctioneer and lowered until one of the bidders accepts it. In sealed bid auction each bidder sets only on bid and the best one wins. [30, 31]

Effects of e-auctioning have been widely studied. For example, the lowered procurement costs and increased efficiency have been found as the positive outcomes of utilizing e-auction. [30, 31]

Organizations ability to utilize e-procurement also varies. Some of the found key factors affecting the successful adaption of e-procurement are structural change organizing and accountability with purchasing, internet skills of information system specialists, clear and fluent approval and workflow system and support from top management. [31]

2.10 Hashing

Hashing is commonly used to compare equality of bigger sets of data, such as documents or files. It is a process of transforming an arbitrary sized data into a fixed size output called hash. The main benefit of hash is that two exactly same inputs produces the same output. Even a small change in the input produces completely different output.

There is however not a complete certainty of the equality of two input with the same hash. This is because two different inputs might also produce the same hash. This is called a collision.

The birthday problem or birthday paradox discusses the probability of two randomly chosen people from a given sized group having the same birthday. This is a common example of the probability of a collision for given number of inputs. The probability is surprisingly high even with relatively small number of inputs. For the probability of two people having the same birthday in the group of 22 people is already 52% and with 46 people it is 95%. This show that the probability for collision increases quickly as the number of inputs increases. [32]

The approximation of probability of collision (p) for given number of inputs (n) and values (d) can be calculated with the following function

$$p(n, d) \approx 1 - e^{-n^2/(2d)}$$

The procedure of converting the input data to the hash is called hashing function. There are multiple different hashing functions in common use. Some of these are for example SHA1 and SHA256. These functions cut and transform the input data multiple times to produce the hash.

2.11 Database Technologies

Databases is a collection of organized data. The databases are often divided to relational (SQL) and non-relational databases (NoSQL). The relational databases have been the more used option, but NoSQL has been increasing its popularity lately. Both of these types have their strengths and weaknesses and they are shortly discussed in this chapter. There are multiple different solutions classified as both of these types and couple of examples are introduced here.

2.11.1 Relational databases and SQL server

Relational databases are based on the Relational data model introduced already in 1970 by E. F. Codd. Relational data model depends on strictly defined schema. This means that the format of data in the database is fully defined. Structured Query Language (SQL) is defined by ISO/IEC 9075 standard [

Relational data model organizes the data in tables which in turn consist of rows and columns. The columns, also called properties, define what kind of data the table holds. The columns for example for personnel table could be first name, last name and age. Each row in a table is an actual instance of data. This means that in the same personnel table each row would hold data related to a person.

Each table must have a primary key which uniquely identifies each row. This could consist of one or more columns. These can be natural keys, for example country name in table of countries, or surrogate keys that are artificially generated. These can be Surrogate keys are often used as it might be difficult to find a natural key uniquely identifying the row. For example, in the case of personnel table the combination of first name and last name might seem like a tempting natural key. However, two people might sometimes have same first, and last names and they could not be differentiated with this kind of key.

Another key concept of relational data model are the relations between data rows. This means that data between tables or within a table can be linked together using keys. Our data model could for example have an additional called departments, which could hold data related to each department of a company. By adding an additional column with primary key of the departments table to personnel table, we can define what department this person is working at. This way the information of each department has to be defined only ones and only referenced for each person.

Traditionally relational databases are not very suitable for storing data related to entities with varying properties, as they require the schema to be strictly defined. Straight forward solution would be to implement one table with all possible properties as columns and each row representing an entity. This would however result to most of the table being filled with null values if there would be big variation of properties between the entity types.

Another traditional solution to this problem is to use so called entity-property-value model (EAV). This means that the information of entities is stored in multiple tables. One table for entity and the properties that all entities share and another table with columns for entity, property and value. In this design each entity would have one row in the entity table and zero to many rows in entity-property-value table describing each of the properties of the entity. Benefit of this approach is that there can be as many properties as wanted for each entity and adding new properties is easy. There is also no space wasted as value for each property does not need to be defined for each entity. The downside of this design is performance as each query for entity requires multiple joins.

Now days many RDBMS have solutions that allow schemales data to be stored. For example, SQL server has support for xml and json and PostgreSQL special jsonb datatype. SQL server does not have a separate datatype for JSON but it provides functions that allow nvarchar datatype to be handled as json.

2.12 Summary of the theoretical background

In this chapter the theoretical background for the thesis was introduced. The following topics were presented. Firstly an example case of the business area of the scope of the thesis. Secondly the philosophies and management systems closely related to the itemization were discussed. These philosophies included Lean, Industrial internet, ERP, PDM and PLM.

After this the existing best practices for itemization were discussed, as they provide the base for the solution. The existing itemization standards were also introduced as they are a key to successful communication between companies. Common procurement methods were discussed to provide perspective on the methods commonly used to procure components. In the last part the technologies that could be utilized to implement the component management system were introduced.

3. METHODOLOGY

This chapter introduces methodology utilized in the research. The reasons for the made choices considering the methodology are also discussed.

3.1.1 Qualitative versus Quantitative research

Qualitative and Quantitative are two types of research approaches. Quantitative research generally aims to determine whether a generalization of a theory holds true. It is used with statically analyzable data and commonly involves a large number of measurements or respondents. Quantitative research including surveys use structured questions and might include for example multiple choice questions. The quantitative research is limited to matters that can be measured and observed objectively. [33, 34 p.187-205]

Where quantitative research refers to counts and measures of things, the qualitative research focuses on the definitions, characteristics, meanings and concepts. It commonly focuses on smaller samples and aims to understand the research topic on a wider manner. The qualitative data are represented rather in language than in numbers. The objective of a qualitative research is to gain an insider understanding of the researched topic by discussing with the subjects. [33, 34 p.187-205]

In general, it can be said that the qualitative research methods can be used to describe and gain an understanding of the research topic and the quantitative methods to test a hypothesis. They both have the strengths and the selection should be done based on the type of research and desired type of results. [34 p.187-205]

3.1.2 Case study

Case study is a method of qualitative research. It focuses on researching a small sample of whole research population in detail. The research sample can be for example an organization, group of people or even one person. Case studies can also be conducted on other entities than people, for example documents. The main point of the case study is to gain full understanding of the research sample. [34 p.187-205]

There are aspects that should be considered with case studies. Firstly the boundaries of the studied case should be determined. The boundaries of the research sample can however be changed during the research if necessary. Secondly the data should not only be described but inductively searched for reoccurring patterns. Thirdly as the researcher is the research instrument, an attempt should be made to use several different approaches to understand the topic. This is important as the available samples are often small. [34 p.187-205]

The case study can be conducted with multiple different techniques. Some of the commonly used ones are participant observation and unstructured interviews. These techniques provide means to widen the understanding of the research topic without exact preexisting hypothesis. [34 p.187-205]

3.1.3 Interviews

Interviews differ from completely structured to unstructured interviews. As implied by the name, the structured interviews have predefined structure, whereas the flow of an unstructured interviews might vary during the interview. The interviews are not only divided to these too groups, but aspects both types can be combined. The unstructured interviews are usually used in qualitative research whereas structured interviews are used in quantitative research. [34 p.187-205]

Structured interviews are commonly used to conduct questionnaires on great number of people. The interview can be performed by telephone, which makes reaching interviewees easier. The aim of a structured interview is to keep each separate interview as comparable as possible. Because of this the questions and their order follow strict plan which is to be followed in each interview. In addition to this, all the questions should be always read with the same tone and speed. The possible answers to the questions are also often predefined and set to a scale for the interviewee to select the most suitable one. This is done to enable a statistical analysis of the answers. [34 p.187-205]

Unstructured interviews are best suited for collecting explorative information or deepening the understanding of a topic. This can be utilized for example to identify important aspects of given topic for base of further research. On the other hand, free structure allows detailed and specific questions to be made based on the previous answers. This enables the researcher to collect detailed information about topics of interested found during the interview. Even though the questions of an unstructured interview are not predefined, the interviewer should have a clear understanding of what topics are to be researched. This way he can focus the interview on the desired topics. [34 p.187-205]

The questions of an unstructured interview are often open and focus on the interviewee’s experiences. This makes statistical analysis of the answers difficult. The interviews are also often performed as face to face meetings which makes performing the research mote time consuming than with structured interviews. For these reasons the unstructured interviews are usually conducted on smaller groups of people than structured interviews. [34 p.187-205]

One aspect of unstructured interviews is that the interviewer actively participates the conversation. This increases the risk of interviewer effecting the results with his own opinions. Because of this the interviewer should be extra careful not to imply his views to the interviewee. [34 p.187-205]

3.2 Selected research approach

The main research question of this study is “What aspects should be considered in subcontracted component management?” The research was concluded in three parts as a case study. The subject of the case study was a company matching the example case introduced in chapter 2.1. The aim of the first part of a study was to understand the starting point and to find the requirements that the company has for their component management system. This was done by interviewing the employees of a company and literature review. The second part of the research was to find a suitable solution based on the requirements set by the interviews and pre-existing work on the topic. The third part was to create an example implementation of the solution and evaluate the suitability based on the gathered requirements.

The research question for the first part of the study was “What is required of the component management solution”. The research was concluded as unstructured interviews of the industry experts. The interviewed personnel included process engineers and IT solution architect. The interviews were concluded as face to face interviews and Skype meetings as natural conversation. The first round of interviews was conducted in the beginning of the research. Further rounds of interviews were done through whole research process to deepen the understanding of the topics.

The unstructured interview was used as the method of collecting information as the sample size of interviewees was relatively small and the aim of the research was to find important aspects and requirements related to the topic. Unstructured interview made it possible to first gather general understanding of the topic and make more detailed questions during the same interview.

4. SOLUTION

The second phase of the research was to develop a solution based on the requirements found in the first phase and existing literature. The aim was to fill as many requirements as possible and implement the solution as a proof of concept. The solution was done by researching existing solutions and reflecting them against the found requirements.

4.1 The procurement process

There are several ways to find the suitable components after the requirements for them are determined. The simplest solution is to browse suppliers' catalogs and find the suitable components. This can however be time consuming if there is no single source for browsing different suppliers' components. This is also not possible with components that are custom made and thus are not included in the catalogs.

Two used methods for procurement were identified in the interviews. The more used method is to leave the selection of the suitable components to the suppliers. This is done to utilize the supplier's expertise of their products and to set the responsibility of the correct selection for them. This is possible with a process with following phases

1. Definition of requirements
2. Request for quotations
3. Quotation from suppliers
4. Purchase order

As discussed in the chapter 1, the procurement process begins from the definition of the requirements for each component. These requirements are derived for example of the design of the product that the components are required for. Other sources can be for example industry standards and enterprises preferences. After this is completed the requests for quotations can be sent to the suppliers providing the desired type of components.

Quotations returned by the suppliers provide the information of their offered prices, promised delivery times and possible inability to supply the requested components. By comparing these quotations, the best offer can be found. After this the actual Purchase orders can be made to the selected suppliers. Many ERPs link the all these phases together providing traceability over the whole process. One limitation set by the case company ERP system is that each component should have an item code assigned to it already in the RFQ phase. This is notable as the exact purchased components are not known in this phase. The quotation process also enables procurement of custom-made components as the quotation is always done by the supplier based on the RFQ. The key point is that the exact components are not know before the item codes are required. The simplified visualization of the process used in the case company for quotation is presented in the figure 9.

Figure 9. *Simplified quotation process*

In the second procurement process utilized by the case company the exact procured components are already known in the RFQ phase. This is important as the exact item codes could be used in the RFQ and Purchase order.

4.2 Itemization

One of the critical factors for a successful ERP system is data accuracy. [9] For this reason many ERP systems managing the resources require that all bought components are itemized. The role of an item is to group together actual physical components on the desired level. A common way to itemize components is to gives all identical components the same item. This is how for example catalogs work, as customer can order several pieces of the same item. This enables the system to keep track of the storage balance of each item. The extra components can be stored and used later if the components are bought in bigger batches than required for example to lower the costs. As the solution should support the ERP systems the principle of using the itemization of components is to be supported by the solution.

Minimum requirement for an item is a code uniquely identifying it from the other items. This can be a for example randomly generated code such as GUID, running number or a descriptive code. The benefits of randomly generated code and running number are that they are easily assignable and manageable. They however do not provide any information about the actual item. In comparison, a descriptive code is more complicated to assign automatically but in turn it can provide the reader with a hint of what kind of item code is linked to.

The main principle of itemization is to identify the assigned components. This can be accomplished by multiple different means. Each item must be unique on the level desired from the items. These can be based for example on the unique drawing id of a manufactured item. In this case the separation is done on a highly detailed level as each even a slight difference in drawings would cause the separate item code to be assigned. This principle is suitable for example when exact shape of the component is crucial for the use case. One of the benefits of this method is that it can be easily automated as each unique drawing induces an unique item. However, in this case grouping similar components together would be complicated.

Another way to separate items is to compare all the information that is available for them. This information can be for example technical designations of components provided by suppliers or simply suppliers own type codes. This is however often quite challenging as the human readable descriptions of components provided by suppliers vary in form. Benefit of this type of separation is that it can be done on any level from detailed to grouped. The weakness is that it usually requires a human or an algorithm capable of understanding free formed text to separate the items with desired rules. This in turn is either time consuming or technically challenging. There exists research of the interpretation of text. [35]

The third option is to use combination of properties to define the uniqueness of an item. One solution for this process is the utilization of generic components introduced by Peltonen et al. [12 p.42-44]. These generic components combine the exact components based on their properties. The separation of items can be achieved by comparing the uniqueness of these property value combinations. The property-based separation also includes the drawing-based separation as the drawing number can be assigned as one of the properties. The challenge of property-based separation is management of all required properties and ensuring the uniqueness of the values. This principle is suitable for the RFQ itemization in cases where the exact items are not known.

4.3 Procurement item

In general itemization of components on the exact level is useful as it provides the separation of components on the detailed level. This is useful for managing warehouses and providing customers a catalog of different products. However, as discussed in the previous chapter, exact items desired to be purchased are not always known in the procurement phase. Instead the general items could be used, as they could be filled by multiple different exact items. From this rises the need for a separate level of itemization, procurement item.

By separating the requirements to their own item level, the RFQs can be easily created in ERP system. Components for separate positions sharing the same requirements can easily be managed as they have the same procurement item id. Requirements also easily be made available to suppliers from separate interfaces as the item code can be used to link them to the RFQ.

As the suppliers return their bids for the RFQs the information of compatibility of specific items for each case can gathered. With this information a library of compatible exact items for each requirement case can be created. We can also gather property-based information even from suppliers who do not specifically provide it, as each component offered by suppliers fills the requirements set by the properties of the procurement item. If same requirements are used in other positions, we already have list of suitable components and suppliers. The relation of procurement item is visualized in figure 10.

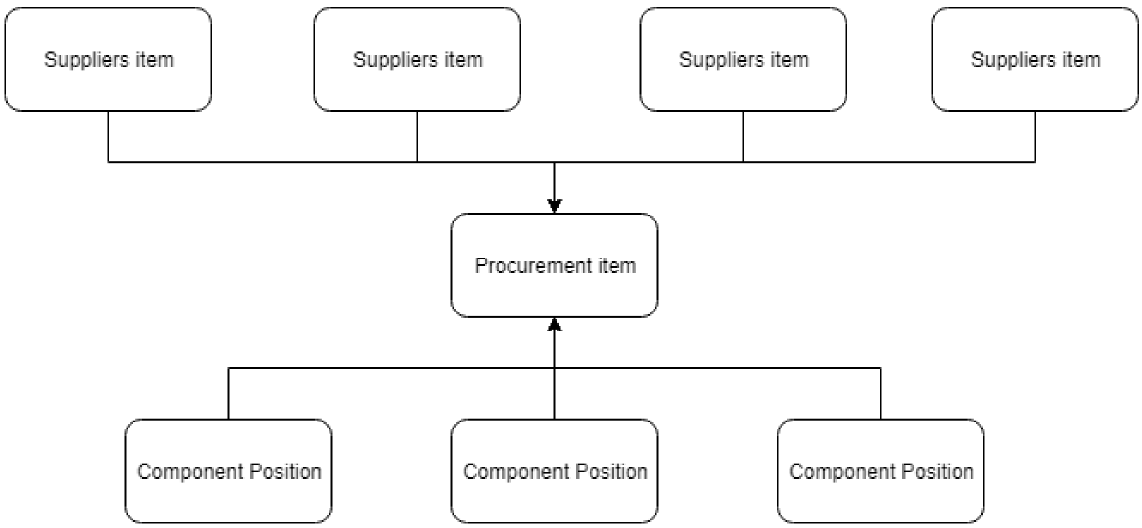

Figure 10. *Relation of procurement item*

When actualized prices of procurement items are linked to the properties defining them, the data can be analyzed to identify possible key properties and values raising the price of the component. This could then be considered in the design process to make informed choices where possible. In the end procurement costs could be lowered by avoiding the identified price raising properties. An example of such a property could be as specific lining material of a valve.

The benefit is even greater with suppliers who provide property-based e-catalogs of their products. In these cases, the requirements of the procurement items can be used to directly query the catalogs to automatically find the suitable options. This would speed the procurement process immensely. Having the catalog of supplier's products and requirements is however only a part of this process as the requirements and catalog also have to be compatible. The easiest way to accomplish this is that all parties support the same standard of classification. Examples of suitable property based third party classification standards are ETIM, ECl@ss, ISO13584 and IEC61360 [18, 36]

A use case of procurement item in the process piping environment having a valve as the component, is described in figure 11.

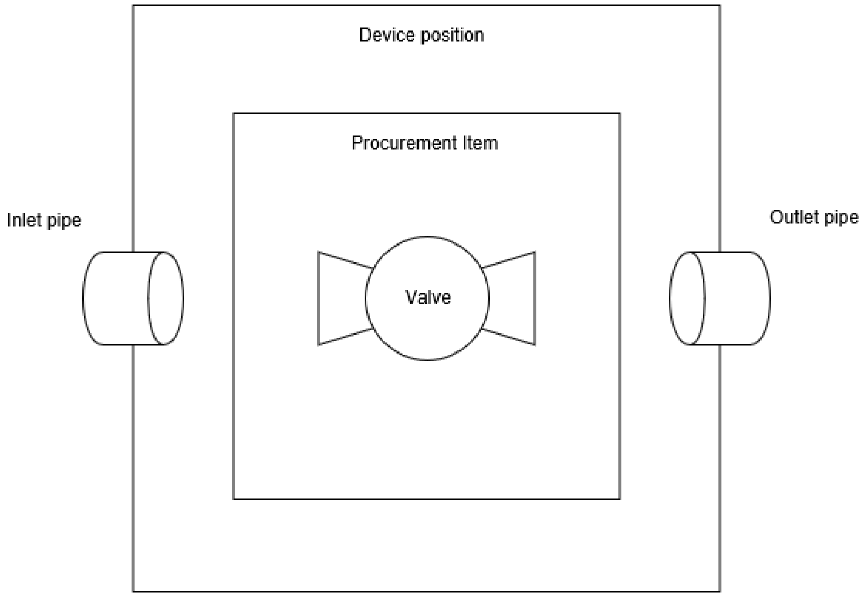

Figure 11. *Logical environment of procurement code*

Component position describes the environment in which the component will be used. In case of valves the main factors are the connected pipes and the flow media. These have there their own properties which in turn define what is required from the valve. For example, the nominal diameter (DN) of the outlet pipe defines that the valve has to be compatible with the size [37].

The final component bought to the component position has also its own properties. These define the component exactly. These include for example supplier's id for the component, exact body material and maximum operating pressure. The role of the procurement item is to work as bridge connecting the two entities. The component position defines the procurement item which in turn defines what requirements the final component should meet. A simple example of this is the operating pressure defined by the component position. The maximum operating pressure of the valve provided by the supplier should be at least this, but it can exceed the minimum requirement.

Requirements related to for example delivery times and conditions are often important part of procurement of components. These requirements differ from the technical requirements for the components as they are more related to the specific case than the component itself. The procurement item aims specifically to define the technical requirements for the components to ensure the compatibility within the product. For this reason, the delivery times etc. should not be considered by the item and handled separately in procurement process.

4.4 Descriptive code

Another aspect identified in the interview is the need for a descriptive code. This need is related to management of items in the case company's ERP system. It would be beneficiary to use visual item codes as many listings of items in the ERP system only shows the item code. The descriptive code has two objectives. Primarily to uniquely identify item and secondly provide user with general idea of the item it is linked to. The code should have three parts: prefix, descriptive part and running number. The role of the prefix is to help identifying the code as a procurement code. It is used in front of every procurement code. The prefix should be common inside the whole enterprise.

The descriptive part is the most complicated of the three parts. It should provide the user an idea of the item. In the simplest form this could be a character combination describing the type of the item. For example, all valves could have the characters "VAL" and pumps "PUM" in the code. More complex and informative option is to create the descriptive part based on the property value pairs of the item. In this version the most important properties of the characterization class would be visualized in the code. Either every allowed value of the properties included in the code should have a symbol used in the code assigned to them, or the property should have a formula for calculating the descriptive characters from the values. The length of the descriptive part should however be kept as short as possible to keep the code understandable.

The third part is the running number. This part is required if all the properties of the class are not included int the descriptive part or if the characters describing the values do not have one to one relation to the values. This could be the case for example with rounding the decimals to shorter version for the code. An example of a possible descriptive item code and the parts is shown in figure 12.

Figure 12. *Descriptive code*

In this example the different properties included in the code are color coded for the clarity. The red “VAL” would describe that this is a valve, green 50 could be the DN-size, yellow 25 could describe the pressure class, purple “G” that it is a globe valve and the blue “BB” could describe the connection types of inlet and outlet. The running number in the end tells that this is the fourteenth used property value combination with this descriptive part.

The user has to know what properties are visualized in the code and how many characters they use for this type of coding to be useful. For this reason, the most common properties should be prioritized to the beginning of the code. This way for example pipes and valves with same size and pressure class would have common beginning of the code. Exception to this is the component type description in the begin of the code.

4.5 Suggested Data model

The used data model is crucial part in keeping the data consistent and manageable. The principal of procurement items could be implemented with multiple different data models. This chapter suggest a solution enabling the implementation and discusses the arguments for and against it. Different options for choices are also introduced and compared. Detailed description of the implementation is not in the scope of this thesis, but instead the crucial points considering the design are described.

One of the key aspects of the procurement items solution is to ease interchangeability of information between separate companies’ product databases. To enable this the solution should comply with common standards of component characterization. The solution is based on the ISO 13584 standard as it is an internationally acknowledged standard supported for example by ECl@ss [13, 20, 38].

As discussed earlier in chapter 4.1.1, the procurement items should be characterized by property-value pairs. Keeping these properties and items manageable and suitable for the purpose is to be solved by the data model.

The most open option is to allow any item to be characterized by any properties. In broadest sense this would mean that new properties could be created by anyone and then used by any item. This type of model would allow very flexible and quick way of working. However, this would make analyzability of the data weak as there could be created multiple separate properties with the same actual meaning. For this reason, all the allowed properties should be predefined and managed by authorized personnel. This will slow process when new properties are required but greatly increase the data consistency.

Similar question rises considering the values of properties. The data consistency can be further improved by predefining all allowed values as lists. This could however prove inconvenient for example with numbers. However even in these cases there should be rules allowing only as limited range of values as possible. The different data types and their restrictions are defined in ISO 13584-42. [38] The use of predefined lists of values should be preferred where possible.

Often requirements for separate components have commonalities. For example, requirements for a valve used in process piping often include a requirement for pressure class and diameter of inlet and outlet. Organizing these commonalities under same structures would further improve the data manageability. The Product characterization class defined by ISO13584-42 is suitable for this purpose. It is defined as “Class of products that fulfill the same function and that share common properties”. [38] The definition of product characterization class also includes the principal of class inheritance. The principal is defined in the standard as “is-a relationship”. This means that classes can be specializations of other classes and thus form a hierarchical structure. This enables the definition of classes and thus assigned requirements be multileveled. In other words, the common properties could be defined upper in the hierarchy and every level of specialization would enrich the definition.

ISO 13584 defines two types of characterization properties: visible and applicable. The properties defined by a characterization class are visible to it. This however does not mean that each component belonging to the class must have an aspect corresponding to it. The property is applicable if every component belonging to the class must have an aspect corresponding to it. [38]

For the descriptive code assignation to be possible, few more properties should be added to ISO13584-42 definition of properties. These properties are is_describing, description_order and description_rule. Every allowed value of a property should also have a descripitive part used in the code as property. These properties determine whether the property is included in the descriptive part and how the code is formed from the value.

A constraint relating to the class inheritance and descriptive rules is that a child class should never include properties with smaller descriptive_order than its super class. This means that any properties introduced by classes cannot preside the possible properties of their super classes in the descriptive part. This rule is used to prevent contradictions and to promote the principle of using most common properties in the beginning of the code. The suggested data model is visualized in appendix A.

4.6 Architecture

The actual implementation of the component management system should be integral part of the PDM or PLM system used by the company. In this study the example implementation was implemented as separate database and linked to single engineering application via dedicated Dynamic-Link Library (DLL). Similar DLLs could be used as Application Programing Interfaces (API) between the actual PDM system and used engineering applications.

The application is divided into three layers. Core of the application is the database, which is responsible for the data consistency. Second layer is the DLL which handles data formatting and provides an API. The third layer are the applications using the API directly. The application layers are visualized in figure 13.

Figure 13. *General application layout*

The DLL provides the API for the engineering application. It provides standardized communication with the database. The database is responsible for managing the item information and consistency of the automatically created procurement items. It also stores the rules used to form the descriptive codes and forms the codes based on the rules and requirements provided by the engineer.

4.7 Supported standards

As suppliers could support different standards it is important that the solution could support as many standards as possible. The base for the data model is defined by ISO 13584 [13]. As Ecl@as also supports ISO13584, this makes our implementation easily translatable to Ecl@ss. In addition to this the solution should provide mapping between the properties used by ETIM and the properties of our implementation. This mapping is how ever not complete as not complete as our implementation has to support more properties than ETIM has currently defined. The mapping to ETIM is used as an example and the properties could be mapped to other standards too.

4.8 Selected technologies

The suggested data model induces a common problem considering relational data base implementation. Each component has multiple different properties with specific values and the properties vary vastly depending on the type of the component. There are multiple known solutions for this kind of data. The first division considering solutions is between relational databases and nonrelational databases also known as noSQL databases. The noSQL databases such as MongoDB have been lately growing in popularity as they provide open schema solution well suited for data with varying properties. [39] The comparisons between these two principles however shows that the noSQL is not always a better option. [40, 41]

Nowadays relational databases commonly provide ways to implement similar functionalities as noSQL. For example PostgreSQL and MS SQL server provide schemales architecture by utilizing JSON.[42, 43] The Microsoft SQL server was selected as the implementation technology for its ACID transactions, JSON support and familiarity to case study company. Similar functionality could however also be achieved with other technologies.

4.9 Database architecture

This chapter describes the architecture of the database on general level and inspects with more detail some of the more important and special parts. It also defines the responsibilities of the database in the solution and reasons for why the selected solutions where chosen.

The database has three main roles. Keeping track of the required properties and allowed values for each class, keeping track of the existing items and assigning the running number when creating item codes for new property value sets.

Relational databases have three commonly used approaches to manage data with varying properties. These are implementing each possible property with dedicated column, Entity-Property-Value model (EAV) and open schema columns. Using dedicated columns for each property valid option if amount of properties is limited or if same properties are shared with most of the entities. In our case the properties vary vastly between different component types and the allowing new component types to be created should be relatively easy. For these reasons tables with dedicated columns were not a viable option.

Entity-Property-Value model is one of the most commonly used relational database models addressing this issue. Nowadays the open schema columns provide an alternative solution to the same problem. [44, 45] Both of these models were implemented to test their suitability for our solution.

The database tables are divided into two different responsibility areas: item data and meta data. Item data is the data defining the actual items and their uniqueness. Meta data means all the additional data used to manage the rules used in automated creation of items.

Database implementations for EAV and open schema implementations are equal except for the properties defining an item. In open schema implementation the properties defining an item are included in the item table itself in attr_json column. In EAV implementation a separate table called item_property_value is used to save the many-to-many relationship between items and property value pairs defining them. The structure of the data base combining these both implementations is visualized in figure 14.

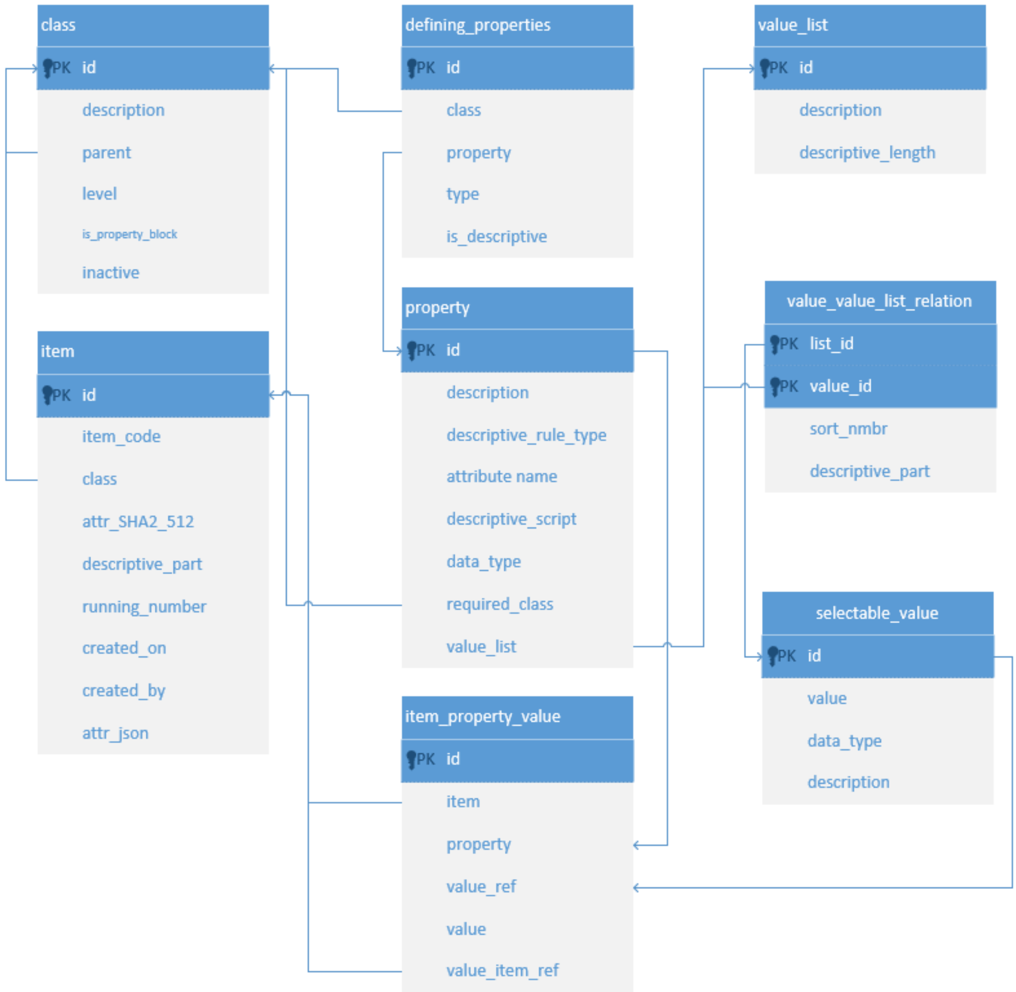

Figure 14. *Data base structure related to procurement items*

The items table breaks the second normal form as multiple of its columns are dependent on each other. For example, column attr_json has all properties and their value id's in json form. This column is used to analyze items based on their properties and values. One of the main requirements for the system is that it provides unique item codes based unique property-value combinations. To ensure this, all existing property values combinations need to be checked when reserving a new code. Comparing hundreds of thousand of json cells would however be too slow. For this reason, each set of properties is hashed with SHA_512 hashing algorithm and the has is stored in separate column. These hashes are used to check the uniqueness of the property value combination instead of the json to ensure performance with large number of rows. The descriptive part of the code is also stored in addition to the actual code. This is done the keep track of the running number related to each descriptive part while still storing the actual code.

Data base also has to maintain the rules on which the item codes are formed. Each item is based on a class. Each class has a row in class table. The classes can further reference other classes and so inherit their definitions. Defining properties for each class are defined in defining_properties table. This table acts as a connection between properties table and classes. In defining properties, it is also set weather property is included in describing part of the code for this class or not and in which order the properties are used in describing part and in technical designation. The list allowed values for a class property combination is also linked in this table. The same lists can be used by multiple properties and multiple classes and different classes might have different sets of allowed values for the same property.

All selectable values are listed in values_selectable table. The values in attr_json column of items table are the foreign keys to this table's id column. The lists of values are linked to values_selectable with value_list_relations table which allows the many to many relationships. Each value has the actual value, description and reference to an unit. They might also have additional information such as ETIM code.

The descriptive codes for values are stored in property_values_descriptive table. This table has a row for each combination of value and list that has a role in descriptive part of an item code.

4.10 Functionality and operating principles

This chapters describes the main use cases of the application and the process flow for them. The described use cases are: reserving item code, retrieving the property value description for an item code and querying items with given property value combinations.

4.10.1 Item Code Reservation

One of the tasks of the solution. This task is divided to four subtasks. The tasks are executed using c# and SQL procedures. These are:

1. Forming the descriptive part
2. Checking the existence of combination
3. Checking the validity of the provided properties and values
4. Reservation of the unique code

The code reservation function is given the ID of the class and List of PropertyValueItems as parameter. Each of these PropertyValueItems has a propety id and value id as properties. This information is passed to a database procedure which retrieves the describing parts corresponding the values for properties of the class. The procedure is shown below.

```
CREATE procedure [item_class].[get_describing_rules]( @classId int,
@params item_class.property_value_unit_table readonly )
as
begin
-- get all class id with parent relation starting from provided
@classI
with comb_class as (

select id, parent
from item_class.classes
where id = @classId
union all
select c.id, c.parent
from item_class.classes c
join comb_class on comb_class.parent = c.id
)
select df.property p.PropValue as prop_value, df.descriptive_order,
de.descriptive_part, f.descriptive_rule_type, df.class_id
from item_class.defining_propeties df
join comb_class c on c.id = df.class_id
join item_class.properties as f on f.id = df.property
join @params as p on p.PropId = df.property
```

```
  left join item_class.property_value_descriptive as de on de.list_id
= f.value_list_id and p.PropValueRef = de.value_id
  where df.is_descriptive = 1
  order by df.descriptive_order

  end
```

Program 1. *Selection of descriptive part*

Then Checking of the existence of matching set of properties and values is based on hash of the properties and values. The hash-based uniqueness is used instead EAV based model to ensure performance even with large number of items. Down side of this solution is that there is no absolute certainty of the uniqueness of property value set. However, the probability of collision of hashes of different sets is negligible even with much larger number of row than expected. With selected hashing algorithm SHA-256 the probability of collision even with 4.8x10^9 rows is 10^-18. The performance is further improved by indexing the hash column.

The validity of the properties and values is checked by comparing the provided values with SQL procedure to the ones defined for the class. These procedures check that the properties are set defined for the provided class or its parent classes and that provided value of each property is found in the list linked to the property.

A new code is created if no code with matching properties and values was found. Database keeps track of running numbers for each descriptive part and this is always increased by one when a new code is created. The running number is filled with preceding zeros to the desired length and it is combined with the prefix and the descriptive part. An example of a code is PRTVSGEBS3AS1510001

4.10.2 Retrieving properties and values defining an item code

One of the key functionalities of the application is the ability to get the properties and values that were used to reserve the code. This provides the back traceability and describes the items in more detailed level than the code alone.

The process of retrieving the description is mainly executed in the database. Each code is having a JSON column with an array of property ID and values ID pairs for each property used to reserve the code. This column is then cross applied with the tables containing the actual values and descriptions of each property. The SQL code used in the query is shown in program 2.

```
  Begin
```

```
select f.id,
f.description as property_description,
vs.type as value_type,
j.value as free_value,
j.ValueId as value_ref,
vs.value as selected_value,
vs.description as value_description,
i.class as class_id,
f.is_open_value

from item_class.items i
CROSS APPLY OPENJSON(i.attr_json_array)
WITH (  Property int '$.Property,
ValueId int '$.ValueRef',
Value nvarchar(500) '$.Value') as j

join item_class.property as f on j.property = f.id
left join item_class.values_selectable as vs on vs.id = j.ValueId
where i.item_code = @itemCode

end
```

Program 2. *Retrieving properties and values defining a code*

These values are then either handled in the DLL in the desired way before providing them the caller. The values can be retuned for example as an object or as a string combining the descriptions and values. These could be used to implement for example online catalogs of the components.

4.10.3 Querying the items with sets of properties and values

The user has to also be able to query items matching the desired sets of properties and their values. In a case like this the user could be for example searching for all the ball valves of with DN size 50, pressure class 90 and flanged connections. He should get the list of all item codes filling these requirements.

The set of parameter properties and values is given to the item tool’s member function which forms escapes the values and class the stored procedure used to query the items. The property sets of the items are also stored as a json object with property id as property key and value id as linked value. This makes using querying the json easier as the key value pairs of the json can be given directly as query’s conditions.

5. RESULTS

In this chapter the results of the thesis are presented and discussed. The goals of the thesis were divided into two parts. The research questions for the were:

RQ1*: What aspects should be considered when creating component management solution?*

RQ2: *What kind of solution could be used to meet these aspects?*

The aspects identified in the interviews and literature review are introduced as following parts:

1. Stakeholders
2. Business related aspects
3. Component type specific aspects

The second goal of the thesis was to develop a solution considering the identified aspects. The key points of the developed solution are collected in this chapter as follows:

4. Considered item types
5. Defining properties for manual valve procurement items
6. Suitability of the standards
7. Requirements met by the solution

5.1 Stakeholders

This chapter introduces the different stakeholders and their needs and benefits considering the items. The stakeholders and their needs were identified in the case study.

5.1.1 Capital

This group of stakeholders is defined as a part of the business when new products are designed and manufactured for customers needs. The capital phase includes multiple different departments. These are: sales, engineering, purchasing, manufacturing, logistics, erection and spare part package.

An aspect specific for this business is that the used components can be selected somewhat freely. In most cases there is no existing installed base and the detailed design has wide freedom. There are however almost always general constraints set for the components by the customer and legislation. These can be for example required component type specific standards and safety standards.

In the capital projects there is no direct benefit of identifying the exact same components supplied by multiple different suppliers. This is because the cheapest offer filling the requirements is always selected. However, the capital phase lays the foundation for the later service and spare part cases.

5.1.2 Spare Parts

Spare parts sales as business are usually part of the capital project but also focus on after sales. The specific aspect of spare parts business is that it is greatly defined by the previous work. The components used to build the process need to be identified accurately to be able to identify the compatible spare parts for them. The spare part requirement for detailed information of components differs from Capital and service requirements, as spare parts need to know the internal structure of components whereas capital and service are mainly interested in identifying only the main level of components.

In capital projects the spare part package is sold as part of the project and it contains spare parts estimated to be critical during agreed time period of use of boiler. This can mean for example wearable or process critical parts.

The other part of spare part business is so called daily spare parts. This business focuses on providing specific spare parts for customers with existing boilers. Usual cases during periodic maintenance rundowns of boilers or when something is already broken.

5.1.3 Sales

In capital phase the sales department does not consider the components separately, but the product as a whole. The main objective of the capital sales department is to sell the project. In this phase the exact design of the product and so the exact used components are not known.

The benefits of well-structured and accurate product and item data for sales are in better estimation of project material costs. This information could be utilized with a product configurator referencing previous designs and the average prices of the used item types. The sales department rarely defines the specific required components, but of the sets the first border requirements for the project, such as used standards.

5.1.4 Engineering

Engineering department is responsible for design of the boiler. It can be divided into multiple subdivisions with specific responsibility areas and specific needs for items.

These are for example process engineering, piping engineering, automation engineering and mechanical engineering. Some of these design processes are parallel where as some are subsequent to each other.

The subsequent engineering processes set different requirements for the same items. For example, with hand valves the first phase is process engineering. This phase sets the process values required from the components. Based on these requirements the hand valves are selected and purchased. In the piping engineering phase, the outside measurements and the orientation of the actuator are also needed for the valves.

Data management in engineering phase is in the key role considering the consistency of the item data.

5.1.5 Procurement

The procurement department is responsible for finding and purchasing the required components for lowest price. The requirements are passed to procurement department from engineering and procurement based on these requirements the requests for quotations are passed to suppliers. The purchased components are selected based on the quotations.

Procurement team requires clear definition of requirements for each component. In capital procurement cases this definition could be based on required process values. In case of spare parts the exact suppliers component needs to be identified.

5.1.6 Logistics

Logistics department is responsible of ordering the transportation of purchased components to customer. They need to be able to manage which components are transported, when and how. Crucial information for each component from logistics point of view are size measurements, weight and special transportation requirements.

The logistics departments also require the commodity code for components in case they are transported over country borders. [46]

5.1.7 Suppliers

For commercial items the suppliers are the main source of information. Suppliers are provided with the requirements for the components and they offer corresponding components from their selection. Suppliers provide their own manufactured and subcontracted components. It is in suppliers’ interest to not reveal the original manufacturer of the components to prevent customer from purchasing the components in the future directly from the original manufacturer or competitors.

For the same reason the suppliers commonly do not reveal the exact information of the structure and subcomponents of their components. However, they are usually willing to list the spare parts used by the main component. Their ability to provide detailed information of even their own item codes for components varies widely depending on whether the components are custom made or standard stock items. Suppliers ability to identify their equal components varies depending on their product data management. This means that supplier might have multiple item codes for the same components.

5.1.8 Customer

Customer requirements for component identification vary. After the guarantee period the customer will be responsible for maintaining the boiler. Customer needs to be able to identify the broken components and order compatible spare parts. Customer should also be able to identify the corresponding components used in multiple different positions to optimize the storage and use of spare parts.

5.1.9 Data management team

Data management team is responsible for maintaining the consistency and correctness of the data. They must be able to easily find similar existing items to avoid duplicate items.

5.2 Business related aspects

5.2.1 Component requirements defined in design process

The engineers set the requirements for the components with the engineering applications during the design process. The design process is based on a library of predefined modules. These modules define the basic layout of the product and required components on the level of component type for each device position. A device position means a specific position for a component in the product. An example of a Piping and Instrumentation diagram (PI-diagram) displaying device positions in a process is shown in the figure 9.

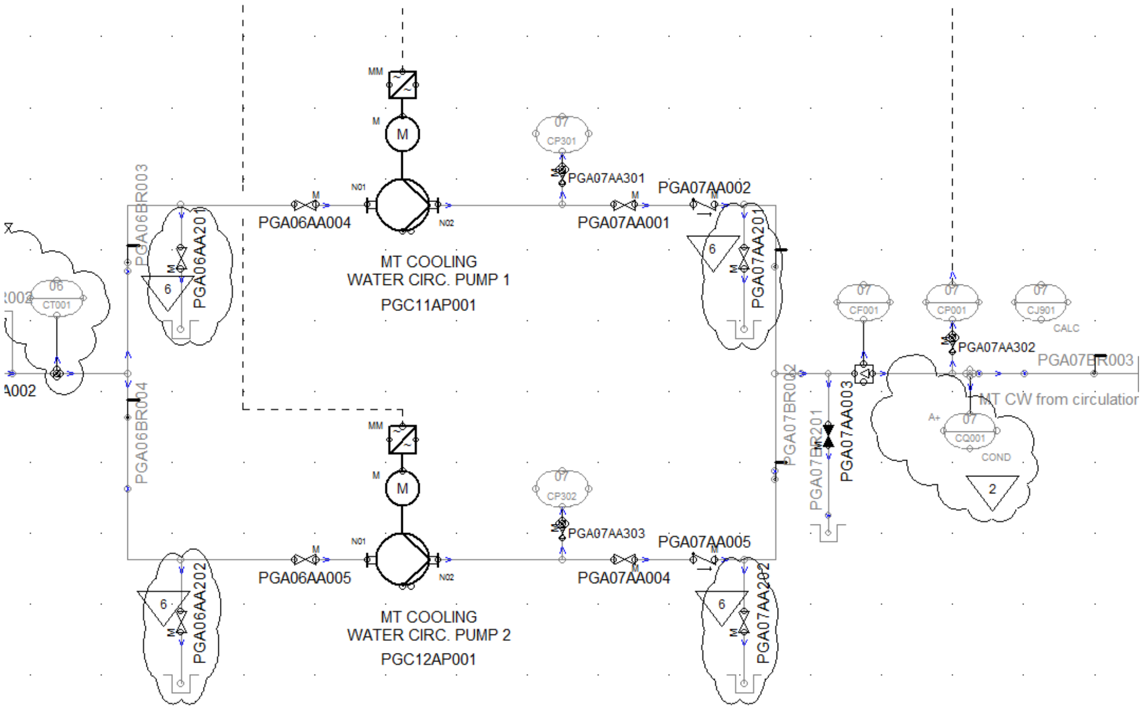

Figure 15. *PI-diagram*

The process values for these device positions are set by designers based the requirements set by the customer. The process values of the device positions set the requirements for the components. The design process is concluded as an iterative process in multiple separate applications. Based on these requirements the most suitable components should be identified.

5.2.2 Component types

The components can be categorized into three different main categories. The categories are own manufactured, own designed and commercial. The own manufactured components are both designed and manufactured within the company. The own designed components are designed within the company and manufactured by the subcontractors. In these cases, the exact manufacturing drawings exist for each component. The third category is commercial components. These are designed and manufactured by the subcontractors.

The own designed components are itemized based on the drawings of the component. Each drawing has unique drawing number which is linked to the item. The item may also have a Bill Of Material (BOM), which lists the subcomponents of the item. These subcomponents may also recursively consist of BOMs of their own. The items may be project specific in which case they are meant to be only once. Commonly used components may also be generalized as standard items. In this case they can be used in multiple different projects.

The components can be divided into a hierarchical type or class structure. Main classes of the components could be for example valves, filters, pumps etcetera. Valves can be further divided into manual and automatic valves.

5.2.3 Properties of components

The same type of components also share similar properties determining the requirement for the component. Some of these properties are also shared by multiple different types of components. For example, the DN-size is common to hand valve and a pipe and it can be used to compare their compatibility to each other. However, there is variation in requirement properties even within the same component group. For example the wall thickness of hand valves is a crucial property if the connection of the valve is welded. However, with the flanged connections the pressure class of the flange is the requirement instead of the wall thickness.

The requirements for the properties can be either exact, minimum or maximum. For example the DN-size of the valve is an exact requirement as it should be compatible with the connecting pipe. The diameter of the valves inlet has to be same as the pipes. An example of a minimum requirement is the pressure class of the valve. This means that the allowed maximum pressure of the valve has to be at least as high as the calculated maximum pressure of the pipe line with the safety limits. Commonly the higher-pressure class reflects as higher valve price and thus makes the valve less desirable.

Some properties, such as the material of the valve depend on multiple different properties, such as operating pressure and operating temperature of the valve and corrosiveness of the flow medium. The engineers want to define the allowed materials themselves as requirement instead of providing these differentiated properties to supplier. This is because not all suppliers can be trusted to have the expertise of all flow mediums and the requirements they pose. The exact materials can however be divided into groups filling the same requirements. These groups can be used as requirements for the valve body material.

5.2.4 Constraints set by suppliers

The level of detail of the available information for these components depends what the subcontractor is willing to provide. Often the subcontractors are not willing to provide the detailed information of the components to prevent the customer from buying the corresponding products from their competitors. Many component suppliers also act only as vendors for their subcontractors' components. It is commonly in vendors interest to conceal the actual manufacturer of the component. This way they try to prevent the customer from buying the components directly from the manufacturer in the future.

In some cases, the supplier cannot even provide their own identification for the component until the components are delivered. This might be the case when components are highly customized or when the supplier's own product management is deficient. Similar components should however be identifiable earlier for the management of the procurement process.

5.2.5 Component identification

One of the key requirements for the solution is that it should provide an itemization level separating the possible suppliers item codes from the ones provided to the customer. This means that while the company itself should have the knowledge of which component of which supplier is used, this information should not be passed to the customer. Instead a separate identification code should be created. This is needed to prevent the customer from buying the components directly from the supplier in the future.

The system should also provide an identification for the equal components even before the actual exact components are known. These codes can be used in ERP system for procurement of the components and to identify how many of each component is needed. The uniqueness should be determined by the requirements set by the engineers. This way all components with the same procurement identification can be used in any of the positions with the same requirements.

The code should describe the components that it is linked to. This means that the code should provide the user with an idea of what the component is. This is beneficial as many of the component lists only display the component code. With descriptive code the different types of components can be easily differentiated, and the user is able to get an idea of what is included in the list.

5.2.6 Automation of item management

The assignment of codes for the requirements sets should be automated. This is required as hundreds of component positions might need codes at the same time, once the design process is completed. The codes are needed to identify corresponding components in the procurement phase. The procurement should be started as soon as possible and thus the time for code reservation should be minimized.

5.3 Recognized component types

The components used by the boiler system can be divided into two main categories. These categories are own design components and commercial components. Both of these component types can be further divided into subcategories based on the aspects related to their management. This research focused on the commercial components.

Commercial components identified in the interviews are categorized in this chapter. These components could be categorized in multiple different ways. The division used here is based on the technical use of the component and aspects related to the procurement of the components. Only the procured components are listed here.

5.3.1 Piping components

Piping components are components used in the piping, such as bends, pipe, flanges and reductions. Specific to these components is that they are relatively simple thus can be fully defined with given properties such used standard, diameter of the pipe and material. Following component types were identified in the interviews.

1. Bend
2. Bolt
3. Cap
4. Elbow 45º
5. Elbow 90º
6. Flange
7. Gasket
8. Pipe
9. Quick hose coupling
10. Reduction
11. Reduction Tee
12. Tee

This means that engineer defining the process requirements can already define exact item needed. The same item can be used with all the components fulfilling the requirements set by the engineer regardless the final supplier.

The component must fill certain requirements to be valid as a fully definable item. Firstly, it must be possible to define set of properties that define the component on level that make all the components with matching property-value sets interchangeable. Secondly these components cannot use spare parts that are not directly deducible from the property-value set defining the component.

5.3.2 Manual Valves

Manual valves are used in the process to control flows. The process specific requirements for these components can be defined in the process engineering phase. The procurement of the manual valves in capital phase is concluded based on these requirements. The requirements are sent to multiple different suppliers whom provide their suggestion for suitable components as quotation.

It is desirable to have suppliers select the suitable valves in capital phase based on the requirements set by the engineers. This is done instead of requesting for quotation of specific suppliers' items to utilize their knowledge and to set the responsibility of the selection on the supplier. This makes it possible to demand for replacement in case of mistakes.

The manual valves filling the same set of requirements are purchased as single suppliers' single item. This makes the set of requirements uniquely identifying within a project. This is however not the case over different projects. Components provided by different supplier can be used to fill the same requirement in a separate project.

More detailed information of the selected components is required after the supplier and exact components for each requirement set are selected. Such information is for example the outside measurements of the valve which are required for the piping engineering.

Manual valves are often completely replaced in case of break down. In some cases, spare parts might be used. For this reason, the exact suppliers or manufacturers component must be known after the project.

5.3.3 Electrifications and instruments

Process automation of the boiler process requires considerable amount different components. These components are in many cases supplied by suppliers. Special consideration has to be taken when managing these components. Examples of different instrument types are flowmeters, pressure measurements, level switches, pressure switches and transmitters.

In addition to being compatible to the process system, the automation components have to be compatible with rest of the automation system. Connectivity between sensor and rest of the system is usually implemented with transmitters. These transmitters might be integrated within the sensor component or sold separately. The transmitters commonly support variety of standardized inputs and outputs, such as HART, Profibus and Modbus.

One of the special aspects of automation components compared to other inspected components is that the same physical components could be calibrated differently. This is important to acknowledge for example in cases where the customer need to have pre calibrated instruments. However, it is also important to identify the equal physical components as same item regardless of the calibration as the instruments can often also be calibrated on site. In these cases, the same components could be stored as spare parts as reserve for multiple positions requiring different calibration.

In many cases the broken instruments are replaced with new equal components. In some cases, it might however be reasonable to provide subcomponents as spare parts. Such a case could be for example broken plastic casing of a transmitter.

5.4 Considered item types

Two different itemization main principles were recognized during the research. The first principle is based on a one or more sub identifiers. These identifiers can be for example manufacturing drawing number or suppliers item code for a component. The second principle is based on the technical properties of the component. These principles and their benefits and challenges are introduced in this chapter.

5.4.1 Exact manufacturer items

Exact manufacturer items are the basics building block of a PDM system. This item should be based on the components original manufacturers item code or drawing numbers. Each item should be assigned an unique item code. Components identified by the same code are always interchangeable as they are based on the original manufacturer's exact component implementation. These items should also be linked to compatible spare part items. This type of items can be used to manage product structure in PDM system and warehouse balances in ERP.

Each item should have minimum of following properties assigned:

1. Identity Code
2. Item Family
3. Description
4. Manufacturer
5. Manufacturer type code
6. Customs codes
7. Weight
8. Outside measurements
9. State
10. Unit

Additionally, each component type should have type specific technical properties determined. These properties can be managed by classes and they should be linked to international standards such as ETIM.

Creation and management of these items requires considerable effort as it should always be ensured that duplicate items are not created when new suppliers item is used. This can be challenging as many suppliers provide same manufacturers items with different type codes.

Two principles can be followed managing these components. First option is to always handle the itemization process when new supplier’s component is used. Benefit of this approach is that only the used components are itemized. This is suitable for example with seldomly used suppliers. The problem however is that this might increase the lead time especially in cases where great amounts of different new components are required to be itemized at the same time.

Second option is to integrate the item management system with certain suppliers PDM systems. This can be done either with periodical integrations or with active synchronization. In this case the items would already be processed when they are required. However, this increases the overhead work in case some of the components are never used. For this reason, this method should only be used with important suppliers and already used components.

The items could also contain item family specific properties. These properties could be used to find suitable options for specific requirements. Integration with suppliers PDM system could be utilized to acquire this information.

5.4.2 Automatically created procurement items

Concept of automatic creation of procurement items based on the requirements was researched as possibility for capital phase item management. The concept was based on predefined classes with dedicated properties. Each item would be a unique combination of property value pairs.

This concept would fill the requirements of the capital procurement as unique supplier independent items could be used in requests for quotation. This also minimizes the item management work required before the actual purchased components are decided.

This concept can be used to manage the components over specific project only in with component types that are simple enough to be completely determined by requirements set by the engineer. An example of this kind of components would be the piping reductions and tubes.

With more complicated components such as manual valves and sensors this concept creates duplicate items for same components. This is because same component could be used for different requirements. For example, a manual valve with maximum allowed pressure of 50 bars could be linked to procurement item requiring 30 bars and other requiring 40 bars.

This is not desirable considering warehouse balance management as the same component could be shown multiple different quantities. Another problem is that the related spare parts or any detailed information cannot be assigned to the item if the same requirement set can be implemented by multiple different components. This lowers the benefit of items for spare parts after sales.

For these reasons the purchased components should be itemized with manufacturer type specific items after the quotation phase. Relation between the procurement item and actual manufacturer type specific item can be utilized to recommend these components for engineers if the same requirements are used later. This would be beneficiary in cases where property-based information is not available for the manufacturer type specific items.

5.5 Defining properties for hand valves

Properties uniquely defining the components were studied for hand valves. These properties are to be used to identify unique valves and create them procurement items within a project. These properties were identified with the interviews and study of related standards.

Hand valves are an example of a component with a wide range of properties but not all being critical for the process. For example, the exact length of the valve is not considered as a significant property for process as the lengths of the connected pipes can be modified in the design phase. The found significant properties are collected in table 2.

Table 1. *Defining properties for two way hand valve*

	Single property	**Per inlet / outlet**	**Condition**	**Type**
Valve type	X			Select
Standard	X			Select
Material	X			Select
Limit Switch for handvalves	X			Select
Sealing Material	X			Select
Manual actuator type	X			Select
Valve Body lining material	X			Select
Valve Disk lining material	X			Select
Pressure class input		X	Flanged inlets /outlets	Numerical
Connection type (inlet)		X		Select
DN / NPS		X	Per inlet/outlet	Select
Flange Pressure Class		X	Other inlet types	Numerical
Material (inlet/outlet)		X		Select
Schedule		X	For welded inlets/outlets (ASME)	Select
Wall thickness		X	For welded inlets/outlets (EN)	Numerical

Some of the properties are considered relevant for all hand valves and some only when certain condition is filled. The possible conditions of the properties are listed in the condition column of the table. Part of the properties are inlet or outlet specific and should be defined of each inlet specifically. In most cases these properties will have corresponding values, but there might be cases where the requirement differs between inlets. For example, the connection type.

Most of the properties can be assigned a list of allowed values as the number of possible values are limited. The type of the values allowed for the property are shown in the type column. The “Select” shows that the property has a definite set of values that can be predefined. The “Numerical” shows that numerical value is to be assigned for the property.

The valve type refers to the valves working principle. The possible types are for example ball valve, disk valve and needle valve. Each working principle has its strengths and weaknesses and the process designer defines the desired type of valve based on the device position.

The standard that the valve should fill is also to be defined. This standard is usually defined by customers' requirements. Common standards for hand valves are EN and ASME standards [16, 17]. The used standard has on effect on what properties are used to define the requirements for the valve. For example, the ASME uses the combination of NPS and schedules to define the sizes of inlets and outlets. In this case the actual wall thickness is not directly defined but can be concluded based on the NPS and schedule by using a standard table. With EN-standard the size of the inlets and outlets are defined based on DN-size and wall thickness. [16,17]

The wall thickness of an inlet is however relevant only for inlets with welded connections. The wall thickness is always a crucial property considering the durability of valve. The required pressure class for the valve is however defined separately. The minimum wall thickness for the valve inlet is however also defined by the welding process. So in addition to being thick enough to withstand the pressure, the inlet wall must also be thick enough to be safely weldable.

5.6 Describing item code

The implemented solution included automatic assignment of the descriptive codes for procurement items based on the defining requirements. The rules for assigning codes were implemented for hand valves. This proved to be technically possible and the codes could be created based on the predefined rules.

Implemented solution was based on the predefined allowed values for each property included in describing code. Each of these values was assigned characters included in the code.

5.7 Suitability of the standards

Some of the found requirements are relevant to the itemization standards. These requirements were used to compare the selected itemization standards. The results are gathered in the table 2. The "X" describes that the standard supports the specific requirement.

Table 2. *Itemization standards by found requirements*

Requirement	eCl@ss	ETIM	UNSPSC
Property based / Item characterization	X	X	
Item classification	X	X	X
Cross component type properties	X	X	
Minimum, Maximum and exact requirements			
Dependencies between properties			
Item codes	X	X	X
Descriptive item code	X	X	

As shown in table 2, none of the standards fully supported all the requirements. The standards have also aspects that are not related to the found requirements but are still relevant. These aspects are gathered in table 3.

Table 3. Other aspects of standards

Aspect	eCl@ss	ETIM	UNSPSC
Supports ISO-13584	X		
Free to use		X	X
Provides implementation for itemization			
Versioning of the standard	X	X	X
International	X	X	X

These standards were selected as examples and for example ETIM specializes in specific industries where as eCl@ss is not industry specific [19, 20]. UNSPSC on differentiates from the other two as it is a categorization standard where as eCl@ss and ETIM also provide characterization [20, 24].

5.8 Requirements met by the solution

A solution aiming to fulfill as many of the requirements found in the interviews and literature review was developed in this thesis. The solution was implemented with C# language and Microsoft SQL-Server utilizing SQL .

The found requirements are divided into two tables. The table 4 gathers the requirements found in the interviews and the requirements found in the literature review are gathered in table 5. The requirements fully met by the solution are marked with X. Requirements that are only partly met by the solution are marked with P. Requirements that are not supported by the solution are left empty.

Table 4. Comparison of solution against requirements found in interviews

Requirement	**Interview**	**Literature**	**Requirement met**
Separation of suppliers item codes and codes provided to customer	X		X
Property based / Item characterization		X	X
Item classification		X	X
Cross component type properties		X	X
Minimum, Maximum and exact requirements			X
Dependencies between properties			X
Item codes	X	X	X
Descriptive item code	X		X
Must allow custom properties	X		X
Automatic assignment of item codes	X		X
Possibility to integrate external systems	X	X	X
Enable cross usability of suppliers components	X	X	X
Automatic HS-Code assignment			

The solution meets all other requirements except the automatic HS-code assignment.

6. CONCLUSION

6.1 Analysis of solution

The objective of this thesis was to find what aspects should be considered when managing the subcontracted components for industrial power boiler systems. Based on the found requirements two different concepts for managing the components were introduced and studied further.

A procurement process based on property-based procurement items was suggested as the solution. This solution proved to be suitable for simple components such as tubes and pipe reducers. With these components the component could be fully determined based on the properties defined by the engineer. With these simple components the property-based items could be used as primary items in ERP and PLM systems.

Property based items were also suggested for more complicated items such as manual valves. With manual valves this item type can only be utilized as quotation item and should be replaced with fully determining manufacturer type code-based items after the supplier is selected. This is required for example for management of the warehouse balances in ERP and for after sales spare parts.

The suggested solution provides a way to automatically generate and manage procurement items based on the properties derived from requirements. These items can be used in the procurement phase and then later substituted with the exact items. This enables the procurement process to be concluded in a short time window and without managing the exact items. It also makes it easy to compare components offered by suppliers as they all have the same item id.

The solution also collects the information of the relation of procurement item and the exact item implementing it. By utilizing the relation and the properties and values of the procurement item we can derive the possible use cases for each component even without the supplier providing the specific property-based information for each component. This enables the creation of a library of exact items implementing each set of requirements.

The introduced solution supports the ISO-13584 standard. The ISO standard was chosen to enable the integration to possible suppliers' systems. By supporting the international standard it is possible for anyone supporting the same standard to understand what the items actually define. This makes it easier to integrate for example e-catalogs to support the procurement process. ISO-13584 is also supported by eCl@ss.

The greatest challenge in utilizing the solution is in the definition of the properties and allowed values related to the classes and the descriptive code. To keep the code understandable to the reader the characters should have as logical as possible relation to the values they are linked to. Finding the set of properties suitable for all cases was challenging even with the smaller variation of component types used for the demonstration. With bigger amount of component types this might mean that the descriptive part of the code loses its meaning as the reader does not know how to interpret it. Also managing the descriptive codes might prove cumbersome as new values for properties are introduced and old ones deprecated.

6.2 Research validity

The research question was “What aspects should be considered with subcontracted component management?” The research was concluded as case study. The utilized methods were unstructured interviews and a literature review. In addition to these an example solution was implemented based on the aspects found in the study. This implementation was done to find possible earlier unidentified aspects.

The sample size of the case study was considerably small as it only included the personnel of one company. This affects the validity of the identified aspects as each company has variation in the designated processes. This was compensated by comparing the interview results to aspects identified in literature review.

The research results should be considered as a sample of possible aspects related to component management. However, they can be utilized as an example of the aspects in possible wider research.

6.3 Further research

Similar research with wider scope should be concluded to validate the results found in this research. This research should study the suppliers of the components in more detail to gain their view on the matter. This would provide better understanding of the current possibilities and the utilization of ISO-13584 in supplier catalogs.

Another challenge related to exact items is the need for commodity codes for exported or imported items. Commodity codes are used by customs for example to assign tariffs. The rules for assignment of commodity codes differs based on area. For example, EU uses Combined Nomenclature (CN) which is further developed from World Trade organizations Harmonized System (HS-codes). These systems divide the products based on their properties, purposes and manufacturing methods. [46] System with manageable rules of commodity codes and knowledge of item properties could connect the items with their corresponding commodity codes. Development of such a system is suggested as further research topic.

The integration of procurement items and possible e-catalogs should also be researched further as this could provide way to fully automate the procurement process in some cases. This was however left outside of the scope of this thesis.

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APPENDIX A: SUGGESTED DATA MODEL