Product structure modeling for ETO system product considering the product lifecycle
A case study of ABB Mine Hoist

Sumei Zhang
Abstract

Product structure modeling for ETO system product considering the product lifecycle

A case study of ABB Mine Hoist

Sumei Zhang

In order to gain competitive advantages in markets, companies have provided a variety of customized products to satisfy customer-specific requirements, leading to not only a large amount of product data but also high cost, long lead-time and complexity of quality control. Efficient product data management throughout the product lifecycle has become increasingly crucial, of which product structure management is regarded as the most important constituent.

The study took ABB Mine Hoist system as a case to investigate how to construct a generic product structure model fit for engineer-to-order system offerings with the consideration of their sales-delivery product lifecycle. The aim of the model is to facilitate the product-related information sharing and reuse across a company, and the integration of different business operations throughout the entire product lifecycle as well.

Based on the current situation analysis of product data management on ABB Mine Hoist, three major issues were identified which need to be addressed in the formulation of a generic structure model: namely the integration of requirements of multiple disciplines; the consistency of product information throughout the product lifecycle; and the constant update of product repository.

Through illustrating the formulation of ABB Mine Hoist generic structure model, the method of how to construct a generic product structure model for engineer-to-order system product was presented. The model was achieved by applying the framework of the step-based product model and was regarded as a result of integrating domain-specific requirements. The adaptive generic product structure model was then employed to display the role of this generic model in the different phases of a sales-delivery lifecycle.

The model could serve as a “master concept” to transfer common product information in the product lifecycle. It’s expected to benefit the business of engineer-to-order system product through improving the integration of different disciplines, enhancing information exchange and reuse. It could also provide an abstract and conceptual basis for potential product repository to reinforce data consistency and completeness.

Key words: product lifecycle management (PLM), product data management (PDM), product structure management (PSM), product structure model, engineer-to-order (ETO) product, sales-delivery process.
Acknowledgement

It has been a great experience and exciting challenge to carry out the thesis work at ABB which was assigned by the mining section. I sincerely appreciate all the supports and helps given by ABB mining. Firstly, I would like to express my special thanks to Torbjörn Ottosson for not only giving me an opportunity to do such an interesting project but also setting the keynote of how the thesis has been developed. Secondly, I would like to give my thanks to Daniel Nolkrantz, my supervisor at ABB who has constantly provided inspirations, advice and concrete support all the way through the thesis process. In addition, I would like to thank all the employees who participated in the interviews and offered valuable inputs making up the basis for the further analysis of the thesis. At last, I’m truly grateful to Håkan Kullvén, my supervisor at Uppsala University. It has been a wonderful experience working with you – the guidance, suggestions and instructions you have given is the key to the implementation of this thesis.

Västerås, 10th May 2019

Sumei Zhang
Popular Science Summary

A model for better information availability and reutilization

In the marketplace characterized by intensified competitions and diversified requirements, a large number of customized products have been produced, leading to high resources cost, long launching time and complicated quality control, especially for those complex system products. Meanwhile, it has become more and more difficult to acquire accurate and complete product data for effective product configurations. Whether be able to efficiently manage product data throughout the product lifecycle and reuse existing product data for subsequent projects at an early stage have become crucial for a company to gain its competitive advantages over its rivals.

The concept of product lifecycle management centering on the generation, preservation and utilization of product-related information has become increasingly popular to address the above issues. It captures and discusses the relevant problems in a general and integrated way, which enables the fast and easy refining, distributing and reusing of the product data required for daily operations throughout the product lifecycle.

During product lifecycle, information availability, consistency and reutilization depend heavily on the structural description of the product, namely how a product is composed of. In another word, product structure represents the backbone for product lifecycle management to govern complex product information. In order to capture and manage product structures in an efficient way, a generic, scientific product structure model is required.

Though the topic of product structure model has been discussed and investigated from different perspectives, most of them has focused on the design or manufacturing aspect rather than an overall view of the product lifecycle. Moreover, previous research efforts have concentrated on the computer-aided software applications, not enough attention has been paid to a unified product structure that integrates the requirements from different disciplines. Additionally, the application of the product models into business practices has been confined to a limited area.

ABB Mine Hoist is a complex engineer-to-order system product with long product lifecycle and service supports. It is a typical customized product solution operated in a mature business mode. The thesis took ABB Mine Hoist as a case to study how to construct a generic product structure model fit for engineer-to-order system offerings under a sales-delivery lifecycle environment. The model can be applied to improve the product-related information sharing and reuse across different departments, as well as the integration of business operations throughout the product lifecycle.

Like other engineer-to-order system products, the business of ABB Mine hoist involves a set of collaborative works from multiple disciplines and in the different phases of its sales-delivery product lifecycle. This has resulted in a large amount of product data generated from multiple data sources and remained in the hands of different data owners. During the formulation of a generic product structure model, many factors could affect the way of how the model was developed. Thus, prior to creating the model, a preparation based on current situation analysis was carried out to identify three major issues that need to be addressed in the context of the product lifecycle. They
are namely: the requirement integration of different disciplines for product structure; the information consistency throughout the product lifecycle; and the product repository update considering product changes.

Usually, different business disciplines have different requirements for product structure according to their respective usage of the structure. To address the issue of integration, the requirements from different disciplines and corresponding product structure types were analyzed. Thereafter, the integrating principles of product structures were discussed for constructing a generic model with an appropriate degree of exactness. Following this, on the basis of document analysis and previous project mapping, a generic product structure model of ABB Mine Hoist was developed through applying the framework of the step-based product model. Due to the common product characteristics and similar business operations, such a method of formulating the generic product structure model and the basic constituting frame of the model could also be applied to a broad range of engineer-to-order system products throughout the sales-delivery lifecycle.

In order to address the integration, consistency and evolution of product-related information in the product lifecycle, the adaptive generic product structure model was then employed to illustrate the role of this generic model in different phases of the sales-delivery lifecycle. It could be seen that serving as a “master concept”, the generic model plays a central role in the integration of different disciplines as well as in a closed loop of the product information lifecycle. The constantly updated product repository would be not only the element but also the outcome of such an iterative lifecycle loop.

This generic product structure model was expected to benefit the business of engineer-to-order system product through improving integration of different disciplines, enhancing information exchange and reuse. It could also provide a conceptual basis for the potential development of domain-specific product structures and product repository. Furthermore, it could probably enrich the product training with presenting a visualized conceptual model.
# Table of Contents

1. Introduction .......................................................................................................................... 1  
   1.1 Background .................................................................................................................. 1  
   1.2 Previous works ............................................................................................................. 4  
   1.3 Objective and research questions ................................................................................. 6  
   1.4 Thesis disposition and implementation ........................................................................ 7  
2. Theory .................................................................................................................................. 8  
   2.1 Product data management ......................................................................................... 9  
      2.1.1 Product data, information and knowledge ......................................................... 9  
      2.1.2 Product data management ............................................................................... 9  
      2.1.3 Product data management system .................................................................. 10  
   2.2 Product lifecycle management ................................................................................... 10  
      2.2.1 Product lifecycle ............................................................................................. 10  
      2.2.2 PLM concept .................................................................................................... 11  
      2.2.3 PLM system ...................................................................................................... 12  
   2.3 Product structure ......................................................................................................... 13  
      2.3.1 The concept of product structure .................................................................. 13  
      2.3.2 Different perspectives on product structure ................................................... 14  
      2.3.3 Product structure management ........................................................................ 15  
   2.4 Product modeling ......................................................................................................... 16  
      2.4.1 Product information model ............................................................................. 16  
      2.4.2 Product structure model .................................................................................. 17  
      2.4.3 Product modeling methods .............................................................................. 17  
   2.5 Challenges and Limitations ......................................................................................... 21  
   2.6 Key aspects of theory application .............................................................................. 21  
3. Method .................................................................................................................................. 23  
   3.1 Methodology ................................................................................................................ 23  
      3.1.1 Research design ............................................................................................... 23  
      3.1.2 Abductive study ............................................................................................... 23  
      3.1.3 Qualitative research ......................................................................................... 24  
   3.2 Study Method .............................................................................................................. 25  
      3.2.1 Literature review .............................................................................................. 25  
      3.2.2 Interview .......................................................................................................... 26  
      3.2.3 Document analysis ......................................................................................... 27
3.3 Validity ......................................................................................................................... 28
3.4 Bias .............................................................................................................................. 29
3.5 Ethical and legal considerations ................................................................................... 30
4. Empirical Study .............................................................................................................. 31
  4.1 Introduction of ABB Mine Hoist system ..................................................................... 31
    4.1.1 The main offerings ................................................................................................. 31
    4.1.2 The range of applications ....................................................................................... 32
  4.2. PLM practices of ABB Mine Hoist ............................................................................ 33
    4.2.1 The characteristics of ABB Mine Hoist ................................................................. 33
    4.2.2 The ABB Gate Model ............................................................................................ 33
    4.2.3 Current PDM/PLM situation .................................................................................. 33
    4.2.4 The perceptions of the product structure model .................................................... 34
  4.3 Conclusion ................................................................................................................... 35
    4.3.1 The complexity of ABB Mine Hoist system ......................................................... 35
    4.3.2 The multi-domain perspective requirements for the product structure model ........ 36
    4.3.3 The challenges of product information integration ................................................. 37
5. Analysis .......................................................................................................................... 39
  5.1 The product data management analysis ..................................................................... 39
    5.1.1 The product data of ABB Mine Hoist .................................................................. 39
    5.1.2 The data management of ABB Mine Hoist ......................................................... 40
    5.1.3 The major PLM/PDM issues of ABB Mine Hoist .................................................. 42
  5.2 The product structure analysis .................................................................................... 44
    5.2.1 The requirement analysis for the product structure .............................................. 44
    5.2.2 The analysis of product structure types .................................................................. 45
    5.2.3 The analysis of product structure management .................................................... 47
  5.3 The product modeling method ..................................................................................... 49
    5.3.1 The product modeling based on step-based product model ................................. 49
    5.3.2 The product modeling based on AGPS product model ...................................... 50
  5.4 The general applicability of the model ..................................................................... 52
6. Results ........................................................................................................................... 54
  6.1 The functional composition ......................................................................................... 54
  6.2 The product diagram ................................................................................................. 55
  6.3 The generic product structure model .......................................................................... 57
  6.4 The role of the generic structure model in the product lifecycle ............................... 58
7. Conclusion and discussion........................................................................................................... 60
  7.1 Conclusion .......................................................................................................................... 60
  7.2 Discussion ........................................................................................................................... 61
    7.2.1 Theoretical contribution ............................................................................................... 61
    7.2.2 Practical contribution .................................................................................................... 62
    7.2.3 Research credibility ....................................................................................................... 62
    7.2.3 Suggestions for future studies ...................................................................................... 63
References ....................................................................................................................................... 64
Appendices ..................................................................................................................................... 69
  Appendix 1: The global distribution of ABB Mine Hoist system .............................................. 69
  Appendix 2: The application of three Mine Hoist types ............................................................ 70
  Appendix 3: The complexity of Mine Hoist system .................................................................... 71
  Appendix 4: Interview record sheet .......................................................................................... 72
# Figure index

Figure 1 Overview of thesis disposition ................................................................. 7
Figure 2 Implementation of thesis work ............................................................... 7
Figure 3 The product lifecycle phases ................................................................. 11
Figure 4 The three pillars of PLM ........................................................................ 12
Figure 5 Domain - focused ................................................................................ 14
Figure 6 Business logistics – focused ................................................................. 14
Figure 7 The factors affecting PSM .................................................................... 15
Figure 8 Product structure integration through product lifecycle ..................... 16
Figure 9 A generic product structure model of an individual product ............... 18
Figure 10 A generic product structure model of a customizable product .......... 19
Figure 11 AGPS model of the sales-delivery process of ETO product .............. 20
Figure 12 The sales-delivery process of ABB Mine Hoist .................................. 36
Figure 13 The information integration of ABB Mine Hoist in the sales-delivery process ................................................................. 37
Figure 14 The two characteristics of ABB Mine Hoist data ............................... 39
Figure 15 The sales-delivery process of ABB Mine Hoist .................................. 40
Figure 16 The factors affecting PSM of ABB Mine Hoist ................................. 47
Figure 17 Product structure integration of ABB Mine Hoist through the product lifecycle ................................................................. 48
Figure 18 Product structure modeling of ABB Mine Hoist ............................... 50
Figure 19 Schematic diagram of constituent types for ABB Mine Hoist ............ 51
Figure 20 The sales-delivery process of ABB Mine Hoist ................................ 52
Figure 21 The function composition of ABB Mine Hoist ................................. 54
Figure 22 The diagram of ABB Mine Hoist ........................................................... 56
Figure 23 The interfaces of ABB Mine Hoist control system ............................ 57
Figure 24 The generic product structure model of ABB Mine Hoist ............... 58
Figure 25 The generic product structure model in the product lifecycle .......... 59
Table index

Table 1 The functionalities of PDM system ......................................................... 10
Table 2 PLM activities ....................................................................................... 12
Table 3 PLM functions and properties ............................................................... 13

Picture index

Picture 1 ABB Mine Hoist .................................................................................. 2
# List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Complete Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGPS</td>
<td>Adaptive generic product structure</td>
</tr>
<tr>
<td>AHM</td>
<td>Advant Hoist Monitor</td>
</tr>
<tr>
<td>CPM</td>
<td>Core Product Model</td>
</tr>
<tr>
<td>DTC</td>
<td>Direct Torque Control</td>
</tr>
<tr>
<td>ETO</td>
<td>Engineer-to-order</td>
</tr>
<tr>
<td>NIST</td>
<td>International Institute of Standards and Technology</td>
</tr>
<tr>
<td>OCS</td>
<td>Advant Open Control System</td>
</tr>
<tr>
<td>PDM</td>
<td>Product Data Management</td>
</tr>
<tr>
<td>PIM</td>
<td>Product Information Management</td>
</tr>
<tr>
<td>PLM</td>
<td>Product Lifecycle Model</td>
</tr>
<tr>
<td>PSM</td>
<td>Product Structure Management</td>
</tr>
<tr>
<td>ROC</td>
<td>Rope Oscillation Control</td>
</tr>
<tr>
<td>STEP</td>
<td>Standard for the Exchange of Product Model Data</td>
</tr>
</tbody>
</table>
1. Introduction

In this chapter, the background and previous works related to the study topic will be presented briefly. Based on this, the aim and objective of the study will be identified, and research questions will be proposed as well. At last, the thesis disposition and implementation will be displayed in short.

1.1 Background

Due to globalization and intensified competition in markets, companies over the world are striving to provide customized and innovative products to satisfy the diversified requirements of customers. Traditional industries such as the mining industry are increasingly interested in offering customers a wider range of value-added product solutions to find new business opportunities and gain higher competencies over others (Saaksvuori & Immonen, 2008). Such a trend leads to the high cost of resources, the long launching time of products to the market and the complexity of quality control. Along with this, acquiring accurate and complete product data and effective product configuration have become more and more difficult during the business processes. In the sales-delivery process of customized engineer-to-order (ETO) products, companies need to offer a variety of new solutions to address new specific requirements of customers in short lead time (Côté et al. 2010). Under the make-to-order setting, individual products could satisfy different customer requirements by delivering various variants with “slightly different constitutions” (Ni et al. 2008). New solutions for specific customer-needs are usually developed separately in a project-to-project form, with which product data are perceived as transient and dissociate, therefore be managed randomly throughout the product lifecycle (ôet al. 2010). In addition, the project-specific product knowledge associated with new products or components is often retained among a small group and can’t be accessed by people within various sectors throughout the whole product lifecycle (He et al. 2005). The lack of an ability to efficiently reuse validated product data, and the absence of a unified way to transfer specific product information into validated generic product data that can be used company-wide in subsequent projects as early as the sales lead phase have become a significant hindrance for a company to gain its competitive advantages in the marketplace (Côté et al. 2010; He et al. 2005).

Meanwhile, the concept of the Fourth Industrial Revolution which integrates computation, networking and physical processes have been highlighted among business society (Bank of America Corporation, 2016). Driven by Big Data, Artificial Intelligence, robotics, the Internet of Things, cybersecurity and 3D printing, the Fourth Industrial Revolution is believed to fundamentally change the way companies operate their businesses in several main aspects. The degree of automation and optimization of product in the whole supply chain would be significantly increased due to the network centered on massive data; the level of personalization and customization of product would be reinforced thanks to computerized and optimized operation processes; data mining including collecting, organizing, analyzing and utilizing data would become increasingly important for businesses; constant monitoring would be largely achieved to help identify and resolve problems during product management; the rise of robotics would combine the power of robots and the human brain to improve productivity and efficiency; the
technology of virtual reality will bridge the gap between product designers and consumers (Hawthorne, 2018). The Fourth Industrial Revolution not only brings benefits to customers but also creates challenges and opportunities for companies. On one hand, a large amount of added-value is delivered to customers through faster, cheaper and more convenient access to products and services, liberating customer’s purchasing power for more products and services. (Bank of America Corporation, 2016). On the other hand, the profit margins of industry incumbents are squeezed to a very low point, however, the Internet-of-Things ecosystem, as well as the Cloud and Big Data analytics enable companies to optimize their product solutions and manage their product portfolio in a more efficient way (Bank of America Corporation, 2016). The Fourth Industrial Revolution provides a new opportunity for data exchange, information sharing and knowledge reuse across companies, among various sectors and in different stages. Still, for some types of products, commonly accepted, standardized models are required to enable fragmented data to be organized in a structural and validated way. This remains partly unsolved somehow, especially in traditional industries.

ABB is a pioneering technology leader in the global markets that serves customers in a broad field such as utilities, industry and transport & infrastructure. With about 150,000 employees, ABB carries out its businesses in around 100 countries (ABB Group, 2019). Its operations are organized into four business units which focus on particular industries and product categories: the division of Electrification Products provides digital and innovative technology for low- and medium-voltage across the full electrical value chain; the division of Industrial Automation offers solutions designed for optimizing the productivity of industrial processes including turnkey engineering, control systems, specific products of industry and measurement, life cycle services and outsourced maintenance; the division of Robotics and Motion delivers motors, generators, drives, mechanical power transmission, robotics, wind and traction converters; the division of Power Grids offers the portfolio of power and automation products, systems, service and software solutions across the generation, transmission and distribution value chain (ABB company, 2019).

The mining industry is one of the main customers that Industrial Automation division targets, and the underground mining haulage system, namely Mine Hoist is one of the system solutions that ABB delivers to mining customers. The mine hoist is designed for haulage of ore and waste and/or transportation of personnel to and from the different levels in the shaft. Basically, ABB provides three types of Mine Hoist system: friction hoist, drum hoist and Blair multi-rope hoist. Through involving in the whole process operations from designing to supplying, installing, as well as long-term service and support, ABB intends to offer the customized solutions to achieve low possible life cycle cost, high system availability, short project execution time and a single source of supply for the complete system (ABB company, 2019).
As a significant shift of customer markets undergoing and internet-based technologies taking hold in the industrial sectors, ABB has adopted “Next Level strategy” focusing on operational excellence to move its center of gravity to “a simplified, strengthened, digital and market-leading portfolio”, unlocking value for customers and improving its competitiveness in market segments. (Annual Report 2017). ABB Ability™, “an innovative solutions-based digital offering” was commercially launched in 2017 as the central part of its strategy (Annual Report 2017). With a secure, open-architecture system extending from device to edge to cloud, ABB Ability™ is believed to leverage the installed base of its connected products, stimulating business growth through delivering a wide scope of high value-add solutions and services (Annual Report 2017). Through such a strategic change, ABB intends to facilitate its data management as a whole and to improve its operational performance by means of digitalizing its product portfolio. Despite this big effort, there is still a large amount of valuable product data in the company that has been collected and stored in an unstructured way. The information cannot be treated systematically, causing the difficulty to get accessed to and to be utilized during the business operations in the long term. Thus, “text mining” has been proposed from inside the company to try to reveal and present knowledge that is otherwise hidden in textual format, impossible to pass through automated processing (Jetley, 2018). A set of processes such as information retrieval, data mining is required to transform unstructured documents or resources into meaningful and organized information which can then be applied to “automatically discover hidden patterns and predict future outcomes” (Jetley, 2018).

With the changing of both the external environment and organizational strategy, different business units of ABB are facing the same challenge of delivering customized and value-added product solutions with shorter time and lower cost. Managing product data in a structural way to improve internal productivity and to unlock organizational value appears more and more essential for a business unit to succeed. Through effectively and efficiently managing existed data, business units can not only reinforce their information flow but also enable product-related information visible, acquirable and reusable across the unit.

Regarding to ABB Mine Hoist – an ETO system product, although customized solutions have been delivered, not enough attention has been paid to the utilization of existing product information throughout its sale-delivery product lifecycle. The business has usually been carried out on project-to-project basis rather than in an integrated way, leading to the idling of some valuable information in previous projects and low efficiency of the validated information reuse for new solutions. Meanwhile, due to the lack of a proper product structure representation, the integration of business processes and the information communication among the actors in different disciplines have been deterred to some extent. Both of them have made up part of the reasons for the low efficiency of business operations and the high cost of company resources. In such a business that offers customized and one-off solutions, it is of apparent interest to find ways to deliver new customer-specific products based on proven components of existed projects to achieve time-saving, cost-efficiency and quality-security. Therefore, a standardized and unified product structure model is required which could both appropriately describe the structure of Mine Hoist system and accurately map the important aspects that can serve as a basis to address the requirements from different disciplines.
The model based on the existing product solutions of ABB Mine Hoist would provide structural and conceptual assistance for future projects to identify need categories, to optimize product configurations and to formulate quick solutions for customers. It would be an open platform that could not only allow new components to be incorporated in with continuous product changes, but also possibly fit in the other systems of the mining business such as Mine Hoist training programs. Additionally, the model is also expected to be used as a reference model by any other organizations in the mining industry to improve their data management of the ETO system products.

1.2 Previous works

The problem mentioned above is actually familiar to almost all traditional industries. It has been more or less referred to in various theories related to product management, and the consensus has been largely achieved about the importance of information availability and reutilization. Among those, Product Lifecycle Management (PLM) has increasingly become popular in achieving quality-improving, cost-reducing and time-saving during the business processes. It addresses the issue from the product lifecycle perspective, capturing and discussing the problem in a general way. In comparison to other methods of product management such as agile product management which focus on how product management works in an agile context, PLM is centered on the creation, preservation and storage of information associated with the company’s products and activities (Saaksvuori & Immonen, 2008). It enables the fast and easy finding, refining, distribution and reutilization of the data required for daily operations throughout the product lifecycle (Saaksvuori & Immonen, 2008). “At the same time, the idea is to convert data managed by the company’s employees, skilled persons and specialists into company capital in an easily manageable and sharable form – as bits” (Saaksvuori & Immonen, 2008, p.3).

During product lifecycle, whether or not information can be maintained consistent and traceable, and reused efficiently is mainly dependent on “the definition and management of equivalence information” between product data and “structure representations” (Côté et al. 2010). Product structure represents the data backbone for PLM to manage complex product systems, and PLM System is utilized to maintain product structures and track changes of product information (Adolphy et al. 2015). Therefore, the concept of product structure is central to help us to perceive and analyze the problem for searching for right solutions.

Product structure is initially generated through the process of product design and afterwards referenced by various business processes throughout the entire product lifecycle (He et al. 2005). It provides a hierarchical classification of items composing a product and describes systems, subsystems, components and parts in the tree structure. Product Structure Management (PSM) provides a mechanism to capture and manage product structure, and further on to facilitate the generation and re-utilization of generic parts and assemblies to construct many different variations of a basic, one-of-a-kind, or complex structures (He et al. 2005).

In order to implement PSM, a generic, scientific product structure model is called for to build up. The topic of the product structure model and its relationship with PLM has been discussed in the field of product management from some view angles. Ni et al. (2008) suggested that new requirements constantly emerge, demanding a PLM system that enables flexible system
reconfigurations. They further stated the performance of this dynamic PLM system depends heavily on how far the supportive product structure model could extend. Shu & Wang (2005) pointed out that product structure models should be generated by taking the needs of all business processes throughout the product lifecycle into account, which is extremely difficult to achieve in business reality. In this sense, product structure models are often applied to business practices together with product information models.

Product Fenves (2001) from the International Institute of Standards and Technology (NIST) introduced the Core Product Model (CPM) to describe various product information. It emphasized artifact representation of products including function, form, behavior, etc. and relationships among these concepts with two sets of definitions: object and relationship. CPM was then developed into a new version of CPM2 to support a wider range of information relevant to the product lifecycle.

An international product model standard – “STEP” (Standard for the Exchange of Product Model Data) ISO 10303 provided a practical tool to define a generic product model (Saaksvuori & Immonen, 2008). A STEP-based Product Information Model was developed by Xie & Rui (2010) according to the rule of integration. It is composed of five parts: General Information Model, Structure Information Model, Shape Construction Model, Physical Feature Model, Management Information Model (Xie & Rui, 2010).

Moreover, an ontology-based modeling method has been studied recently which focused on the formal representation of product knowledge in one specific domain and the interoperability with other related domains (Lyu et al. 2017). Ontology modeling brings a taxonomic approach to manage product complexity through identifying, formalizing, managing and reusing domain product knowledge (Lyu et al. 2017; Bock et al. 2010). Usually, it builds up open semantic models partially describe product in certain domains, and then integrates those independently developed models into one mega model along product life cycle with precise consistency (Bock et al. 2010; Bruno et al. 2015).

Zhang et al. (2010) suggested an Ontology-Based Product Information Model which includes two parts: Concept Model used to describe the general-purpose ontology of Product Data Management (PDM) system and Domain Model related to specific industries that PDM applied to (Zhang et al. 2010). The main concepts of product ontology are recapped as: item, requirement, feather, attribute, resource and phase (Zhang et al. 2010).

Zhang et al. (2013) introduced an ontology-based semantic representation model based on the Issue-based Information System (IBIS) model. Several definitions were given with Web Ontology Language and Semantic Web Rule Language, such as: categories of concept elements and their semantic relationships, principals and rules used for Design Rationale analysis.

In addition, Ni et al. (2008) suggested a product structure model for developing PLM system that could be applied under flexible make-to-order circumstances. It’s believed “the model is capable of enforcing the consistency of a family structure and its variant structure, supporting multiple product views, and facilitating the business processes” (Ni et al. 2008, pp. 243). Côté et al. (2010) proposed an Adaptive Generic Product Structure (AGPS) based on product family data model in
the PLM context. It improves the mechanism for the reutilization of product-related knowledge through the systematic assembly of product variants with their particular components.

However, though some product structure models have been developed, most of them emphasized certain activities in the design or manufacturing process rather than took an overall view considering all business processes throughout the product lifecycle at the same time. Meanwhile, previous research efforts of product model concentrated mainly on the computer-aided software application, not enough attention has been paid to forming a unified product structure that integrated the most important requirements from different disciplines into one entity. Moreover, the application of the product models into business practice is confined to a limited scope. There is a lack of employing these models into some specific industries such as the mining industry. Thus, there is a call for a generic product structure model to achieve product optimization by considering the requirements of different business operations simultaneously.

1.3 Objective and research questions

In order to reduce customer-driven cost and lead-time, as well as to secure product quality for competitive advantages in the marketplace, a generic product structure model considering the product lifecycle is required in the business of the ETO system products.

The aim of the model is to facilitate the information sharing and reuse across different departments within a company, as well as the integration of different business operations throughout the sales-delivery product lifecycle. On one hand, it should provide a unified structure framework for business activities such as need assessment, solution generation and evaluation. On the other hand, the model should also promote product knowledge acquisition, traceability and exchange to improve effective communication between different stakeholders.

The thesis will take ABB Mine Hoist as the case to study how to create a generic product structure model for accelerating the business processes of the ETO system product. PLM is identified as the background for the study to be developed, and data management is the string to tie up the different parts in the entire course of the study. The model will build up product items and the interrelation among them based on the information developed, presented and captured in previous projects, as well as the requirements of different disciplines in the sale-delivery business process.

Thus, the objective of the study is

- To propose a generic product structure model fit for the engineer-to-order system offering with the consideration of its product lifecycle.

More specifically, the research questions (RQ) are as follows:

- **RQ1.** What are the key issues that need to be addressed when formulating a generic product structure model of the engineer-to-order system product in the context of product lifecycle management?
- **RQ2.** How can a generic product structure model for engineer-to-order system product considering the product lifecycle be constructed?
1.4 Thesis disposition and implementation

The thesis is divided into separate sections based on the contents contained, as illustrated by Fig. 1. The introduction chapter provides brief background and supporting information for the study. Chapters 2 focus on those relevant theories which build up the theoretical framework for the study. The methodology chapter explains the approaches of how to implement the study throughout the thesis process. Empirical evidence and interpretation of the case ABB Mine Hoist system are introduced in chapter 4. A detailed analysis by means of combining both theoretical framework and empirical evidence is covered in chapter 5. Based on the analysis, a generical product structure model and its role in the product lifecycle are presented in chapter 6. Summary of the thesis in chapter 7 gives the conclusion, reflects on the study results, as well as potential future research topics.

![Figure 1 Overview of thesis disposition](image)

The project of thesis work was carried out through a combination of several ways as displayed in Fig. 2.

![Figure 2 Implementation of thesis work](image)
2. Theory

The theoretical ground for the study will be presented in this chapter. The theories will be reviewed to obtain a general understanding of literature relevant to the topic, to identify research gaps among the existing researches, and to provide tools for the empirical analysis. The chapter will cover a comprehension of four topics: product lifecycle management (PLM), product data management (PDM), product structure and product modeling. The literature relevant to the study has its basis in the theoretical field of product lifecycle management (PLM), and the “structure” for how a product is constructed will be the key word in the study.

Since customized products are becoming increasingly popular in the global market, comparing to the huge amount of fragmented data produced during the product lifecycle, there is a lack of efficient ways of managing product information for the integration of business operational processes. How to organize a variety of product data in a structured way to facilitate information sharing, exchange and reuse among multiple disciplines have raised as a crucial issue for a company to gain competitive advantages over others. In this respect, the concepts of PDM and PSM linked to each other in the context of PLM, are considered to be of the most relevance and interest among other theoretical areas. They are closely associated with the research questions proposed and the empirical evidence to be discussed in this study.

PLM provides an integrated way for different business processes to operate in the most efficient way by means of a set of systems centered on product information. According to Kissel et al. (2012), PDM is considered as the essential constituent of PLM system. It serves as a central hub to manage all product data and related workflows, enabling necessary information available to related participants in each lifecycle phase. PLM vision which covers the whole lifecycle has appeared more and more important as a strategic approach, especially for those large companies which carry out their business operations in the global market.

According to Stark (2016), the generation and maintenance of information related to product and its activities is the center of PLM. Smooth and efficient information management of products across a company ensures the fast and easy searching, processing, acquirement and reutilizing of the data required for daily operations. Zhang et al. (2010) suggest the interoperable support for information sharing and exchange is in urgent need between not only different product phases but also different disciplines. Saaksvuori & Immonen (2008) claim that product structure forms the foundation on which many functions of PLM-PDM system are based on, particularly for product configuration, change management and information specification. Hence, as a carrier of product data, product structure model (PSM) become the necessary enabler for the implementation of PLM and PDM. Since product structure is a crucial part in the product information system, the studies on it are certainly of significance in improving product management (Janardanan et al. 2008). Thus, a unified, standardized product structure and its modeling will be central in this study.

ABB is a pioneering technology company, and Mine Hoist is one of the system solutions offered to mining customers. In the sales-delivery process of product Mine Hoist system, a variety of solutions have been offered to address different customer-specific requirements. The businesses have been carried out in a one-off way, and product data have been mostly treated as transient,
fragmented pieces. There is a lack of a mechanism to make the best use of validated information from existed products for new solutions. Meanwhile, during the different product lifecycle, product data from different stakeholders are usually partial and sometimes discrepant. The importance of creating an integrated model of Mine Hoist system which addresses the main requirement from different disciplines still remains underestimated. Hence, the concepts of PLM, PDM and PSM will be employed to answer the RQs proposed in the previous chapter.

The fundamental concepts and theoretical framework were given in the following parts of this chapter.

2.1 Product data management

2.1.1 Product data, information and knowledge

According to ISO 1994, product data are defined as “representation of information about a product in a formal manner suitable for communication, interpretation, or processing by human beings or computers” (cited in Feng et al. 2009). Likewise, information is not only the explicit content of knowledge, but a medium to transfer valuable product-related knowledge which can be repeated used for new products (Peng et al. 2017). As such, the terms “data”, “information” and “knowledge” in this study will be applied equivalently, particularly when referring to business operation issues (Vehkapera et al. 2009, Peng et al. 2017).

Product data describes not only a product itself but also how it is designed, produced, operated, used and then disposed of. It is created, preserved and utilized across the whole organizational functions in different ways. Basically, product data can be divided into three categories, namely: “definition data of the product” that defines physical and functional features of the product; “life cycle data of the product” that is usually associated with the phases and processes of the product; and “meta-data” that describes the related information about product data (Saaksvuori & Immonen, 2008). Additionally, master data is widely mentioned in the description of a product. It usually refers to the key objects of products that plays a critical role in business success (Otto, 2012). Volume and complexity are two important characteristics of data, and data needs to be structured for further interpretation and extraction of reliable information and knowledge (Feng et al. 2009).

2.1.2 Product data management

Product data management (PDM) is an electronic mechanism to achieve information reutilization, product customization and organizational efficiency through managing a large number of product-related data (Ahmed, 2009). In an organization, PDM pays a central role in performing the function of organizing, governing, and distributing product data (Otto, 2012; Huhtala et al. 2014). This function covers a wide range of activities associating with product-related data projects, processes, practices and systems, from design to implementation and monitoring (Otto, 2012). The main purpose of PDM is to help companies to manage their business processes in an efficient and effective way through governing relevant data produced during the whole product lifecycle (Vehkapera et al. 2009).
2.1.3 Product data management system

The PDM system is a set of systematic tools handling all product-related information (static or dynamic), to serve product management and development. Actually, PDM system can be regarded as a set of product storage systems based on concept, domain or other model presentations. It manages fragmented product information, especially those implicit and abstract ones, to facilitate product data availability, controlling, processing and utilizing (Demoly et al., 2013; Papinniemi et al. 2014). From a holistic perspective, PDM system is a system closely encompassed by other systems such as computer-aided design and enterprise resource planning, together constituting an integrated architecture (Zhang et al. 2010; Otto, 2012). As a central system, PDM system preserves product data as a resource pool, fulfills the tasks of delivering the data to surrounding systems, improving data communication among operational processes (Boris Otto, 2012).

Combining product-related data and process management together, PDM system provides a platform for product information governing and exchanging (Vehkapera et al. 2009). Basically, PDM system should provide and support at least the following functionalities:

Table 1 The functionalities of PDM system (based on Sung & Park, 2007, pp.616)

<table>
<thead>
<tr>
<th>Group</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data vault and document management</td>
<td>Providing services for the storage and retrieval of product information</td>
</tr>
<tr>
<td>Workflow and process management</td>
<td>Controlling procedures for handling product data and to provide a mechanism to drive the business with information</td>
</tr>
<tr>
<td>Product structure management</td>
<td>Handling bills of material, product configuration, associated versions and design variations</td>
</tr>
<tr>
<td>Parts management</td>
<td>Providing information on standard components to facilitate re-use of designs</td>
</tr>
<tr>
<td>Program management</td>
<td>Providing work breakdown structures and to allow coordination between processes, resource scheduling, and project tracking</td>
</tr>
</tbody>
</table>

2.2 Product lifecycle management

Since being introduced at the beginning of the 2000s, PLM has been widely recognized as a business necessity for companies to cope with the challenges from the current competitive industrial context. The PLM strategy covers a managerial spectrum of all data-information-knowledge throughout the entire product lifecycle, and it has become both essential tool and decisive factor for an organization to achieve competitiveness in various fields of industry (Stark et al. 2004; Liu et al. 2009; Stark, 2016).

2.2.1 Product lifecycle

It has been generally acknowledged that product lifecycle can be categorized into three stages: “beginning of life” usually referring to product development period, “middle of life” often
involving activities after product delivering to customers, and “end of life” when products reaching
their end of usefulness (Zhang et al., 2017). Regardless of what specific area a company belongs
to, the product-related activities can be somehow mapped into five phases in the generic product
lifecycle (Fig. 3).

![The product lifecycle phases](based on: The 5 phases of the product lifecycle. Stark, 2018, p. 14)

2.2.2 PLM concept

PLM is a holistic conceptual presentation that focuses on all product associated data.

"Product lifecycle management is a strategic business approach that supports all the phases of
product lifecycle, from concept to disposal, providing a unique and timed product data source.
Integrating people, processes, and technologies and assuring information consistency,
traceability, and long-term archiving, PLM enables organizations to collaborate within and
across the extended enterprise” (Corallo et al. 2013, pp. 6).

With the join-up approach of PLM, organizations are able to unify a variety of segregate and
dissociated operations, disciplines and functionalities under a single umbrella (Stark, 2016). And
all of the product-related activities of a company shown in Table 2 are included into the PLM
scope.

The objective of PLM is to streamline product development and promote innovation through a
unified information platform where the generation, organization, and distribution of product-
related data can be facilitated across a broad organization network (Sudarsan et al. 2005; Zhang et
al. 2017).
Table 2 PLM activities (based on Stark, 2016, pp. 2)

<table>
<thead>
<tr>
<th>PLM Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managing structured and valuable Product Portfolio</td>
</tr>
<tr>
<td>Maximizing financial return from Product Portfolio</td>
</tr>
<tr>
<td>Managing products across the lifecycle</td>
</tr>
<tr>
<td>Managing product development, support and disposal effectively</td>
</tr>
<tr>
<td>Providing product control and visibility throughout the lifecycle</td>
</tr>
<tr>
<td>Managing product feedback from customers, field engineers and market</td>
</tr>
<tr>
<td>Managing collaborative work among design engineers, supply chain partners and customers</td>
</tr>
<tr>
<td>keeping product-related processes coherent, joined-up, effective and lean</td>
</tr>
<tr>
<td>Capturing, managing and maintaining the integrity of product definition information</td>
</tr>
<tr>
<td>Making necessary product data available</td>
</tr>
<tr>
<td>Tracing product technical and financial characteristics throughout its lifecycle</td>
</tr>
</tbody>
</table>

2.2.3 PLM system

PLM system is a set of tools for implementing PLM concept. It functions as a heart to deal with a variety of product business operations from product specification to workflow management, cost estimate, performance evaluation and so forth (Bruun et al. 2015). “Product Data Management”, “Process Management” and “Engineering Project Management” constitute three cornerstones supporting the PLM system (Fig 4.) (Gmelin & Seuring, 2014). Among those, the first refers to the central data supply system to facilitate communication and collaboration in product development; the second means a supportive system to accelerate the implementation of business operations cross functional departments in an organization; the third is a project-based tool to connect those two systems to solve product related issues through efficient allocation of product resources (Gmelin & Seuring, 2014).

Figure 4 The three pillars of PLM  (adapted from Gmelin & Seuring, 2014, p. 169)
Different business processes are usually involved in the generation, preservation, updating, allocation, utilization, and restoration of different information (Saaksvuori & Immonen, 2008). In order to support those processes, the PLM system creates a wide scope of main functions and properties as follows:

*Table 3 PLM functions and properties (based on Saaksvuori & Immonen, 2008, pp15)*

<table>
<thead>
<tr>
<th>PLM Functions &amp; Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item management</td>
</tr>
<tr>
<td>Product structure management</td>
</tr>
<tr>
<td>Managing products across the lifecycle</td>
</tr>
<tr>
<td>Document management</td>
</tr>
<tr>
<td>Providing product control and visibility throughout the lifecycle</td>
</tr>
<tr>
<td>Information retrieval</td>
</tr>
<tr>
<td>Change management and workflow</td>
</tr>
<tr>
<td>Configuration management</td>
</tr>
<tr>
<td>File vault</td>
</tr>
</tbody>
</table>

Such vertical departments inside an organization as product development and engineering, resource planning and procurement, sales and marketing, sub-contracting and partners, manufacturing and production, maintenance and after-sales service are typical disciplines to apply PLM system (Saaksvuori & Immonen, 2008).

2.3 Product structure

2.3.1 The concept of product structure

Product structure is key information or master data that has been employed broadly in different business processes and for different lifecycle phases (Ni et al. 2008). A consistent and unified definition of product structure has become a necessity for PLM to integrate all business operations under a single product architecture (Kissel, 2012).

Although product structure came from the concept of BOM (Bill of Material) and sometimes is mingled with BOM, it actually has a distinctive definition from BOM in the strict terms. The former is used to describe the whole structure of how a product is constructed with multi-levels or classes, while the latter is “item-oriented” and refers to a single-level list of parts used in product assemblies (Saaksvuori & Immonen, 2008; Brie`re-Co`te´ et al. 2010). Item refers to “a single piece part, an assembly of arbitrary complexity, a raw material, or a tool. An item version can have multiple applicative views such as design-discipline” (Vosgien, 2015, pp. 29).

Product structure is defined as a hierarchical classification of items that forms a product, describing the correlation between components, structural layers, overall architecture, and configuration rules.
(He et al. 2006; Brie´re-Coˆte´et al. 2010; Şenaltun & Cangelir, 2012). In another word, the product structure identifies item types and their relationships, and explains how these items are organized and configured into the final product (Janardanan et al. 2008).

The product structure is regarded as a hierarchical breakdown of the product into a tree structure. It is usually described by the term of “object” that refers to a data element, such as functional module, subsystem, individual part or assembly (Saaksvuori & Immonen, 2008). The levels of which the product structure is composed or the degree of how many objects are included, depends on the exactness of the product description. (Saaksvuori & Immonen, 2008)

2.3.2 Different perspectives on product structure

Different product structures can be obtained based on from which perspective a product is perceived. When stressing domain categories as Fig. 5 shows, functional, technical and physical perspective should be taken for product decomposition. While, when entering the view angle of the business process as Fig. 6 displays, more perspectives of business processes should be considered for product breaking down. Usually, due to the distinctive functions and actors involved in a certain business operation, different disciplines or departments have their own requirement for the decomposition of product structure, as well as for the corresponding information system serving as a vehicle to carry such a product structure (Svensson & Malmqvist, 2000).

![Figure 5 Domain-focused](based on Axiomatic Design, Zhang et al. 2010, p.184)

![Figure 6 Business logistics-focused](adapted from Product and order-delivery processes and their relation, Saaksvuori & Immonen, 2008, p.38)
More specifically, the requirements of different disciplines on the breakdown of product structure are determined by the different purposes of applying a product structure in practices (Svensson & Malmqvist, 2000). Several types of product structure are created and transfer as master data in corresponding information systems as follows: “design structure”, “manufacturing structure”, “sales structure”, “purchasing structure”, “spare parts structure”, “forecasting structure” (Svensson & Malmqvist, 2000).

2.3.3 Product structure management

Product Structure Management (PSM) emerged as a comprehensive measure based on BOM, and it is a managerial mechanism of modeling, generating, updating, integrating and optimizing product structure for efficient business operations throughout the entire product lifecycle (He et al. 2006). PSM not only represents one of the most important aspects of PLM, but also constitutes one of the most crucial functions of PLM (Côté et al. 2010; Svensson & Malmqvist, 2000). Actually, PSM includes all functionalities of dealing with a product structure throughout the different lifecycle phases: managing product configuration; tracing design history; ensuring consistency; connecting product specification information with structure; supporting multi-domain specific views and etc. (Janardanan et al. 2008). Since the representation of the product structure differs from disciplines and evolves throughout the product lifecycle, PSM presents a dynamic system of integrating heterogeneous views into a holistic picture on product data and structure (Côté et al. 2010; Svensson & Malmqvist, 2000).

Apparently, it is not easy to build up an integrated product structure in a single data system due to that the implementation of PSM can be affected by many factors as Fig. 7 displays.

![Figure 7 The factors affecting PSM (based on Svensson & Malmqvist, 2000, p. 6)](image)

A framework of product structure integration has been proposed by Papinniemi et al. (2014) as shown in Fig 8. It illustrated a vertical integrating process of a product from specific product
domains in every phase of the product lifecycle to a generic product model. Among those, generic product structure serves as a “master concept” gathering various product information and delivering them in a unified and consistent way to business processes of the product lifecycle. Whereas, product-related structures such as requirement, function and design serve as common vehicles of particular product information, and connect bidirectionally with the generic product structure model. On one hand, they are derived from the generic product structure model with different domain considerations and specific information. On the other hand, they provide a concrete information base for the generic product structure model to be extracted from.

2.4 Product modeling

2.4.1 Product information model

The product information model (PIM) is defined as a systematic representation that supports and facilitates product information exchanging and sharing through different stages and among different disciplines (Xiao et al. 2010). In another word, it is an abstract and comprehensive description of all product information, including product metadata determining product characteristics from various aspects, such as physical features, functionalities, technological specification, manufactural and managerial attributes and etc. (Xie & Rui, 2010; Marchetta et al. 2011). PIM is used to support collaborative product development, as well as the creation,
management, distribution and usage of product-related information in its lifecycle (Xiao et al. 2010).

Product information modeling not only form the basis of PDM approach but also constitutes the essential component of PLMS, and it has developed rapidly with the advance of computer-technologies (Sudarsan et al. 2005; Xie & Rui, 2010; Marchetta et al., 2011). Product information modeling confers PLMS with measurable parameters, which makes PLM to be effective (David & Rowe, 2016). Meanwhile, the PLMS starts to have semantic content with a set of PIMs as its ontological structure (David & Rowe, 2016).

2.4.2 Product structure model

Product structure model is the center of PIM and often applied to business practices together with PIM. Ni et al. (2008) claimed the adaptability of PLMS to changing internal or external environment is mainly determined by the extensibility of a product structure model that forms the foundation of PLMS. Product structure model is regarded as a framework that reflects product structure in general and can be served as a reference in PDM practices (Ni et al. 2008; Kissel et al. 2012). It represents the product architecture that synchronizes product families and product variants with attention to different business processes, and closely associated with data such as CAD files, process descriptions and so forth (Ni et al. 2008; Kissel et al. 2012).

2.4.3 Product modeling methods

Many methodologies and practices of product structure modeling have been developed with different focuses and from various viewpoints. The generic object-oriented product model will be the main interest and focus of the study. The generic object-oriented product models closely related to the study can be summarized into the following categories:

1. Step-based product model

The model is defined by an international product model standard – “STEP” (Standard for the Exchange of Product Model Data) ISO 10303. STEP provides a set of international standards for formulating product structures and models, as well as their product information exchange between different data processing systems and different stakeholders (Saaksvuori & Immonen, 2008, pp.45). STEP describes two conceptual categories of definition: common objects classes and special objects of the product model (Saaksvuori & Immonen, 2008).

Once being conferred with concrete contents and their relationships which together define a product, a conceptual product model then becomes a product structure (Saaksvuori & Immonen, 2008). Two typical customer-driven product structures are illustrated as follows (Saaksvuori & Immonen, 2008):

*Individualized product:*

The product is delivered totally according to specific requirements and demands from both customers and local situations. The product structure can be broken down into the following levels (Fig. 9) (Saaksvuori & Immonen, 2008):
The product level: object of product.
The system level: the first decomposition of product into several logical entities
The subsystem level: the second decomposition of product into smaller logical totalities.
The component level: concrete parts constituting subsystem.
The element or part level: small separate parts or parts building up components.

**Customized product**

Usually, the product is produced and assembled according to the customer-tailored configurations of different levels of items. Some standard items and reused item variants can be pre-engineered, while some new item variants need additional “customer-specific planning and engineering”.

Specific requirements of customers are typically presented in such ways as “optional and alternative functional properties” in the product structure. The product structure can be broken down into the following levels (Fig. 10) ([Saaksvuori & Immonen, 2008](#)):

- The product level: uppermost object of product.
- The product family level: object at sales level.
- The property level: properties of product family that can be configured according to customers’ needs.
- The variable module level: technical modules for implementing particular product properties.
- The component level: common parts and part variants constitute certain modules.
2. Adaptive generic product structure model (AGPS)

The model is a structure-based modeling approach emphasizing the evolution of product family through the systematic integration and update of product variants (Côté et al. 2010). It’s developed on the basis of the generic bill-of-material (GBOM) approach, aiming to efficient reuse of existing product variety during the sales-delivery process of engineer-to-order (ETO) product (Côté et al. 2010). Côté et al. (2010) described the AGPS model-related concepts and the application of model as follows:

**Composition of ETO product:**

ETO is one of the customer-driven production approaches. ETO product is configured and delivered according to the specific demands of customers, thus it requires the implementation of a series of engineering activities to realize the order. The product configuration for ETO is a process of systematic reuse of standard and proven components, as well as the distinctive design of new components matching customer-specific requirements within product specification constraints. Thus, an ETO product can be described as an entity constructed by three types of constituent connected with two relationships “part-of relationship” and “type-of relationship”

- Base product with common features: the fixed part of an ETO product configuration with a group of components performing regularly occurring features.
- Reused variant with parameterized features: outcome of previous product configuration with predefined features.
- New variant with special features: newly designed component with unique features presenting customer’s very specific needs and preferences.

**The sales-delivery process of ETO product:**

It refers to a whole process (Fig. 11) from the inputs of customer’s requirement to the complete release of new variants, including three main phases: “sales lead, quotation and order phase”. The
product family update is one outcome of this process.

- **Sales lead phase**: to formulate structured and accurate documents of customer’s requirements for the following quotation details. “Sales-configuration” is involved and a “parameter structure” characterized with functional decomposition is applied in this phase, making the most use of parameterized features pre-defined in the product family model and associating special features with similar existing features.

- **Quotation phase**: to assess resource needs and cost with a rational risk level. The preliminary description draft, operational cost and lead time of base and reused components can be obtained and estimated based on the existing ones. The “proposal generation” subphase is involved for the generation of new component preliminary description draft and estimation of their operational cost and lead time through comparison with similar components. It is expected that near-optimal solutions can be achieved during this phase.

- **Order phase**: the “project definition” subphase is first involved to determine new components-related tasks, lead times and resource requirements. The “detailed order review” subphase aims to ensure order-related requirements and conditions have been correctly evaluated and satisfied. Thereby, a new technical product structure is created, and a preparation for new components is fulfilled as well by association with previously developed components. Afterward, at the subphase of “order specification generation”, the detailed description of reuse components is accomplished, and related information is collected for the next step. Hereafter, the “customer-driven design” subphase is involved to complete the final release of new components. The corresponding product technical structure then serves as an engineering base for the different definitions of subsequent product structures such as industrial and logistics structure.

![AGPS model of the sales-delivery process of ETO product](adapted from Brie`re-Co`te` et al. 2010, pp.59)
Family updated process:

The family updated process of the AGPS model systematically recurs in the sales-deliver process of the ETO product. It builds up a continuous process during which new design solutions are integrated into the product family model and newly developed components are converted into the group of reused components. The family updated process enables the reuse of all existing information for new customized solutions as early as the sales configuration phase.

2.5 Challenges and Limitations

Although PLM provides a holistic approach to manage products throughout the whole lifecycle, the implementation of PLM is still facing challenges. There are many obstacles ahead, especially in a collaborative setting and with complicated products. It appears difficult to manage various data under an integrated system due to the divergence of data types, the heterogeneity of data sources and the problematic communications between different data sources (Vehkapera et al. 2009; Xu et al. 2009).

Meanwhile, for most companies, a consistent and unified system underpinning PDM to help the integration of all business operations and activities is still missing. Usually, more than two application systems exist jointly in a company to support PDM, leading to a chaotic situation for product management. Two most commonly used are: “engineering oriented” system that focuses on physical structure originated from Computer Aided Design systems; and “business-oriented” system that stresses other structures required from different business processes (Otto, 2012).

Likewise, product structure differs from disciplines because different disciplines have different demands for product decomposition and corresponding information systems (Svensson & Malmqvist, 2000). Thus, it would be a big challenge to achieve a generic product structure and its model that satisfy the needs of all disciplines at the same time. Besides, the product structure evolves throughout the product lifecycle, it is hardly possible to create a product structure and its model for once and for all. How to constantly update them to reflect precisely the product in real life would be another challenge faced by companies. Both of them would probably cause additional workload for information maintenance.

Furthermore, the approaches of modeling products are still far from their perfection and have limitations respectively. The model-based approach neither supports other product models for the same product, nor the consistency is satisfied when the models are combined. More specifically, although the STEP has been improved to exceed the initial functions and include more convenient information exchanging, only the geometric information is taken into account (Lyu et al. 2017). Similarly, as for the function-based products, due to the less intervention from people, the process of creating new products could be overlooked, and the knowledge underlying the model needs to be updated constantly (Lyu et al. 2017).

2.6 Key aspects of theory application

The concept of PLM intends to integrate a variety of business processes, disciplines, functions and applications into a unified entity. Such a holistic view matches the macro and micro environment
of company ABB. Meanwhile, all the phases of the product lifecycle from concept to disposal, are involved in how to manage product data efficiently to ensure information availability, consistency and long-term reutilization across a company. Such product data-focus of PLM relates itself closely to the problem of information management faced by most companies like ABB under the high competition of product customization. When managing the complicated products involving a wide range of collaborators as ABB does for its delivery of Mine hoist system, PLM system creates an integrated information environment for different operational processes. Thus, the theoretical framework of PLM and PDM will be used to analyze the key issues that need to be addressed when creating a generic product structure model throughout the product lifecycle.

Product structure has been highlighted in the literature. The issue of data redundancy and poor communication caused by different structural representations of the same product also exists in Mine hoist business. Actually, in PLM system, the filtration of key product structure is used to facilitate the information management of large and complex product (Saaksvuori & Immonen, 2008). And a suitable description of a product with appropriate degree of precision needs to be defined to support the implementation of PLM (Saaksvuori & Immonen, 2008). Therefore, the product structure theories will be applied to evaluate the requirements from different disciplines when dealing with Mine Hoist system and to determine what information needs to be prioritized in the generic structure model.

Lyu et al. (2017) provided a general review of product modeling from knowledge, distributed computing and lifecycle perspectives. Considering the empirical evidence of company ABB and the product solution of Mine Hoist, the study will focus on both knowledge and lifecycle perspectives. In fact, it’s almost impossible for product structure modeling to be completely separated into from knowledge or lifecycle perspective, they are intertwined with each other and overlapped to a large degree. In fact, knowledge sharing and reuse is an important construct of PLM content. Bock et al. (2007) classified modeling approach of product structure into two groups: “model-based approach” and “ontology-based approach”. As for Mine Hoist System offered by ABB, considering the specific requirement for a broad model application and the engineering-unfriendly modeling languages used in the ontology approach, the model-based modeling method would be preferred to adopt as the framework to formulate Mine hoist system structure model.
3. Method

This chapter will describe the methods employed in the study. The methodology of how to conduct the thesis work will be briefly introduced. Hereafter, a literature review and two particular approaches of data collection will be presented. Then the discussion of several aspects associated with quality assessment such as validity, bias and ethical consideration will follow after.

3.1 Methodology

3.1.1 Research design

The study was intended to explore a generic product structure model of ETO system product and its function as a tool to facilitate the information sharing and reuse in the sales-delivery business across an organization. The case study design has been chosen due to the fact that a real phenomenon of Mine Hoist in ABB was given.

Case study was defined by Yin (2003, p. 13) as an “empirical inquiry that investigates a contemporary phenomenon within its real-life context and addresses a situation in which the boundaries between phenomenon and context are not clearly evident”. It has remained as a preferred approach in research design which involves “an intensive, detailed examination of a case” and interaction with the setting (Bryman & Bell, 2015). Different methods such as interview, observation and document analysis can be integrated under the name of case study, providing multiple empirical support for the study at the same time (Bryman & Bell, 2015). Besides, the availability of various sources with rich information and frequent interplay with informants helps to improve the reliability and validity of the study.

There are three different types of case study: “intrinsic case study”, “instrumental case study” and “collective case study” (Stak, 1995, cited in Bryman & Bell, 2015). An intrinsic case study was undertaken here which aimed to “gain insight into the particularities of a situation, rather than to gain insight into other cases or generic issues” (Bryman & Bell, 2015, p. 68). Mine Hoist system of ABB was the particular case designed for the study. It has special meaning to make a comprehensive description and analysis of it because ABB has been a technical leader in the global mining market since several decades ago.

3.1.2 Abductive study

The case study strategy was used in the study as mentioned above. Though being applied as a viable tool to “develop theory by in-depth insight of empirical phenomena and their contexts”, case study faces the big challenge of how to deal with the interrelationships among different elements during the research process (Dubois & Gadde, 2002, p. 555). In this regard, abductive approach with an “intertwined nature” emphasize the interplay between theory and empirical phenomena through “constantly going back and forth” between them and among various research activities (Dubois & Gadde, 2002). Thus, it was an appropriate way to carry out the study for a better outcome.

Deductive approach is about testing theory-driven hypotheses based on existing theory. And inductive approach is concerned with generating theories from empirical data. Whilst, abductive
approach is a systematic combination in between induction and deduction, but not a simplified mixture of both (Dubois & Gadde, 2002). It is actually an iterative reasoning process in which “theoretical framework”, “empirical fieldwork”, and case analysis develop reciprocally and concurrently by stressing “a continuous movement between an empirical world and a model world” (Dubois & Gadde, 2002). In general, abductive process can be divided into two subprocess: “matching theory and reality”; “direction and redirection” (Dubois & Gadde, 2002).

In this study, the empirical data on the issue of product information sharing and reuse was firstly gathered and interpreted in the light of the theoretical framework about PLM, PDM, and PSM. And then, the empirical discoveries were unveiled during the process of interviewing staff members and document retrieving from existing projects and related documentations in the case company ABB. Through identifying the new factors relevant to the topic of the study, expansion and refinement of theoretical framework were yielded. In another word, the theoretical framework was not only the input but also the output of the study. Afterward, the modified framework was used to guide the product structure modeling, forming a gradually developing process. As Dubois & Gadde (2002) claimed, the framework evolution during the research process comes with theoretical insight changes inspired by empirical discovery, and vice versa.

3.1.3 Qualitative research

According to Bryman & Bell (2015), qualitative research is a research strategy featured with “inductivist”, “interpretivist” and “constructionist”. It involves “the systematic collection, organization, description and interpretation of textual, verbal or visual data”, thus has significant value to explain social phenomena associated with “experience, meaning and perspective” (Hammarberg et al. 2016, p. 499). Qualitative research emphasizes the process, an intimate and holistic understanding of a specific event, organization, situation, group or individual is achieved through deep engagement in and close interaction with the real setting of the topic (O’Leary, 2017). Usually, qualitative data are rich and complex with human’s views, but not fitting for measuring in terms of quantity, intensity, or frequency (Denzin & Lincoln, 2005).

This study is to develop a generic product structure model of ETO system product considering the requirement from different disciplines, and to explore its role in the information sharing and reuse during the entire sales-delivery product lifecycle. Considering its socially constructed nature, qualitative research was employed to capture what participants had experienced about product information transfer across an organization, and what they had perceived of product structure model in their minds. On the basis of these empirical data and further coding and interpretation, a comprehensive understanding was attempted to gain over people’s perspectives of the issue in focus. Qualitative research is multimethod-characteristic by nature. Hence, a combination of interview and document analysis was undertaken to secure the width, depth, completeness and complexity of understanding about the topic in question. A set of tasks from an appropriate sampling of interviewees and document projects to on-site interviewing, constantly negotiating with participants and thorough self-reflection were performed in the process in an endeavor of keeping such a qualitative study as much objective as possible.
Adopting qualitative research could benefit the study from the following aspects (Mack et al., 2005; Claire, 2010; USC Libraries, 2019):

- Obtaining rich, detailed and in-depth data of the given study topic with a realistic and holistic view;
- Providing a textual description of the issue from the “human” perspective of participants;
- Seeking hidden factors which may not be readily identified and examined;
- Being able to develop multiple ways for data collection, analysis and interpretation.
- Creating a flexible and dynamic process in which interaction between researcher and participants is not restricted to a particular mode.
- Checking and revising study framework and focus on the real-time changes;

Applying qualitative research could also face limitations in the study from the following aspects (Mack et al., 2005; Claire, 2010; USC Libraries, 2019):

- Weakening research quality due to heavy reliance on researcher’s individual knowledge, experience and capability;
- Being difficult to maintain neutrality and objectivity due to the researcher’s personal preferences and biases;
- Lacking consistency and reliability due to multiple data collecting techniques and diverse responses of participants;
- Easily deviating from initial goals of the study as a result of changing social context;
- Causing analysis and interpretation time-consuming due to the volume and complexity of data;
- Undermining potential opportunities for obtaining more useful information due to the small sample size.

3.2 Study Method

A multimethod approach including semi-structured interviews, document analysis and literature review was employed in this study to achieve methodological triangulation. The case database was established based on the primary data from interviews and the second data from documents, helping to enhance information richness and eliminate single-informant bias.

3.2.1 Literature review

Literature review is a crucial start point for the study. Considering the qualitative and abductive characteristics of the study, a narrative review approach was adopted. The field of PLM linking PSM was identified and literature was mainly selected from scientific journals and books in this field during a time span of 2000 to 2018. The keyword searching method was employed to find relevant materials. Keywords used in the searching process were defined as follows: product lifecycle management (PLM), product data management (PDM), product information management (PIM) and product structure management (PSM). Meanwhile, the reference lists of each article were reviewed in detail to find additional articles. The articles and books were selected by examining their relevance levels to the topic, and then were reviewed before and after the key
problems were identified. Most of the literature was obtained from Uppsala University’s library and its scholarly database, while some were attained via internet search engines. As for the online sources, the quality of materials was evaluated according to ADAM (age, depth, author, money) and TLD (top-level-domain) principles to assure their reliability, credibility and accuracy (Lumen, 2019).

As Lau & Kuziemsky (2016) stated, the literature review in this study was applied for several purposes. Firstly, it was used in the introduction section to provide a fundamental understanding of the topic-related concepts and theories of product structure models developed in the past decades from different perspectives. Then the research gaps were identified in the field where the empirical issue was addressed. Whereas, the research problems emerged from empirical evidence were conferred a substantial meaning. Secondly, in the theory section, the literature review built up a theoretical ground for the study to develop. In addition, the literature review also served as a tool to validate the methods and approaches used for the proposed study, as well as to justify the contributions the study has given to the relevant knowledge accumulation.

3.2.2 Interview

As depicted by Bryman & Bell (2015), data collection and analysis provide a fundamental base for qualitative research. Interview as a practical, flexible and attractive tool for data gathering has been widely used for researches in different settings and with various targeted groups. As one of the hermeneutic methods, it distinguishes itself from scientific as well as quantitative methods, and presents enormous potential for researchers to dig in and achieve “intersubjective truth” through both self-reflection and high-quality interaction with respondents (Michrina & Richards, 1996). It can take the forms of unstructured, semi-structured and structured interview, depending on the different roles that respondents play in the process of interview.

With a clear topic focus, as well as an intention of gaining background information and insight into study issue-related opinions with key informants, a semi-structured interview was conducted in this study. An interview guide was predetermined, and a list of questions was formulated beforehand that covered the following topics of interest:

- The key issues (problems) about product information reuse and sharing across different disciplines;
- The requirements for product structure model from different disciplines.

Meanwhile, interviewees were allowed to freely express their opinions and thoughts, which helped the interviewer to gain a picture of what the respondents perceived to be of importance. Each interview lasted forty minutes to one hour and all of them took place in the face-to-face meeting except one via Skype. In order to better code and reflect on the interview contents in the data analysis phase, interviews were audio-recorded along with short notes. During the interviews, not only the preset issues were addressed, but some new questions were raised, providing the empirical material for further study and refinement. The challenge could be that interviews might be restrained from digging deeply due to the interviewer’s inadequate understanding and knowledge of Mine Hoist system and the operational procedures in ABB. Meanwhile, the view scope of the
interviews might also be limited, and bias might exist due to only one interviewer involved on site and lack of “member checking”.

As stated by Bryman & Bell (2015), purposive sampling is the main approach in qualitative research, in which participants are sampled in a strategic way corresponding to the research questions proposed. Being aware of the importance of respondents’ variety among those relevant groups, purposive sampling was conducted in the study so that more different perspectives can be taken into consideration. The aim of sampling is not to generalize to the population as probability sampling does, but to ensure the research questions to be answered. Thus, the sampling was performed according to the goals of the study, and respondents selected were regarded to be representative of the key departments relevant to the research questions.

Bryman & Bell (2015) also suggested purposive sampling is an evolving and contingent process where the sample number increases to fit research questions and sampling criteria shift as research questions change. In the study, at the beginning, considering the inherent technical characteristic of product structure, participants from engineering discipline were the sampling focus. However, with the further going of the study, more and more factors were taken into account, especially under the background of PLM, the respondents extended to cover a wider scope.

Moreover, it’s suggested by Michrina & Richards (1996) that when using the power of selecting respondents, researchers must ensure their choices are representative of the groups being investigated and all voices are certainly heard. Additionally, during qualitative research, the sample size shouldn’t be too small to achieve “data saturation, theoretical saturation, or informational redundancy” (Bryman & Bell, 2015). As for the study, nine respondents were selected whose working responsibilities ranged from sales to project management, supply chain management, engineering, service/maintenance and department manager. The people from different departments that were interviewed all have above ten-year-experience working for Mine Hoist system.

3.2.3 Document analysis

As Bowen (2009) claimed, document analysis is a research method during which existing documentation are systematically reviewed, examined, evaluated and interpreted to “elicit meaning, gain understanding, and develop empirical knowledge” for the study. Such an instrument is particularly fit in the setting of a qualitative case study. Documents can be regarded as a viable data source and its analysis can produce a rich contextual description of a certain object touched on in the studying field. In comparison with other qualitative methods, it has advantages of efficiency, accessibility, cost-saving, stability, precision, wide-coverage and less interaction with participants on one hand. On the other hand, the validity of the study drawing upon documents are obviously relied on the availability and quality of topic-related documents. In this study, document analysis served as a complement to interview for data collection.

Documents from the typical projects of Mine Hoist system delivered to customers in different countries during the past ten years will be selected. They will be used for the following research purposes in the study:
• To provide rich background information or conceptual context for the study;
• To trace changes of Mine Hoist solutions in the past ten years for developing a historical insight to it;
• To augment and support interview data;
• To be applied as a tool to verify the final model.

Yet, document analysis still has its limitation of incompleteness and unevenness resulting from the selective deviation and bias of informants, as well as the departure of extracted information from authentic documents due to the preference and bias.

3.3 Validity

As Bryman & Bell (2015) claimed, validity is the most important criterion for evaluating the quality of research. Unlike the scientific method in which validation of results is achieved through the process of replication, the validity of qualitative interview is determined by whether the interviewer’s interpretation of reality is consistency with the interviewee’s understanding of reality, the degree of the coherence of them. There are different ways for qualitative results to be validated. The interviewer can get a close match with the interviewee’s understanding through repeatedly reflecting on the data and the analysis of data. Such reflection occurs in all stages of the qualitative interview and takes the forms of either solely on the interviewer-self or reciprocally on the interaction between two sides. Still, as Michrina & Richards (1996) proposed, “on-the-spot verification” and interviewee’s comment on the transcript are two commonly used approaches.

For example, during the interview, the information about the product structure model was not explicitly and sufficiently explained in the introducing question. Thus, the interviewees were asked for further elaboration in the follow-up and the probing questions, trying to gain a holistic picture of their understanding of product structure model from different disciplines. Of course, as Michrina & Richards (1996) suggested, the interviewee’s affirmation of interviewer’s interpretation is the most comprehensive way to validate the interview results. Through presenting the transcript to the interviewee, corrections could be made, and the interviewee could even further refine his (her) descriptions based on the existing interpretation.

Whereas, in the document analysis, validity relies on the quality and content of documents selected rather than the quantity of document. Despite providing rich information for the study, documents themselves can’t prove to be authentic and trustworthy. It is important to look at them with a critical eye and evaluate them in a cautious way. Document analysis is not a simple transfer of documentary information researcher gains from document review. Rather, it is an evaluating and interpreting process of documents to develop empirical knowledge and understanding (Bowen 2009). In order to ensure the “authenticity, credibility, accuracy, and representativeness of the selected documents”, documents should be assessed back-and-forth at least from following aspects: relevance of content, completeness on topic, originality of material, meaning for the topic and targeted audience (Bowen 2009, p. 33). Meanwhile, researchers also need to make their understanding of the document as objective and sensitive as possible, to maintain the credibility of the research. In this case, documents and contained data were examined and filtered in a critical view. The information acquired from documents were discussed and confirmed by the informants.
3.4 Bias

According to Michrina & Richards (1996), it’s impossible to approach “objective social reality” even with scientific research methods. What we strive to achieve is a “shared meaning” about a certain “social existence”. In order to describe the social phenomenon in an “intersubjective” true way, an investigator needs to control his (her) biases, repeatedly revise them and finally, to reach a “shared understanding with the group being investigated. This is an evolving process involving proactive interactions with different sources, especial via interview.

Bias no matter from cultural, political or personal aspect does exist all the way through an interview, from the early preparation stage to the final data analysis. As an interviewer, his (her) background, knowledge, experience as well as world view, value orientation will definitely leave an imprint on the interview process, exhibiting various forms of bias.

When setting out to formulate an interview guide, bias not only is reflected between the lines of questions but also confines the width and depth of the interview. During this stage, questions are by and large formulated from the researcher’s preconceived notions and knowledge, which could probably not capture the true picture or maybe describe in a distorted way. For example, when looking into the topic of product model, due to the limited knowledge of mine hoist, the interviewer was prevented from putting more consideration related to the technical properties of mine hoist. It could result in that most questions were introduced from shallow and partial perspectives rather than a deep and holistic view.

During the process of interview, bias determines what content the interviewer chooses to ask and hear, consciously or unconsciously. This can be clearly or ambiguously seen in interview practices. In this case, the interviewees might have a broader understanding of the topic, however, the interviewer might guide them towards a specific opinion of the issue in which the interviewer was interested most. To handle such a challenge, the interviewer needs to articulate his (her) understanding to interviewees’ through asking questions like “Am I right?”, “could you make it clearer?”, or “could you tell me more?” during the ongoing conversation, trying to seek the correct information at most.

In addition, bias affects the way how the interviewer digests, codes and interprets the collected data and information, leading to the discrepancy between what the interviewee really concerns and what the interviewer understands. Thus, it would be helpful to turn back to interviewees for further elaborations and comments when the interviewer is unsure of the interpretation of the dialogue undertaken, regardless of on-site or afterward.

Another concern is about the potential biases occurring in document analysis. It could come from three aspects: subjective selection of documents, subject opinions of document author and deviated understanding of researcher (Bowen, 2009). Critical thinking, holistic view and thorough evaluation and reflection on documents and interpretation of documents are the key to eliminate bias throughout document analysis. Although the document is an important source for the study, it does not mean all information contained in documents are complete, accurate and correct (Bowen, 2009). As an interpreter, we should examine and assess the documents through a critical lens, and be prudent in the process of both document selection and analysis.
As Michrina & Richards (1996) claimed, bias is regarded as rather a “detector” than a “jammer” for seeking the “intersubjective truth” in “hermeneutic paradigm”. Actually, either qualitative interview or document analysis is a refined process in which the researcher continuously rectifies his (her) bias, finds solutions to internal and external conflicts caused by bias, and finally closes up the gap between researcher and informant to reach a “shared understanding”. During such a process, back-and-forth interplay with the data, constant reflection on dialogue, interpretation and description of the certain issue of the study is the most important means to keep the researcher far from bias.

3.5 Ethical and legal considerations

Because the study will be carried out in the company, as well as a semi-structured interview and a documentation study will be involved, the ethical and legal issues need to be considered during the entire course of a case study. As Diener and Crandall (1978) claim: harm to participants, lack of informed consent, invasion of privacy and deception are four main areas where ethical issues usually arise. Therefore, questions associated with those areas should be handled carefully and managed according to the principles recommended by Bryman & Bell (2015).

Firstly, a confidentiality agreement needs to be signed with the company to clarify the information allowed to get access to and not allowed to disclose in the study. Considering the concrete projects of mining hoist system referred to and analyzed in the document study, the anonymity will be adopted and maybe some revision of data will be needed to prevent the leakage of business information.

Secondly, during the interview, in order to prevent harms to participants and to protect the privacy of participants especially regarding sensitive issues, the data collected will be processed in a safe way to guarantee the information of participants being held completely confidential. Meanwhile, the anonymity of personal information will also be assumed in the thesis report as well as other occasions where the specific individual could possibly be traced back.
4. Empirical Study

This chapter will cover a brief introduction of ABB Mine Hoist system to give an overall understanding of the case background. The type, functionality, composition of Mine Hoist will be touched upon here. Meanwhile, the ABB Gate Model will be presented which defines the rules for business processes of product development during the product lifecycle. Then, the current situation of PLM & PDM in the business operations of Mine hoist will be discussed in general. The problems, challenges and benefits will be described from the interpretation of interviews performed during the study. At last, a conclusion will be drawn in which three challenges facing the PLM & PDM of Mine Hoist business will be identified. All product information about ABB Mine Hoist cited here can be found on ABB’s website.

4.1 Introduction of ABB Mine Hoist system

ABB is a leading mine hoist supplier in the global mining market with more than 600 hoists delivered to more than 30 countries over the world (see Appendix 1).

4.1.1 The main offerings

ABB offers a complete Mine Hoist system solution from design, supply, installation to long-term service and support. ABB Mine Hoist is a systematic solution for low possible life cycle cost, high reliability and system availability, short project execution time and a single source of supply for the complete system.

Hoist machinery:

The hoisting components of the system are designed by powerful Finite Element Analysis and 3D tools. Different options of pulley and drum, brake disc and bearing are available to satisfy customer requirements and secure full quality assurance throughout the product lifecycle. Additionally, ABB also supplies auxiliary hoisting and shaft furnishing equipment.

Hoist control, operating and monitoring system:

ABB’s hoist control covering skip loading & dumping and local control of multi-level hoisting is based on System 800xA technology. It is designed according to the highest safety standards and reliability requirements for mine hoist systems.

Drive system:

ABB Mine Hoist is powered by ABB’s drive system – the most widely used system in the world. It is based on ABB’s leading-edge technology of Direct Torque Control (DTC). Synchronous motor or induction motor is offered for direct coupled or gearbox coupled mine hoists.

Multi-channel disc brake system:

The hydraulic control unit equipped with dual systems is designed to meet the highest safety requirements. Multi-caliper disc brake is used to realize emergency stops and keeping standstill. The maximum safety is guaranteed by a four-channel system offered in the brake system.
Advant Hoist Monitor:

The Advant Hoist Monitor, known as AHM, is an independent mine hoist safety system that enables protection against overspeed and over- or under-winding.

Rope Oscillation Control:

Rope Oscillation Control (ROC) is developed to reduce longitudinal rope oscillations in deep shafts. It can help the increase of rope life and the improvement of the environment for personnel to stay in the cages.

Argus advanced diagnostic tool:

Argus is a powerful diagnostic tool integrated into the hoist control and drive system. It provides high-speed condition and performance monitoring of the hoist, as well as local or remote functionality for troubleshooting and maintenance of mine hoist systems.

4.1.2 The range of applications

ABB’s Mine Hoist covers a variety of applications of three hoist types: friction hoist, drum hoist and Blair multi-rope hoists (see Appendix 2).

Friction hoist:

The multi-rope friction hoist is a common and most economical solution for high capacity mines operating at depths of between 250 meters and in excess of 1600 meters. Friction hoist with skip/skip fits most for single-level mines, while friction hoist with skip/counterweight or cage/counterweight suits well for multilevel mines. The configuration with counterweight is also recommended for short hoisting distances.

Single drum hoist:

The single drum hoist is often a preferable choice for personnel and equipment transport and shaft sinking in shallow mines with depths of less than 250 meters, usually with one conveyance. Single drum and Blair multi-rope hoists can also be used with two ropes and a single conveyance.

Double drum hoist:

Double drum hoist has a wide application for all shaft depths ranging from about 100 meters down to 3000 meters deep. It is favorable to multiple level mines with the problem of rope stretching due to the separate rotations of the twin. In deep mines, double drum hoist is more welcome comparing with single drum hoists thanks to the advantages of both flexibility and lower unbalanced load.

Blair multi-rope hoist:

Blair multi-rope hoist with two ropes for each conveyance is a normal solution for the highest payloads at the very deep shaft depths. Hydraulically connected compensating sheaves are needed to ensure equal rope tension at the conveyance.
4.2. PLM practices of ABB Mine Hoist

4.2.1 The characteristics of ABB Mine Hoist

ABB has a long experience of delivering Mine Hoist. At the early stage, the company concentrated only on the drive and control system of Mine Hoist. With the technological development, different types of mine hoist, top-class brake system, advanced motors, DC drive and converters have been developed over years. The first microprocessor-based control and monitoring system was introduced in 1980s, and ABB Advant Open Control System (OCS) replaced the previous master product in 1990s. Nowadays, as a complete solution for Mining customer, modern Mine Hoist system has encompassed a set of leading functionalities ranging from hoist monitoring, constant emergency retardation control, basic brake temperature monitoring to automatic compensation of rope elongation.

Mine Hoist is a complex system product with long product lifecycle and service supports. The business of Mine Hoist has been carried out over a long period and in the global market, thus is regarded as a mature business with well-organized operations.

4.2.2 The ABB Gate Model

For more than ten years, the ABB Gate Model has served as one common business decision model used by all technology and product development departments across ABB. It not only highlights the focus on business value in decision-making process, but also emphasizes the importance of cross-functional commitment and accountability in product development. The ABB Gate Model supports the use of different life-cycle models, giving the teams more freedom to operate as efficiently as possible without losing transparency and control. The details of the ABB Gate Model would be kept undercover due to the confidentiality requirement of the company.

4.2.3 Current PDM/PLM situation

PDM and PLM are the systematic approaches to organize, govern, and distribute all product-related data during the whole product lifecycle. One of their key functions is to ensure all necessary data are shared among stakeholders and utilized in an effective and efficient way.

With regarding to the data of Mine Hoist, basically, different departments have their own PDM applications designed for their discipline-specific needs. Even though the ABB Gate Model has been used for process integration in product development, there are no corresponding unified PDM standards for information management throughout the product lifecycle of Mine Hoist. Normally, product structure in engineering has served as a common understanding and representation of the product.

From the interviews carried out in the study, the problems, challenges and benefits of PDM in the product lifecycle were summarized as follows:

Problems:

- The product information is sometimes incomplete when being transferred across different departments;
• The product information has not been well-defined and organized in proper forms.
• Being difficult to reuse the previous product information due to the lack of corresponding documents;
• Product information sharing is inadequate due to the missing standards for product data flow;
• The information communication between different disciplines sometimes is not smooth;
• The product information is not always updated in time;

Challenges:
• To make every stakeholder access to the information needed;
• To make product data history visible;
• To maintain product data complete, reliable and in proper forms;
• To have a standardized description of product structure as a common platform;
• To create an integrated and visualized product structure.

Benefits:
• To make easy and quick access to product information;
• To promote existing information reuse;
• To generate quick solutions to customers;
• To make business processes smoother;
• To reinforce the communication with customers and suppliers.

4.2.4 The perceptions of the product structure model

Product structure is regarded as the backbone for PLM & PDM systems. The interviewees’ perceptions of ABB Mine Hoist presented two main tendencies. Most of them viewed product structure as a tree hierarchy from the physical breakdown of Mine Hoist and preferred the division of two main groups: mechanical and electrical. Some viewed product structure from the business strategy and commercial angle, stressing the cost and risk features of product components. All of them agreed that product structure should describe Mine Hoist in a unified and well-organized way, which contains necessary constituents from modules (or subsystems) to components (or parts).

The opinions of how many item levels are supposed to have for constituting the structure differed from one interviewee to another. Staff from supply chain management and service department expected more fine-categorized levels, while salesperson focused more on parameters defining the product functionalities. The upgrading of product systems and components in the product lifecycle is also mentioned by some of the interviewees, especially from the spare part service department. They thought such product changing should be described also in the product structure. In addition, one interviewee from supply chain management suggested the component variants should have the interface with the decision-making of purchasing, e.g. which component variant alternatives can be selected to reduce cost under the condition of unchanged quality guarantee.
All of the interviewees were quite positive about the use of a generic product structure model of Mine Hoist across different disciplines. They thought the generic model would probably bring the benefits for business operations of Mine Hoist which were summed up as follows:

- To enable easy and quick product configuration;
- To smooth the information transfer in the business processes;
- To improve the information sharing between different disciplines;
- To provide a visual tool to achieve a common understanding of Mine Hoist with customers;
- To provide the conceptual material for the training course of Mine Hoist.

4.3 Conclusion

Under the intensified competition in the global market, the implementation of efficient PDM and PLM throughout the product lifecycle is the key factor to shorten lead-time, reduce cost and secure quality for the business of Mine Hoist. However, it faces many challenges among which product complexity, integration difficulty and multiple requirements are the main concerns.

4.3.1 The complexity of ABB Mine Hoist system

Mine Hoist is not a single product, but a complicated system with a variety of items constructing themselves in certain orders, and interrelated with each other in certain ways, together with fulfilling particular functionalities, properties, behaviors, etc. under the various constraints and conditions predefined (see Appendix 3). The complexity of Mine hoist system is determined by the diversity of constituent items with their own parameters, as well as the interconnections among them.

With three types in product family, and six modules attached by more submodules, as well as a large number of components and parts followed after, Mine Hoist is organized and configurated into a complicated system entity. Within this system, different items like modules, submodules, components are interacted through many particular interfaces. The functional overlap and intertwining of items even occur inside the system. The module of the control system is the heart of Mine Hoist which realizes its controlling function over other modules through its AHC (Advant Hoist Control) controller. The performances of the control system including conveyance positioning, speed adjusting, loading and dumpling sequence, as well as rope inspection define the interrelationship between two modules of the control system and mechanical system. The drive system provides propelling force for shaft equipment unit and hydraulic brake station, specifying the interaction among the modules of the drive system, mechanical system and brake system. Meanwhile, there exist overlaps of the brake module with both the control and mechanical module. The units of brake equipment and brake control are merged into the modules of mechanical and control system respectively.

Due to the complex aspects of Mine Hoist mentioned above, the related effects often take place during the operations of the system. A single change of a certain item or its certain parameters during a certain time span can cause consequent changes of certain subsystems or at the whole system level. For example, a simple act of one parameter change of AHC controller could results in different behaviors of shaft and brake unit, leading to a series of knock-on results.
4.3.2 The multi-domain perspective requirements for the product structure model

The business of Mine Hoist is a typical sales-delivery business of the ETO product. During such a business, the support of PLM throughout the business processes, from the sales lead phase to its end of order phase, requires reliable, precise and complete representations of a product. Appropriate data models are of the necessary for the efficient integration of Mine Hoist business operations to promote information exchange. Consistence and unification of product models is usually the big challenge to be confronted due to the fact that multi-domain and multi-perspective are involved and the harmonization among them is not easy to reach. Mine Hoist is a complex system produced by a collaborative team from different disciplines. Each discipline has its own view and understanding of Mine Hoist system, leading to various descriptions and representations of the system.

As Fig. 12 illustrated, the business of Mine Hoist includes three phases: sales lead, quotation and order phase. The business activities of sales, project management, engineering, purchasing, delivery & after-sales service are involved in the above phases, resulting in different perspectives of how to perceive the complex Mine Hoist system. For example, a functional perspective from sales personnel, an assembling perspective from supply chain manager and a spare part kit perspective from service staff. Meanwhile, with the proceeding of business operations, the description of Mine Hoist can change across different domains. For example, when sales process is developed into engineering process, then into purchasing and spare part service, the domain is shifted from the functional to the technical, and then to the physical domain.

Due to the different usages of the product model, different perspectives and domains have different requirements for the descriptions of Mine Hoist. For example, sales discipline requires an up-to-date product structure and an instant response of functional changes to keep the proper operations of Mine Hoist. As for engineering discipline involving creating a great amount of product data, the smooth information flow and distribution, as well as the reuse of existing information are of apparent interest. While, procurement discipline is more interested in detailed description and specification of parts constituting Mine Hoist system. With regards to aftersales, the necessary information of spare parts and the version descriptions of components are on the top of the requirement list. Therefore, different structural representations are needed to reflect those requirements from different perspectives and domains, which demands different ways of product decompositions or breakdowns.

![Figure 12 The sales-delivery process of ABB Mine Hoist](adapted from Brie’re-Co’té’ et al. 2010, pp.59)
4.3.3 The challenges of product information integration

PLM is a join-up approach with a holistic view. The integration of a variety of different operations, and disciplines center on product-related information is the most important issue in PLM process.

In a sales-delivery business, there are a number of product data inputted and outputted in the process as illustrated in Fig. 13. The function, behavior variables, especially structure variables such as standard component data, validated variant data, new variant data, project data, procurement data, spare part data, etc. have been involved. How to organize the product-related information to fit every operational phase, to match its configuration of each discipline has become the big challenge confronted by Mine Hoist system. The function-support information representation of Mine Hoist cannot be applied directly for Mine Hoist behavior analysis, and verse vice because they belong to different domain-specific configurations. Thus, organizing and managing the complex Mine Hoist system by integrating and coupling various functions with various multi-level and multi-domain structures and behaviors is going to be not only one of its PLM activities, but also the major challenge of its PLM and PDM in business processes.

According to the integrated view of PLM, a conceptual product model should be given to communicate with different representations of Mine Hoist, to achieve information exchange in a unified environment, to ensure the consistency of information among different domains and perspectives. Based on this generic domain-independent model, the domain-specific implementation models are developed to help the accomplishment of different operations in business logistics. From the interviews taken in the mining unit, it can be concluded that the current product models are rather the separate mappings of Mine Hoist from either different domains or
different perspectives respectively. The issue of how to construct a generic product model that takes the requirements of different disciplines into consideration and realizes smooth information transfer between different disciplines still remains unsolved.

The other challenge of information integration faced by the business of Mine Hoist is the continuously updated process of product data repository throughout the product lifecycle as displayed in Fig. 13. As an ETO product, a number of Mine Hoist solutions are delivered to customers according to their specific needs. Based on the PLM thinking, the information of new solutions should be constantly captured and integrated into the product family repository, from which the proven variants can be retrieved and reused for future projects. Unfortunately, such a vertical integration has not been paid enough attention to in the business reality of Mine Hoist. The orders of Mine Hoist have been usually carried out on project-to-project base, most of the validated product data has been treated as fragments and pieces instead of being organized and reserved in a structured and systematic way.

Under the context of PLM, both horizontal and vertical integration of product data are crucial for product-related information sharing and reuse. So, what causes the current situation of inefficient integration in the process of Mine Hoist information transfer in the mining unit? The reason partly lies in a lack of integrated ways to convert specific product information into validated generic product data for information accumulation, as well as a lack of standardized approaches to efficiently reuse validated product data in sequent projects of Mine Hoist.
5. Analysis

In this chapter, the current situation of product information management and product lifecycle management will be analyzed based on the theoretical framework. The major issues that need to be addressed when creating a generic product structure model throughout the product lifecycle will be identified, answering the first research question. Then, the requirements and product structures of different disciplines, as well as its product structure management will be analyzed, then a generic product structure model will be proposed and its role in the product lifecycle will be discussed according to the modeling methods given in the theoretical framework. The research question two will be answered during the generating process of the model.

5.1 The product data management analysis

5.1.1 The product data of ABB Mine Hoist

In the theoretical chapter, product data has been defined as both the description of a product itself and the process it goes through in the different phases of the product lifecycle. As for ABB Mine Hoist system, a variety of data containing an amount of Mine Hoist information has been produced and coexisted in their daily business. As mentioned in the empirical study, ABB Mine hoist is a complex ETO system product that involves a large number of items, functions and interrelations. Its data show a relatively high level at both dimensions of volume and complexity (Fig. 14.).

![Figure 14 The two characteristics of ABB Mine Hoist data](image)

Likewise, Mine Hoist data can also be divided into three categories:

- **Definition data**: A complete definition of Mine Hoist, including its physical and functional features, both concrete and abstract, in document or data form.
- **Life cycle data**: The information associated with the business processes of Mine Hoist, such as engineering, sales, procurement and service operations.
• Meta-data: The information about the management of Mine Hoist data, such as what type of data, where, how to organize the data.

Additionally, engineering data plays a critical role in the business of Mine Hoist, thus it is usually regarded as the master data in the description of Mine Hoist.

Product-related data is the most important resource for a company. It is a necessary support for product development throughout the product lifecycle. Product data needs to be properly organized and maintained to fully function as a supportive resource. The potential problems with regards to product data of Mine Hoist could raise as follows (Stark, 2016):

• Database overlapping among different disciplines;
• Undocumented knowledge remaining in individuals;
• Difficulties of getting access to existing data;
• Obstructed data exchange with other stakeholders;
• Confusion and errors from different descriptive versions of the same data.

5.1.2 The data management of ABB Mine Hoist

The business of Mine Hoist is a typical sales-delivery business of ETO product as illustrated in Fig. 15. For such a business, information management refers to not only the explicit content management of product knowledge, but also the management of how to transfer valuable product-related knowledge throughout the product lifecycle. Apparently, a set of activities associating with product-related data projects, processes, practices, and systems, from design to implementation and monitoring are involved in the business operations of Mine Hoist (Otto, 2012). How to communicate among those product data-related tasks to reach a harmonized state at an overall level is a big challenge that needs to be addressed.

Product data needs to be organized in a proper PDM system to implement data design, controlling and distributing for each business process. PDM system is the main constituent of a PLM solution, providing managerial tools for product data controlling throughout the product lifecycle (Stark, 2016). PDM system serves as a unified infrastructure for product information sharing and reuse, which actually is somehow missing in the business reality of Mine Hoist. According to the theoretical framework, PDM system should provide and support the following functionalities for Mine Hoist (Sung & Park, 2007):

• Data vault and document management: smooth storage and retrieval of Mine Hoist information.

Figure 15 The sales-delivery process of ABB Mine Hoist (adapted from Brie`re-Co`te` et al. 2010, pp.59)
• Workflow and process management: managing Mine Hoist data flow to drive business operations with reliable and consistent data.
• Product structure management: dealing with Mine Hoist breakdown, configuration and design variations.
• Parts management: managing data on standard components to facilitate design reuse of Mine Hoist.
• Program management: promoting coordination between processes, resource planning and project tracking.

ABB Mine hoist is regarded as a complex ETO system product with the involvement of multi-domain and -disciplines, leading to both high volume and high complexity of product data. Apparently, in comparison with the mass-customized product, the data management of the complex product is more difficult due to its distinctive characteristics (Feng et al. 2009). Product data of ABB Mine Hoist are produced and used in various ways within different departments and in different phases of the product lifecycle. Managing various product information from multiple data sources and during different phases of the product lifecycle is not an easy thing. Therefore, integrating them into a unified system to ensure the traceability, consistency and interoperability of the information during the product lifecycle is one major challenge for PDM.

The potential problems for manage Mine Hoist data in the product lifecycle can be summed up as follows from the interview results:

• Different systems of managing Mine Hoist data;
• Lack of a standardized and unified PDM system;
• Poor integration level of product data and corresponding systems;
• A time and resource waste due to the duplicate works in PDM;
• A portion of product data still remains outside the PDM systems;
• Slow transfer of product data.

During the process of complex product data management, two main issues have raised that need to be solved. One is how to deal with the combination of different data forms such as text data, semi-structured data and structured data to achieve efficient data retrieval; another is how to manage the different versions of data history to maintain data consistency in the product evolution (Feng et al. 2009).

Normally, PDM system manages product-related information at the “meta-data” level, leaving those a large number of the detailed data for CAD, CAE and CAM systems to deal with (Srinivasan (2011) as cited by Vosgien, 2015). A standardized product meta-data model is called for to enable the integration of heterogeneous needs from domain-specific systems, as well as the bidirectional linkage between “meta-data” and “lifecycle data” and “definition data”. Meanwhile, to support version management of product data, an appropriate model that is able to define the product, identify and organize the data versions is also required for efficient “retrieving existing versions and constructing new versions” (Feng et al. 2009). Thus, how to define the principles and rules for formulating the standardized models in an ideal and simple way is the other major challenge for PDM system.
5.1.3 The major PLM/PDM issues of ABB Mine Hoist

Immense and diverse information flow is the main characteristic of the working environment under a PLM background. In order to ensure each stakeholder obtains and utilizes the proper product information relevant to their tasks, the information filtering, structuring, integrating, controlling and channeling is of the most importance (Fenves et al. 2008). While, without a reliable product data model, it would be difficult for these activities to be fully accomplished (Fenves et al. 2008). In another word, an appropriate product model is a necessary enabler for successful product information management.

1. Integration

PLM is a join-up business approach to unify a variety of segregate and dissociated operations, disciplines and functionalities throughout the product lifecycle under a single umbrella (Stark, 2016). “Product Data Management”, “Process Management” and “Engineering Project Management” constitute three cornerstones supporting the PLM system (Gmelin & Seuring, 2014). With regarding to Mine Hoist system, the ABB Gate Model has touched upon the latter two: a process-supportive system to accelerate the implementation of business operations cross functional departments; a project-based tool to systems to solve product-related issues through efficient allocation of product resources (Gmelin & Seuring, 2014). However, the former “Product Data Management” has not been paid enough attention.

The business of Mine Hoist is a typical sales-delivery business of the ETO product. A variety of business activities such as sales, project management, engineering, purchasing, delivery & after-sales service are involved. Actually, Mine Hoist is a complex system produced by a collaborative team from different disciplines. Each discipline has its own view and understanding of Mine Hoist, leading to the multi-facet characteristics of product data through the lifecycle of ABB Mine Hoist. This data complexity of multi-source and heterogeneity can cause confusion between different product representations and repeated work on the same “object”.

To promote product information exchange across different disciplines, an integration of multi-domain representations of Mine Hoist is required. The goal is to achieve synchronization of multi-domain’s needs with an appropriate data set. The rules or principles for integration should make sure simpler interfaces and smoother data transfer between multi-domain application systems, and the better compatibility of them. Implementing the information integration of Mine Hoist faces many obstacles with various factors to be considered. It is certainly an important issue that needs to be concerned when considering a generic product structure model in the context of PLM.

2. Consistency

PLM is a holistic conceptual presentation that focuses on all product associated data. It aims to ensure the traceability, consistency, and long-term archiving of product-related information through combining product data, people and processes into an integrated entity (Corallo et al. 2013). The consistency of data covers a range of “disciplinary domains”, “lifecycle phases”, “levels of detail” and “engineering changes”.

42
The ABB Gate Model has been applied for more than ten years inside ABB aiming to support business value creation and cross-functional collaboration for product development during the whole product lifecycle. Even though, it seems that information management has not yet caught up with the step of business process management in the PLM/PDM practices. This situation leads to the discrepancy between the data system and the business process system to some degree, which raises the consistency issue of PLM in Mine Hoist. Meanwhile, different disciplines have their own information applications for domain-specific needs as mention in the empirical study, causing the data disperse among different departments, different lifecycle phases, as well as different levels of detail extent. When applying PLM thinking, a unified information solution is required to achieve data consistency based on various domain-specific applications, which is certainly a big challenge (Vehkapera et al. 2009).

Moreover, Mine Hoist system has been constantly upgraded with new functionalities emerging and new components replacing the old ones, resulting in a dynamic data environment. Product information needs to be updated for keeping the consistency of data history. Whether a generic structure model can help to detect and correct the inconsistency of Mine Hoist information in a multi-dimension and changing environment is also a main concern in the PLM context.

3. Product repository

“The business is not interfered by the lack of materials or components, but the insufficiency of data at critical moments” (Vehkapera et al. 2009, pp.769). PLM is regarded as a strategic approach to facilitate business operations through efficient product-related data, processes and application management. Among those, capturing, managing and maintaining the product definition information as well as making necessary product data available and updated are two major PLM activities.

Although Mine Hoist is an ETO type of product, there are many similarities among the solutions offered to customers. The fundamental constituents of Mine Hoist are the same for different projects, leading to a huge potential for validated components to be reused in the new Mine Hoist orders. Identifying the similar engineering scenarios, retrieving the product data from existing projects as reference resources for new projects has become the common way in Mine Hoist business processes. This approach has been long applied in all departments, which was perceived by the interviews with respondents.

To efficiently reuse existing information of Mine Hoist, a product repository is a necessity to allow an easy and quick retrieval of the validated information from previous projects. Usually, two elements are supposed to be included in the repository system: a generic product (structure) model providing an abstract description of a product, and a pre-defined component collection including standardized components and reused component variants.

In the business of Mine Hoist, in addition to technical specifications and other product descriptions, engineering database including mechanical and electrical engineering has served as the Mine Hoist repository for different disciplines to acquire their necessary data. Although engineering database encompasses abundant product details, it provides product information in engineering language and basically is on project-to-project base. There is a lack of a standardized system to organize and
maintain the proven information in a structured way. A reference product (structure) model is missing with an abstract representation of Mine Hoist. While, variants have remained in individual projects instead of being stored in a systematic and structured way. This situation can cause long retrieving time and possible retrieving errors. Whether a generic structure model can improve Mine Hoist repository to realize the smooth information sharing and reuse is also an issue that needs to be addressed in the context of PLM.

5.2 The product structure analysis

The product structure of the ETO system product is a hierarchical breakdown into a tree structure. It presents different characteristics during the sales-delivery process which rely on the different requirements of different perspectives and domains.

5.2.1 The requirement analysis for the product structure

Basically, the product breakdown is determined by the purposes of using a product structure. Different business disciplines usually have different requirements for product structure. As for ABB Mine Hoist, the domain-specific requirements can be described as follows (Svensson & Malmqvist, 2000; Saaksvuo & Immonen, 2008; Côté et al. 2010):

Sales:

Sales department is the key discipline in the business of ABB Mine Hoist. During the sales lead phase and quotation phase, product configuration proposal, requirements evaluation, and preliminary specifications are given for the sequent project work. Customer’s requirements are documented one by one to formulate a detailed quotation of a new order. When proposing a configuration plan, customer’s specific requirements need to be transformed into particular parameterized features that Mine Hoist system is able to offer. Generally, the parameters of ABB Mine Hoist address certain functional features that are expected to be displayed in a generic product structure model. Other elements like cost calculation and risk evaluation are also desired for the model.

Engineering:

The engineering phase is the most important in the business of ABB Mine Hoist. And data management plays a crucial role because a large amount of data is produced and stored in the engineering process. Product is normally broken down into such different levels as systems, subsystems, and components from the functional view. For the sake of calculation and simulation, usually, a product is also decomposed in a BOM type of way with various detailed information, e.g. shape, size, speed, load-bearing. Although Mine Hoist system is a type of ETO product, different projects are quite similar on the regular base. So, the component standardization and efficient reuse of validated components are of the utmost interest for engineering staffs.

Manufacturing:

In the manufacturing process, the concept of assembly closely associated with how to construct a final product from various pieces is central and of the most interest. Apparently, the functional view from the design discipline is not able to match the need from the manufacturing perspective.
Thus, the product structure should be modified to a new version before being applied to manufacturing operations. Because all components consisting of ABB Mine Hoist are outsourced to internal or external partners, the corresponding requirements somehow are shifted into the discipline of supply chain management.

Supply chain management:

In the procurement operation, product structure is used for purchasing various parts defined by the features of shape, size, materials, etc. From such a view of point, the way of a product breakdown is basically similar to that for manufacturing. In addition, the aspects of quality control and quantity forecast should be accounted into the product structure. The respondents from supply chain management emphasized the importance of giving accurate product information with considerations of quality and commercial risks.

Project management:

The project management is to organize, track and fulfill orders during the order-related business processes which start from taking orders of Mine Hoist from customers. Firstly, all specifications and documents of Mine Hoist delivered from the sales system are used for order-check and assessment of the possibility of putting into business operations. Then all order-related data are transferred into the following disciplines of engineering and supply chain management for product decomposition in different ways. During the whole order phase, project managers need to ensure the product-related data is managed, governed and distributed in a proper way. The respondents in the project management department expressed their requirements focusing on the complete and precise information transfer across different disciplines, especially between sales personnel and project managers.

Service and spare parts:

The service department is responsible for providing various after-sales services for customers. The descriptions and instructions are needed for certain services, e.g. Argus advanced diagnostic system for remote monitoring. All such service-related information should be organized into different groups and preserved in certain information systems.

Spare parts provision is one function of the service department. In this discipline, product structure of Mine Hoist is used to put new spare parts into different categories to help to maintain all spare parts in stock. Unlike other disciplines, a distinctive structure “spare part kits” including a set of spare parts is needed to support the service. The respondents were mainly concerned with the information availability and update, especially the technical specifications of components used to replace those already phased out in the product upgrading. Meanwhile, the information consistency was also their concern which could probably reduce the occurrence of confusing situations.

5.2.2 The analysis of product structure types

During the sales-delivery process of ABB Mine Hoist, several product structure types for different domain-specific needs are involved (Svensson & Malmqvist, 2000; Saaksvuori & Immonen, 2008; Côté et al. 2010):
**Engineering structure:**

Design structure generated and adopted in the design department is regarded as a “master structure” across a company. It is a common resource widely used by the majority of various disciplines and constitutes the basis of other structure systems to be formulated and updated. The design structure includes two levels:

The upper part: namely the “product specification” containing configuration data based on customer’s order. It provides necessary data needed by other structure systems and forms the base for a number of business activities such as order management and manufacturing after the product design process. Part variants are involved in this level.

The lower part: namely the “parts structure” containing “function groups” which are categorized according to part classification. This level of “parts structure” is a fixed structure frame based on particular standards to help organize part-related information for subsequent business activities. Part or an assembly of parts is included in each functional group, but without specific information within it. Part classification is important because it directly affects whether the product-related information can be transferred and searched for smoothly during business processes across a company.

**Manufacturing structure:**

Basically, two main structures in the manufacturing process are the “manufacturing structure” and the bill of material. The former is an intermediate between the design and manufacturing activities with the two same levels as design structure: upper and lower parts. It incorporates not only the identical information from the design structure, but also some changes oriented for manufacturing purpose. The latter of the bill of material is a detailed list of parts, and is automatically generated from the “manufacturing structure”.

**Sales structure:**

The business operation of sales is a comprehensive system involving many information systems. Among those, parameter structure which relates customer’s requirements to functional features of a product is the main tool for sales staff. The upper part of the engineering structure with product specification is the key input for the parameter structure.

**Purchasing structure:**

Unlike structures of design, manufacturing, and sales, purchasing structure is a relatively simple structure dealing with only the data of purchasing parts. It’s similar to the low part of the design structure with part classification, but only parts and assemblies of parts that need to be purchased are involved.

**Spare parts structure:**

The spare parts structure of Mine Hoist is used as a tool to manage all spare parts for the product delivered to the customers. It is determined by both spare parts kits and part classifications.

**Forecasting structure:**
The forecasting structure is a special structure built on “product specification” in the upper part of the design structure. The sold units of each variant are inputted into the structure to forecast future sales volume and its influence on the different parts consumption in the manufacturing process. The forecasting structure is employed in several disciplines such as procurement and marketing.

5.2.3 The analysis of product structure management

As both important constituent and function of PLM, PSM serves as a managerial mechanism to deal with product structure for achieving efficient business operations throughout the product lifecycle. Among the factors having an impact on PSM, only “product”, “process” and “information structure” will be considered here in the study (Fig. 16). The functionalities of PSM such as supporting specific domain views, linking product data to generic structure; ensuring consistency; updating variant repository will be the focuses to discuss the case of ABB Mine Hoist.

![Diagram](image)

*Figure 16 The factors affecting PSM of ABB Mine Hoist (based on Svensson & Malmqvist, 2000, p. 6)*

When implementing PSM, a major issue is how to address the “multi-facet feature” of product data. Since product-related information at different levels and from different sources are involved in the PSM process, and the heterogeneity of operating platforms and applications exists in business processes as well (Peng et al. 2017; Xu et al. 2009). This usually results in the failure of capturing consistent information in a quick and easy way, and time and money have been spent on duplicate searching works as well. To enable effective and efficient information sharing and reuse, it is really necessary to set up a unified, standard model which is able to support domain-integrated view during the product lifecycle, to contain necessary data for retrieval, and to associate with the history of data evolution (Peng et al. 2017; Vosgien, 2015).

According to the framework of product structure integration proposed by Papinniemi et al. (2014), an integrating process of Mine Hoist can be illustrated in Fig. 17. The generic product structure
model is connected with domain-specific structure models bidirectionally. A generic product structure model is created from the gathering of domain-specific information in each phase of the sales-delivery product lifecycle. The functional structure, engineering structure, BOM structure, purchasing structure, and spare part structure provide a concrete information base for the generic product structure model to be extracted from. This generic product structure will serve as a “master concept” to deliver common information of Mine Hoist in a unified and consistent way across the business processes of the product lifecycle. Whereas, the domain-specific structure models are derived from the generic product structure model with different domain considerations and specific information.

![Diagram of product structure integration](adapted from Papinniemi et al. 2014, p. 4420)

The levels of details and the number of objects included in the generic product structure are determined by the tradeoff among different domain-specific structures. The exactness of the generic product description will not be as detailed as BOM, purchasing and spare part structure do. Due to the consideration of different disciplines simultaneously, it will maintain at a proper degree for being able to be accepted by not only engineering, procurement, and service, but also sales and order/project management.

Considering the requirements from different disciplines, functionality is adopted as a criterion to define the modules but the requirements from engineering and supply chain and spare part are also
taken into account. For instance, the module of the brake system is split into two parts instead of being a separate module, one is incorporated into the mechanical module and the other into the control module. Still, the function of the brake system can be identified in the product structure.

5.3 The product modeling method

The purpose of the study is to create a generic product model to describe the basic structural characteristics of the ETO system product. The object-oriented modeling framework was used during the model generation. The cross-domain integration, data consistency, and updating throughout the product lifecycle were the main principles for the product modeling.

5.3.1 The product modeling based on step-based product model

The ETO system product is configurated and produced according to the customer-specific requirements. Its modeling is based on both “individual product” and “customized product” models, with standard items and reused item variants pre-engineered, while new item variants freshly engineered. Specific requirements of customers are typically presented in such ways as “optional and alternative functional properties” in the product structure. Taking ABB Mine Hoist as an example, the product structure can be broken down into the following levels (Fig. 18):

- The product level: the product that is modeled, namely mine hoist.
- The product family level: different types in the hoist family, so-called ground mounted friction hoist, tower mounted friction hoist, single drum hoist, double drum hoist, Blair multi-rope hoist.
- The property level: hoist properties that can be configured according to customer’ needs, including production rate, shaft depth, level numbers, cage capacity, skip payload, hoist speed, hoisting distance.
- The system level: the primary-class technical systems for implementing hoist properties, including mechanical system, control system, drive system, brake system, safety system and remote diagnostics system.
- The subsystem level: the secondary-class technical system for implementing hoist properties.
- The unit level: the tertiary-class technical system for implementing hoist properties.
- The component level: standard parts and part variants constitute the above system classes.

Among these levels, “part-of relationship”, “type-of relationship” and “property relationship” are three major interrelations between items.
5.3.2 The product modeling based on AGPS product model

In the sales-delivery operations of the ETO system product, three phases are often heavily integrated, accomplishing the process of the product lifecycle. The information transfers from the beginning of the sales lead phase to the end of the order phase with the ownership of product data shifts from the sales department to the service department. Afterward, the new-generated data in the new order is integrated into the product repository/library, fulfilling a lifecycle of product information. A generic product structure model based on meta-data plays a key role in the cross-domain integration, data consistency and product repository throughout the product lifecycle.

1. Composition of ABB Mine Hoist

As an ETO system product, ABB Mine Hoist is configured and delivered according to the specific demands of customers. In order to realize the order efficiently, an optimal configuration is required. This is actually a process of systematic reuse of standard and proven items, as well as engineering of new items to satisfy customer’s specific requirements within product specification constrains (Côté et al. 2010). From the perspective of product configuration, ABB Mine Hoist can be seen as a product consisting of three types of constituent like other ETO system product (Fig. 19):
• Standard item with common features: the fixed part of ABB Mine Hoist configuration with a group of items performing regularly occurring features.

• Reused item variant with parameterized features: outcome of previous product configuration with predefined features.

• New item variant with special features: newly designed item with unique features presenting customer’s very specific needs and preferences.

2. The sales-delivery process of ABB Mine Hoist

Like other ETO system product, the sales-delivery process of ABB Mine Hoist also goes through three phases: “sales lead, quotation and order phase” as AGPS product model presents (Fig. 20). The updated product repository becomes one outcome of this process.

• Sales lead phase: Customer’s requirements are documented. The preliminary solution plan of mine hoist is given through “sales-configuration”. The generic product structure is introduced in this phase as a reference to relate customer’s requirements to standard and parameterized features pre-defined in the product repository. The parameter structure is applied in this phase.

• Quotation phase: Based on the generic product structure, a solution proposal is given in this phase. The preliminary specification draft of new items, the estimation of operational cost and lead-time are generated by comparison with similar items in Mine Hoist repository. It is expected that near-optimal solutions can be achieved during this phase.

• Order phase: The project and project-related tasks, lead-time and resource requirements are determined based on the standard product data from Mine Hoist repository. The generic product structure is introduced to review and evaluate the order details, and reused variant data are applied to generate order specifications where the detailed descriptions of reuse items are accomplished. Hereafter, the engineering subphase is introduced to complete the final release of new components. The corresponding product technical structure then serves...
as an engineering base for the different definitions of subsequent product structures such as industrial and logistics structure.

- Repository update: After an order is completed, the new item variants are incorporated into the Mine Hoist repository to accomplish the iterative updating process. One closed loop lifecycle of information is finished.

5.4 The general applicability of the model

Same as ABB Mine Hoist system, most ETO system products are characterized by the system complexity and the high data volume. Distinctive from simplified products, the ETO system product is a complicated system determined by the diversity of constituent items and the interrelationships among them under various constraints. A single change of a certain item can possibly affect the system level, causing a series of changes of particular functionalities, properties, and behaviors of the product. Meanwhile, a variety of product-related information has been generated and held by different data owners in the different phases of the product lifecycle.

Likewise, during the sales-delivery lifecycle of the ETO system products, multiple domains and disciplines are involved in the collaborative works and each has its respective understanding and requirements for the product structure. Usually, the business activities of sales, project management, engineering, purchasing, manufacturing, delivery & after-sales service are included in the three phases (sales lead, quotation and order phase) of the sales-delivery business process. Just as ABB Mine Hoist system does, different structural representations coexist, demanding different ways of product decompositions or breakdowns.

Although the above analyses were conducted based on the empirical evidence of ABB Mine Hoist, with the common characteristics of the product and similar requirements of different disciplines,
they could probably be applied in the same way to the ETO system products with the sales-delivery business process. Three issues of PDM/PLM identified in ABB Mine Hoist need to be addressed when formulating a generic product structure model of the ETO system products in the context of PLM, namely the integration of different disciplines’ requirements for product structure; the information consistency throughout the product lifecycle; the product repository update considering product changes. Likewise, the method of constructing a generic product structure model of ABB Mine Hoist seems also applicable to other ETO system products. And the central role analysis of this generic model in the product lifecycle can fully fit the ETO system products in their sales-delivery product lifecycle.

Thus, the procedures which were performed in the generic model formulation of ABB Mine Hoist can be extended to the modeling process of an ETO system product in the sales-delivery product lifecycle. They include the data management analysis, product structure requirement and type analysis, product structure integration analysis, the step-based product modeling, the role analysis of the model in the product lifecycle.
6. Results

The study results based on the empirical analyses will be presented step by step in this chapter. A generic product structure model of ABB Mine Hoist will be presented, showing the common features of the ETO system product model. The central role of this generic model in the sales-delivery product lifecycle will also be identified and illustrated. Due to the confidentiality agreement, the results related to ABB Mine Hoist will be only partly revealed.

6.1 The functional composition

According to the previous empirical analysis, functionality was adopted as the main criterion to define the modules of an ETO system product. Thus, a functional composition needed to be analyzed first to constitute the basis for the further generation of a product diagram.

Regarding to the case of ABB Mine Hoist, it was mapped up into six functional modules based on the document analysis on both ABB Mine Hoist manuals (function description, etc.) and the previous projects (Pyhasalmi, Cannington, Longgu, etc.). The six modules were illustrated in Fig. 21, namely: mechanical system, control system, drive system, brake system, safety system, and remote diagnostics system. Among them, the mechanical and brake system, control, and brake system have their overlapped contents with each other.

Figure 211 The function composition of ABB Mine Hoist
6.2 The product diagram

Based on the functional composition, more detailed components, units, subsystems, as well as their interrelationships and interfaces needed to be mapped up for the final formulation of a generic product structure model of the ETO system product. The case of ABB Mine Hoist displayed how a product diagram was achieved.

The functional items of ABB Mine Hoist and their interactions were mapped up according to the findings from the document analysis and the interview results with respondents from different departments (Fig. 22). There are a large number of components and parts of the system, and the interrelationships among systems, subsystems, units, and components are complicated. Thus, only the main interrelations were given, and the levels of items were only down to component, the part level was not included in here.

Among the functional modules, the control system is the central hub of ABB Mine Hoist. It not only controls a set of operations of hoists, but also interacts with other systems, people and machinery through various interfaces. The main Human-Machine-Interfaces (HMI) were illustrated in Fig. 23.

Since these two figures (Fig. 22 & Fig. 23) are related to the business secrets which the company does not intend to make public, only the main structures were displayed with the confidential contents covered here.
Figure 222 The diagram of ABB Mine Hoist
6.3 The generic product structure model

According to the principles of the object-oriented modeling framework, the generic product structure model of ABB Mine Hoist (Fig. 24) was developed by taking the requirements of different disciplines in the sales-delivery process into account. This specific model of ABB Mine Hoist displayed the basic framework of a generic product structure model for the ETO system product, including item levels and item types described as follows:

The model was broken down into seven levels of items (Fig. 24): product, product family, property, system, subsystem, unit, and component levels. The standard items and reused item variants are pre-engineered, while some new item variants need additional “customer-specific planning and
engineering”. Base product, alternative, and option were used to represent standard item, reused variant and new variant. Within the model, “part-of relationship” and “type-of relationship” are two main relationships between items as mentioned in the analysis. And “property relationship is also included as well.

Due to the same confidential reason as Fig.22 and Fig. 23, the generic product structure model of ABB Mine Hoist was only partly illustrated, subsystem, unit and component level were kept confidential.

6.4 The role of the generic structure model in the product lifecycle

For the ETO system product, the generic product structure model can be used as a “master concept” in the sales-delivery business process to tie up different disciplines in the context of PLM (Fig. 25). It also plays a central role in the closed loop of product information lifecycle from information capture, validation, storage, retrieval, reuse to information renewal (Fig. 25). It is expected to help the information capturing, managing and exchange associated with the domain-specific product specifications. It may benefit the business operations of the ETO system product throughout the sales-delivery product lifecycle from the following aspects:

- Improved communications among different functional departments and integration of different disciplines;
- Standardized conceptual structure base for the development of domain-specific structures;

Figure 244 The generic product structure model of ABB Mine Hoist
- Enhanced ability to manage product complexity through a common model that can be viewed from multiple perspectives;
- Improved product information sharing and reuse during the product lifecycle by means of a standard product structure model;
- Updated product repository considering information evolution to provide a database for new solutions;
- Improved process monitoring through a visual and precise model to evaluate information consistency, accuracy, and completeness;
- Improved product training on fundamental knowledge of the ETO system product through a visualized conceptual model.

*Figure 255 The generic product structure model in the product lifecycle*
7. Conclusion and discussion

A final conclusion of the study which centers on the objective and two research questions will be summarized in this chapter. Then a discussion will be followed reflecting on the contributions of the study and research reliability. The further research avenues on this study topic will be also suggested in this chapter.

7.1 Conclusion

A complex ETO system product usually involves a set of collaborative works from multiple disciplines in its sales-delivery process, resulting in a large amount of product data generated from different data sources and remained in the hands of different data owners. Managing various product data in a structured way to facilitate information sharing, exchange and reuse throughout the product lifecycle has become crucial for time-saving, cost reduction and quality security in business activities. Therefore, the objective was put forward in the study as: to propose a generic product structure model fit for the engineer-to-order system offering with the consideration of its product lifecycle. Two specific RQs were suggested then, aiming to achieve the objective in a gradual and correlative way. Centering around these, the theoretical framework was built up and the analysis was performed in the form of a case study of ABB Mine Hoist.

PLM provides an integrated way for different business operations to be carried out in an efficient way during the product lifecycle. The product structure constructs the backbone of the PLM system which centers on product information. When creating a product structure model of ETO system product in the context of PLM, three issues were identified as the key factors that need to be addressed as follows, answering the RQ1:

- The integration of requirements of multiple disciplines for the product structural representation;
- The consistency of product information throughout the different phases of the sales-delivery process, namely product lifecycle;
- The updating of product repository considering product changes for easy retrieval of the validated information from previous projects.

Thereafter, based on the object-oriented modeling framework, a generic product structure model was proposed and its role in the product lifecycle was discussed, answering the RQ2:

Firstly, by illustrating a complete process of creating a generic product structure model of ABB Mine Hoist, the way of how to construct a generic structure model of the ETO system product was presented. The model took the requirements of different disciplines into consideration and tried to make a tradeoff among them. The domain-specific structures in different phases of the sales-delivery product lifecycle were analyzed, providing a concrete base for the generic product structure model to be extracted from. The step-based product model was then applied to build up a generic product structure model with seven levels – a model integrating domain-specific structures in a simplified and unified way.
Secondly, to consider the model in a PLM environment rather than in an isolated way, the AGPS model was employed to display how this generic product structure model could act as a standard tool to support the integrated PDM in the sales-delivery product lifecycle. The model would serve as a “master concept” to deliver common information of the ETO system product across different phases of the sales-delivery product lifecycle. Whereas, the domain-specific structure models could be derived from the generic product structure model with different domain considerations and specific information. The model could also play a central hub in the closed loop of product information lifecycle from information capture, validation, storage, retrieval, reuse to information renewal.

The objective of the study has been achieved after the analyses were conducted and the final results were obtained. A generic product structure model fit for the engineer-to-order system offering with the consideration of its product lifecycle has been formulated. It’s expected to benefit business operations of the ETO system product through improving the integration of different disciplines, as well as enhancing information exchange and reuse.

7.2 Discussion

7.2.1 Theoretical contribution

Based on the case study of ABB Mine Hoist, a unified information environment characterized with the integration of domain-specific requirements, the consistency of product data, the update of product repository has been identified as the key to handle the complexity of the ETO system product information throughout the sale-delivery product lifecycle. A generic product structure has then been suggested as an enabler of this unified information setting. This integrated view of managing the ETO system product information from the PLM perspective is one of the main contributions of the study.

A method of how to construct a generic product structure model has been proposed which can be applied to the ETO system product despite being developed on the basis of ABB Mine Hoist case study. This method is not merely a simplified breakdown of the product as introduced in the theoretical framework of the step-based model. Rather, it provides a modeling way of product structure based on the integration of the requirements of different disciplines in the product lifecycle. The generic model exhibits a standardized representation that describes the product structure at an abstract level and with an appropriate degree of mapping its important aspects as well. Meanwhile, considering the characteristics of the ETO system product, the model has been generated by means of not the individual or customizable product model but the combination of them under the theoretical framework of the step-based model. Applying the relevant theories to the practical analyses in critical thinking adds another contribution to the study.

The role of such a generic product structure model in the whole product lifecycle has been identified and summarized. Firstly, it acts as a “master concept” throughout the sales-delivery lifecycle of the ETO system product to tie up different disciplines, and serves as a base to address the different requirements of them. Secondly, it plays a central hub in the closed loop of product information lifecycle from information capture, all the way down to information renewal. At last, it also embraces an evolutionary process of product data in which the used variants database and
product repository constantly remain updated. It suggests the product information management is a long-term mission and a unified data system is required for the storage of base product and proven variants. This holistic and dynamic view of treating the generic model in a connective way also makes up one contribution of the study.

7.2.2 Practical contribution

The empirical study of ABB Mine Hoist identified three major issues of PDM in its sales-delivery product lifecycle: namely integration, consistency and product repository. It illustrates the major challenges of dealing with the complex product information across multi-domain and from multi-source. And integrated product structure under a holistic view of PLM was suggested as an effective solution to these difficulties the company faces.

The analysis of domain-specific requirements and product-related structure types in different phases of the sales-delivery process were given, providing for the company a better understanding of Mine Hoist business operations and their dependencies from a product structure view. Meanwhile, some suggestions of how to realize such a product structure integration were briefly mentioned under the theoretical framework, recommending for the company a practical way of how to coordinate different domain-specific requirements for a generic product structure solution.

Finally, a generic product structure model of ABB Mine Hoist was proposed in the study. It could be used by the company as a standard tool to facilitate product information communication across different departments. Meanwhile, the role of this generic model in the sales-delivery product lifecycle was also highlighted in the study, providing for the company a clear picture of how the generic model serving as “master concept” would promote product information sharing and reuse from the PLM perspective. Meanwhile, it also provides for the company an idea of how domain-specific structures can be generated based on this generic model, and how product repository can be built up in an evolving way in the sales-delivery product lifecycle.

In addition, the results of the study could also be considered as a help for other mine hoist systems in the mining industry. Although differences exist among mine hoist system products and their business operations, they have many similarities in terms of functionality, composition structure, and control methods, especially the challenges of mine hoist information management faced in the product lifecycle. In this sense, the results could probably be applied after some modifications, or at least could be used as a reference for other mine hoist systems in the mining industry.

7.2.2 Research credibility

Although only nine respondents were involved in the interviews, the primary data should be adequate to support the empirical analysis because the purposive sampling was adopted. All respondents were representative of the groups from sales to project management, supply chain management, engineering, service/maintenance and department manager. Additionally, all respondents were with above ten-year-experience working in ETO system product areas, to ensure the empirical evidence was correctly perceived and the real problems were identified to the highest possible degree.
The combination of both interview and document analysis was assumed during the empirical study, providing a relatively complete and accurate understanding of the empirical evidence. The case database was established based on the primary data from interviews and the second data from documents, helping to enhance information richness and eliminate single-informant bias. Two information resources complemented and validated each other to ensure the reliability of the study as much as possible.

The results are merely some suggestions for information management of the ETO system product considering the product lifecycle. They need to be further verified by more case studies and application testing in relevant industries. Since only ABB Mine Hoist was taken as a case study due to the time limit, the results may not fully comply with the PDM practices when being applied to other ETO system products in their sales-deliver business processes. The modeling method of generic structure model proposed in this study is more recommended for those ETO system products which have main constituent types in common and similar business processes with ABB Mine Hoist. Still, the role analysis of this generic model in the entire product lifecycle could probably be applied to a relatively broad range of system product business.

7.2.3 Suggestions for future studies

Although the method of how to construct a generic product structure model of the ETO system product has been proposed and the role of this model in the sales-delivery product lifecycle has been discussed, further efforts are still demanded in the future works. Several major research avenues have been identified derived from this study:

- Firstly, more case studies need to be conducted to enrich the understanding of PLM/PDM challenges that ETO system products are facing, as well as to collect the response of applying this generic model method into business operations. The studies could focus on the applicability and effects of this generic model method in business practices, which would help the evaluation and improvement of its general application in relevant industries.

- Secondly, the bidirectional linking between the domain-specific structures and this generic product structure model should be further analyzed and described in detail. The generic structure fits better for product information exchange and sharing cross different departments, while the domain-specific structures are more suitable for the tasks in their respective phases of the sales-deliver process. The extension of the generic model to domain-specific structure models and the compatibility and interoperability between them would be an interesting issue worth further discussion.

- At last, a unified database for the ETO system product repository should be built up to support easy, quick retrieval and reuse of validated base product and its variants in a structured way. The standards and criteria of how to organize existing product information, as well as the corresponding data system of reserving such information need to be explored with the evolving process of the product information taken into consideration.
References

ABB Annual report 2017


Appendices

Appendix 1: The global distribution of ABB Mine Hoist system (cited from www.abb.com/mining)
Appendix 2: The application of three Mine Hoist types (cited from www.abb.com/mining)
Appendix 3: The complexity of Mine Hoist system (cited from [www.abb.com/mining](http://www.abb.com/mining))

1. Hoist motor
2. Hoist drive inverter
3. Inverter's main transformer
4. Exciter transformer
5. ABB's hoist control and monitoring system
   5.1 Hoist control system
   5.2 Hoist monitoring system
   5.3 Brake control system
6. Hoist control pulse encoder
7. Rope slippage pulse encoder
8. Hoist operators desk near the hoist
9. Hoist operator central control room
10. Local control panel
11. Pulley, friction type
12. Brake caliper units
13. Brake hydraulic power and control unit
14. Skip
15. Hydraulic rope attachment
16. Sheaves
17. Measuring and ore loading flask
Appendix 4: Interview record sheet

Interview Record Sheet

Master thesis: Product structure modelling for ETO system product considering the product lifecycle: A case study of ABB Mine Hoist

Topics:

1. The key issues on Mine Hoist product information reuse and sharing across the mining unit.
2. The requirements for product structure model of Mine Hoist from different disciplines.

Selection criteria:

1. Being related to the business operations of Mine Hoist system.
2. Being representative of the certain discipline group.

Form: semi-structured interview

Interviewer: Sumei Zhang

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Function Section/ Work Responsibility</th>
<th>Note</th>
<th>Time</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project management</td>
<td></td>
<td>2019 - 03 - 28 10:00 – 11:15</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
<tr>
<td>2</td>
<td>Supply chain management</td>
<td></td>
<td>2019 - 03 - 28 13:00 – 13:50</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
<tr>
<td>3</td>
<td>Mechanical engineering</td>
<td></td>
<td>2019 - 04 - 03 13:00 – 14:00</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
<tr>
<td>4</td>
<td>Sales</td>
<td></td>
<td>2019 - 04 - 07 16:00 – 18:00</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
<tr>
<td>5</td>
<td>Electrical engineering</td>
<td></td>
<td>2019 - 04 - 11 13:00 – 14:10</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
<tr>
<td>7</td>
<td>General manager</td>
<td></td>
<td>2019 - 04 - 18 13:00 – 13:45</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
<tr>
<td>8</td>
<td>Service manager</td>
<td></td>
<td>2019 - 04 - 24 13:00 – 13:30</td>
<td>Skype</td>
</tr>
<tr>
<td>9</td>
<td>Project Operations manager</td>
<td></td>
<td>2019 - 04 - 11 15:00 – 15:45</td>
<td>Conf Room SE Vasteras_Aengsgardet</td>
</tr>
</tbody>
</table>
Interview Question List

**Topic 1**

1. What are your work responsibilities in Mine Hoist business?
2. In general, are the projects of Mine Hoist you have experienced similar to each other or distinctive?
3. When carrying out a project of Mine Hoist, what product information is usually needed? Where do you get them?
4. Did you use the existing project information/data as references when managing a new project? Often or seldom?
5. Is it easy or difficult to get access to the existing information/data?
6. What’s your perception of the current product information flow across our mining unit? Any problems? In which areas?
7. Are there any of them related to the description of product structure?
8. Do you think a generic product structure model would be a help to facilitate the product information sharing, as well as the communication across different disciplines? Why and how?

**Topic 2**

1. What does a product structure look like in your opinion?
2. Is the use of product structure related to your work? Under what circumstances?
3. What type of product structure is more applicable for service discipline? Functional, BOM or others?
4. Do you have a product structure model that can be used in your daily work? If not, do you think it’s necessary to have such a model? For what?
5. Are there any problems when applying this model to your work? What kind of problems?
6. If formulating a product structure model, what are the most important factors you think should be considered? Or something concerns you?
7. What modules (or blocks) do you think a product structure model should have? And what components each module should include?
8. Which modules or components you think are closely associated to your work?