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School of Business and Management
Industrial Engineering and Management

Kari Ohtamaa

A FRAMEWORK FOR MODULARITY GUIDELINES IN PROJECT BASED BUSINESS

Master’s Thesis 2016

Examiners: Jorma Papinniemi, Senior Lecturer
Lea Hannola, Associate Professor
Supervisor: Toby Crane, M.Sc.

ABSTRACT
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This Master's Thesis examines the project based industrial engineering business and studies how to build a framework for modularity guidelines in the extremely complex environment. The aim of this framework is to provide guidance for Pöyry when preparing a new modular project management guideline. The work studies also the dimensions of Lean in the context of plant design projects and how modularity affects Pöyry's client project lifecycle. This paper aims assess finally how to measure the effects of modularity to the current level of productivity in engineering. The research was conducted as a qualitative case study, including a literature review and an empirical part. The literature review explores productivity, Lean management, modularity and project knowledge management. This study is based on action research method. Primary material was gathered through internal and external interviews that were conducted with semi-structured method. The results obtained from the literature and the case company analysis shows what the dimensions of Lean in the context of plant design projects are and how modularity affects Pöyry's project based lifecycle business. As a result, this paper provides a framework for modularity guidelines and a suggestion for how the productivity trend of the projects can be measured.

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Tämä diplomityö tarkastelee projektimaista liiketoimintaa tehdassuunnitteluprojektien yhteydessä ja tutkii modulaarisuuden hyödyntämistä monimutkaisessa tehdassuunnittelu ympäristössä. Tämä työ pyrkii viitekehyksellään tarjoamaan ohjeistusta modulaariseen projektin hallintaan. Työ tutkii myös mitä Lean-johtamisen eri ulottuvuudet tarkoittavat tehdassuunnittelu projekteissa ja kuinka modulaarisuus vaikuttaa Pöyryn asiakasprojektin elinkaareen. Tämä työ arvioi myös kuinka tehdassuunnittelu projektin tuottavuuden kehitystä voidaan mitata.

Tutkimus toteutettiin laadullisena toimintatutkimuksena. Kirjallisuusosiossa keskitytään tuottavuuteen, Lean-johtamiseen, modulaarisuuteen sekä projektin aikaisen tiedon johtamiseen. Empiirisen osuuden materiaali kerättiin pääosin sisäisten ja ulkoisten, puolistrukturoitujen haastattelujen ja teemahaastattelujen avulla.

Tutkimustyön kirjallisen ja empiirisen osuuden tulokset osoittavat mitä Lean-johtamisen eri tasot tarkoittavat tehdassuunnittelu projektien yhteydessä ja kuinka modulaarisuus vaikuttaa Pöyryn asiakasprojektin elinkaareen liiketoimintaan. Tämän työn tuloksena saatiin myös rakennettua viitekehys modulaarisuuden hyödyntämiseen ja lisäksi tuloksissa esitetään malli kuinka tehdassuunnittelu projektin tuottavuuden kehitystä voidaan mitata.

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Helsinki, 7th of December 2016

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LIST OF SYMBOLS AND ABBREVIATIONS

AFC	Approved for construction
BOO	Build, Own, Operate
BOP	Balance of plant
CAD	Computer-Aided Design
CRM	Customer Relationship Management
EPC	Engineering, Procurement, Construction
EPCM	Engineering, Procurement, Construction, Management
EPS	Engineering, Procurement, Supervision
ERP	Enterprise Resource Planning
ESS	Extended Scope of Supply
ETO	Engineer to Order
EVM	Earned Value Management
FEED	Front-end engineering design
FEL	Front-end loading
IC	Intellectual Capital
KM	Knowledge Management
ML	Machine Learning
NDT	Non-destructive Testing
OB	Open Book
PBBS	Project Budget Breakdown Structure
PcBS	Process Breakdown Structure
PdBS	Product Breakdown Structure
PED	Pressure Equipment Directive
PPR	Post Project Reviews
PDM	Product Data Management
PLM	Product Lifecycle Management
ROI	Return on Investment
WBS	Work Breakdown Structure

1 INTRODUCTION

The engineering companies that work in Engineer-to-Order project based environment are striving for innovation acceleration. To remain competitive and to maintain a continuously growing trend, that company has to be ready and aware of market trends. To avoid implementing of fads and inappropriate operational practices, it’s important to interpret correctly what the new trends implies in these circumstances where your company operates, states Cox (1997, 51). Therefore this paper studies the dimensions of Lean in the context of plant design projects. Lean thinking points out the crucial aspects that companies need to observe. In other words how to implement new innovations to its products and adapt them to the needs of increasingly demanding clients.

It has been notified that modularity in design and construction gives ground to increased level of productivity and it might be the key to meet Clients’ future demands. Modularity brings opportunities that might increase the productivity of daily industrial plant engineering. Modularity is an effective mechanism to increase the reuse of existing product functions, modules and variants states Briére-Côté et al. (2010. Thus, modularity provides the basis for reuse of new components in the design of future product variants. According to Grieves (2006, 10) the time that are wasted in engineering and design functions are usually related to overproduction that means designing of things that are already designed once or several times before. The insufficient ability of reuse validated design, manufacturing and servicing data will significantly prevent a company's objectives of improved competitiveness, quality, productivity and shorter delays, explains Briére-Côté,et al. (2010). Therefore this paper aims to find out how Modularity affects Pöyry’s own and their Customer’s Project Lifecycle and provides a framework for modularity guidelines in project based business. According to Hvam (2016), the context of industrial plant engineering can be seen to be an extremely complex environment for modularity. The costs of plant engineering are relatively high in comparison with the cost of mass customizing products, explains Lehtonen et al (2016). The most of industrial plant projects are quite unique and the level of project maturity might vary depending on the business sector. In the project context, the maturity model concept assesses the capability and capacity of organizations to manage their service type of products, i.e. projects, states Turner and Cochrane (1993).

Engineering applications are becoming more intelligent and will allow engineering companies to automate design more in the future. Due to the technological development in the field advanced database tools combined with appropriate practices of knowledge management, the modularity can nowadays be seen to be more feasible than before in the context engineering of industrial plants. Therefore this paper explores the dimensions of knowledge management and provides recommendations how to enhance it in the case company by methods of Lean. Because of the fact that the primary aim of limited companies can be seen to bring rewards for shareholders i.e. ROI, this paper estimates how to measure the productivity effects of modularity.

1.1 Background

The need for this Master’s thesis study is based on outcome of internal study conducted by Pinnock et al (2012) at Pöyry. It can therefore be assumed that the internal study suggests that Lean based strategic actions should be utilized during the whole lifecycle of a plant design and construction project. To understand the benefits of modularity it is necessary to broach the notion of Lean in this paper. The internal study declared the benefits of modular features in the construction phase of a project, and in the constructability of an industrial plant. The construction costs for general stick built pulp or paper mills are 15-25 % of the total project costs. Construction costs are material and labor costs e.g. installation and construction work. Construction activities take place for 85% - 95% of the overall implementation duration. By controlling the construction activities well you control 85 – 95 % of the time line that has significant effects on project costs. (Pöyry Plc, 2016a.) The outcome of the study conducted by Pinnock et al (2012), has been taken in account in Pöyry’s internal project Modular Constructability Study guideline (PM0). PMO works as a starting point for the empirical study of this paper. Pinnock et al (2012) study indicates also that Modularity in construction is preceded by modular approach in engineering and design. The study is conducted in behalf of Pöyry, because it has been noted that there is a gap in the company's internal guidelines concerning modularity in engineering.

1.2 Research aim and limitations

The objective of this work is to collect valuable information and provide suggestions that could be utilized when Pöyry is preparing a new internal modular project management guideline. This guideline aims to provide a guidance how modularity could be utilized in the industrial Plant Design projects and in its construction. Thus, this thesis will give starting point for this guideline.

The main question in the Masters is:
How to build a framework for modularity in project based business?
The related sub questions are following:

SQ1: What are the dimensions of Lean in the context of plant Design Projects?
SQ2: How does modularity affect Pöyry’s Client project Lifecycle?
SQ3: How can project knowledge be captured and reused?
SQ4: What suggestions can be found for the modular project management guideline?
SQ5: What are the impacts of modularity on the level of Productivity?

1.3. Research methodology

Due to the nature of the topic, the study follows qualitative action research method with semi-structured interviews. The literature review, which was started during the preparation of the work plan, formed a basis for the conceptual analysis of the study topic on the modularity inspected in the context of lifecycle management of consultancy projects.

When seeking of literature and references, the main themes were following:

1. Lean management
2. Modularity
3. Project Knowledge Management practices

The literature review explores sources related to Lean thinking and product lifecycle management. Literature study explores also the latest scientific articles and books related to modularization and business process development in ETO based business. This work seeks also literature that defines the dimensions of knowledge management. Knowledge management can be interpreted to have a crucial role as method in the lower abstraction levels of strategic actions of Lean, specified by Modig and Åhlström (2012; 139).

In addition, this research contains characteristics of constructive research. Constructive research approach aims to improve existing practices from the current state towards target state. In practice this is problem solving in a real-life organizational setting through the construction. The constructive research approach consists of the crucial steps in order to obtain a general and comprehensive understanding of the topic and innovating and constructing a theoretically grounded solution idea. (Lindholm 2008.)

The constructive research was implemented by combining literature related to this topic and inspecting the current project management guidelines at Pöyry. Based the findings, a suggestion of framework for modularity guidelines was created for testing. The framework shows suggested steps toward modularity that have an iterative nature. This framework aims to pay attention on the crucial factor that gives ground to improvement and increase the level of use of existing designs in repeatable projects and across the boundaries of different projects in global project based engineering. The improvement process in this framework was based on a systematic approach from the current state towards target state.

The information for getting a view of the current stage and analysis is collected mostly by theme interviews but also utilizing other internal material from the Pöyry. With help of the literature review and extended theoretical evaluations and assessments on earlier research findings, the author of this work was able to conduct a data collection survey from the case organization, i.e. Pöyry, an internationally operating consulting company (Pöyry Plc, 2016b). Suggested framework from scientific models was tested and commented by the interviewees from Pöyry. The primary material gathered through semi-structured interviews with specialist that belongs to Global Sales and Project Management group (GSPM). One interview was made outside Pöyry at Meyer Turku that operates in the shipbuilding industry. Data obtained from Pöyry and Meyer Turku for the analysis of this study comprised: 1) recordings of discussions made during meetings that focused on the modularity and project lifecycle procedures related to the consultancy projects of Pöyry, at the headquarters of the company, and 2) project management-related documentations offered by Pöyry. Semi structured interview implies that there are certain questions but answer choices do not exist, thus interviewee answers with own words (Ruusuvuori & Tiittula 2009).

1.4. Structure of the study

The organizing of study was carried out by:

1. Arranging meetings on which modularity and the outcome of internal study conducted by Pinnock et al. (2012) were discussed in the context of the Pöyry.
2. Searching of appropriate scientific literature related to Lean management, modularity, knowledge management e.g. capturing of project knowledge.
3. Familiarizing in the literature material and listing of appropriate references.
4. Defining the dimensions of Lean in the context of plant design projects
5. Defining the impacts of modularity to Pöyry’s Client project lifecycle
6. Shaping framework trough Lean approach and giving suggestion of the main steps toward modularity.
7. Defining of research questions and preparing a list of appropriate interviewees.
8. Conducting interview phase and testing of the suggested framework.
9. Finalizing, conclusions and a suggestion of actions that could be taken to facilitate the way towards modularity at Pöyry.

1.4 Introducing the Pöyry

Pöyry is an international consulting and engineering company that was established by Dr. Jaakko Pöyry in 1958. The Pöyry story began in 1958 when Dr Jaakko Pöyry agreed to do the basic engineering for the Äänekoski sulphate pulp mill in Finland. Pöyry grew first to Sweden and the other Nordic countries followed by Europe, the Americas and eventually to the rest of the world. Nowadays the company provides consultancy services across the full project lifecycle by solving issues and complex challenges faced by the industries around the world. Its product portfolio consists of services from management consulting to engineering and project management to operations support that are supported by the expertise of the company in environmental consulting and underpinned by its project implementation capability and expertise. Pöyry delivers over 10,000 projects a year, serves clients across global energy and industrial sectors and also provides local services in its core markets. From 2000 onwards, Pöyry has further developed its competencies in services related to energy, water and environment, transportation and construction. It has expanded its local office network into about 45 countries. “Pöyry’s vision is to be the trusted partner, delivering smart solutions through connected teams”. Pöyry’s strategy is being an international consulting and engineering company. “Clients depend on our deep expertise and performance-driven focus to deliver sustainable results – together”. (Pöyry Plc, 2016b.)

2 LEAN THINKING IN PLANT ENGINEERING PROJECTS

The dimensions of Productivity and Lean management are defined in this chapter. First, the general characteristics productivity are defined and guidance for its measurement is provided. Then the dimensions of Lean in terms of customer value, flow efficiency, resource based efficiency different types of demands are discussed. The three levels, value, principles and methods related to Lean are explained. Finally, at the end of the chapter, the dimensions of Lean in the context of plant design projects are defined.

2.1 The definition of productivity

According to Porter (1985) companies have to possess the ability to differentiate themselves to reach competitive advantage in the market through innovation and technology. Companies need to understand that gains in productivity are one of their main weapons to achieve quality and cost advantages over their competition, explains Tangen (2005). Productivity can be defined in several ways depending on the production system and the level of productivity that is measured, see Kenley (2014). Improvement in productivity requires establishing benchmarks and standards for measuring and a more strategic approach than just measuring productivity, explains Kenley (2014). According to Tangen (2005) measurement and improvement regimes need to be built with a clear understanding of what is being measured or improved. The decisions of productivity improvements have to be based on a shared and a commonly held view in a company aligns Tangen (2005).

Productivity in the context of plant engineering

The view expressed in the topic of this thesis it is interesting to explore the productivity of a production system. It appears from internal material from Pöyry (2016a) that the current project based plant engineering at Pöyry is one kind of production system that conducts mostly tailored engineering that consumes engineering hours to produce documents and drawings. Kenley (2014) states, that the best-known productivity intervention method for a production system is known as the Lean production or the Lean construction method. In other words how to streamline the process by applying Lean management philosophies.

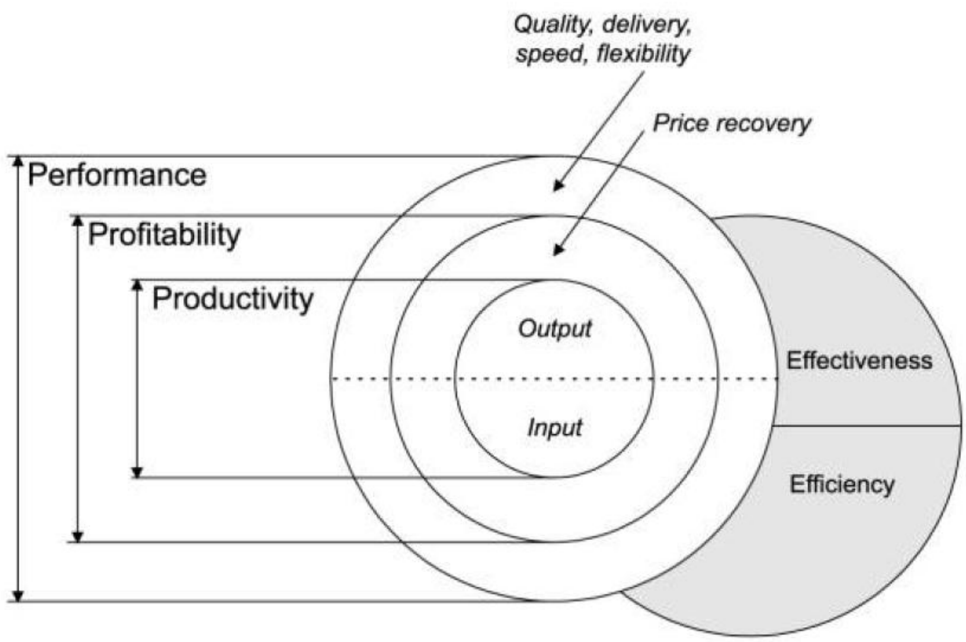

Figure 1. Triple P – model (Tangen, 2005).

Productivity is defined it to be a central core of the triple P-model in Figure 1 above. “Profitability is the overriding goal for the success and growth of any business. Profitability can be defined as the ratio between revenue and cost (i.e. profit/assets)" explains Tangen (2005). The level of profitability might changes for reasons that are not related to the level of productivity; for instance, price or cost inflation. The performance means overall economic and operational aspects and it can be defined to be the umbrella term for the activities that evaluate the success of the company. Effectiveness shows the degree as to how well the desired results are achieved. Efficiency indicates the degree how well the resources of the transformation process are utilized when producing value. (Tangen, 2005.)

The total productivity can be defined to the sum of all these factors that affects the production during a determined period of time. Partial productivity can also be measured, for instance Labor Productivity, explains Tangen (2005). Thus it means that the engineering hours that are consumed to produce drawings during a determined period of time. Productivity is generally defined in industrial engineering, as the relation of output (i.e. produced goods) to input (i.e. consumed resources) in the manufacturing transformation process, see Tangen (2005). The formulas below show one way to measure Productivity:

Tk = total productivity for the period,
O = output per period (i.e. produced goods, drawings)
I = input per period (i.e. consumed resources)
C = input sum for the period, as expressed in units or Euros
R = material input sum for the period
Q = miscellaneous input sum for the period

Total productivity Tk = $\frac{\mathrm{O}}{\mathrm{I+C+R+C+Q}}$ $\qquad$ $Labor\ productivity\ Tl = \frac{\mathrm{O}}{\mathrm{I}}$

Tangen [2005] refers to Bernolak’s (1997) definition of productivity that can be seen to be useful verbal explanation of productivity that is related to the study of this paper and the case company: *“Productivity means how much and how well we produce from the resources used. If we produce more or better goods from the same resources, we increase productivity. Or if we produce the same goods from lesser resources, we also increase productivity. By “resources”, we mean all human and physical resources, i.e. the people who produce the goods or provide the services, and the assets with which the people can produce the goods or provide the services. The resources that people use include the land and buildings, fixed and moving machines and equipment, tools, raw materials, inventories and other current asset”.* (Bernolak,1997.)

According to Tangen (2005) this definition captures two crucial characteristics of productivity. These are the value that are created and transferred to the customer and the use of available resources. It can be assumed that productivity is gained through the speed and an action that adds value to the products that are produced. The level productivity will reduce if the available resources are not used properly or if there is a lack of them. Tangen (2005) summarizes that productivity means such actions that eliminate the waste in order to gain improvements. According to Tangen (2005) waste means the opposite of what productivity is aiming at.

2.2 Connection to Lean thinking

Lean manufacturing, or s "Lean", can be defined to manufacturing, production or construction practice, whose primary objective is the maximization of value for the customer through the elimination of production waste, state Womack and Jones (2003). According to Grieves (2006, 1) Lean thinking implies elimination of waste and inefficiency in manufacture phase that can be interpreted to mean construction phase in the context of Pöyry. Modig and Åhlström (2012, 140) defines Lean rather to strategy for action and not solely practices or group of tools.

To understand the core idea of modularity in the context of Plant engineering and construction it is necessary to broach the notion of Lean. Nowadays the concept of Lean has come broadly into the public awareness and the implementation of Lean manufacturing practices is on the way in a several companies and organizations. According to Modig and Åhlström [2012, 88], the reason to the public awareness of Lean, is the Womack and Jones (1996) book Lean thinking. Womack and Jones studied the philosophy and methods behind the success of the Japanese car manufacturer Toyota and came out with a book of “Lean thinking” that explains how companies should behave to be Lean. Cox (1997, 99) questioning Womack and Jones statements argues that there must be contingent circumstances which encouraged Toyota to do what it did. According to Modig and Åhlström (2012, 87) the attempts to define the notion of Lean are several and many of them are wrong and inconsistent with original definition. Ignorance and lack of understanding of circumstances and operations that make profitable value in business chain can lead to decisions where fads and inappropriate operational practices are implemented, states Cox (1997, 51). Therefore it is important to fully understand the value proposed to the customer and the meaning of new concepts before its implementation. It is important to interpret what new practices imply in these circumstances where your company operates, aligns Cox (1997, 51).

2.3 The definition of value and different types of demands

To understand Lean and the flow efficiency of the work process it is necessary to understand the notion of value and different types of demands state Modig and Åhlström (2012, 24). Only such works and efforts can be defined to bring core value that promotes the fulfillment of customer demands. Not just any demand, but the value that customers actually request. Such time which is spent on waiting for materials or construction equipment cannot be seen to bring value explain Modig and Åhlström (2012, 24). In the context of industrial plant construction It could be argued that the immediate customer demand is to get the construction phase of the plant completed and commissioned. Failure demand and secondary needs arise when product delivery times are long or customers are not served correctly at the first time. This causes situations where service organizations need to start such work processes which are not directly promoting the customer demanded value. Failure demand means situations where organizations are taking corrective measures and repairing. It can be assumed from the statements of Modig and Åhlström (2012, 59) that in the context of plant construction project, the sources of secondary needs and failure demand are such that it is mentioned by Pinnock et al (2012). These sources of secondary needs imply indirect works i.e. handling of materials, time on a site that is wasted due to interruptions in work. The sources of secondary needs cause increased health and safety risks, state Modig and Åhlström (2012, 59).

When the attempt to simply clarify the main aspects of lean thinking, Modig and Åhlström (2012) specify that there are two different types of efficiency which can be emphasized when seeking improvements of the production process performance. It can be assumed of the statements of Modig and Åhlström (2012) that these two different types of efficiencies have different value creation and maximization approach. Especially the object of value, that means who or what should be in main focus when creating of value. Furthermore, the statements of Modig and Åhlström (2012) shows that the two different types of efficiencies differ from each other in terms of who is the object of the produced value.

2.4 Defining of resource based efficiency

The improvements in the resource based efficiency can be seen to be the main reason to the current efficiency level that has been achieved during the last 200 years. The fundamental principle in industrial production has been the splitting services and activities to smaller entities. In the context of engineering, this means that we have nowadays different engineering disciplines i.e. Process engineering, Mechanical engineering and Electrical engineering and etc. As well, in the context of construction, we have skilled labor resources. This splitting drives the competencies to narrower sector that enables entrepreneurs and engineering disciplines to develop deeply their knowhow. From the resource efficiency point of view to reach lower unit prices and increased efficiency the employing of an expensive specialist resources should strive to utilize the resources as efficiently as possible. When the works are continuously similar, it is more likely to reach efficiency. Resources are on the main focus to reach a good efficiency level. The companies should maximize the use of those resources that are not solely human. It can be computers, machines and equipment that are used when serving the clients. It is typical that the value delivery time might be long for the customer. The throughput time for the value might be long especially in cases where the provided value consists of several phases. The lengths of waiting time are related to the number of interruptions between each phase. Especially in cases where the fulfillment of the total value delivery requires use of different sort of special resource, see figure 2 below. (Modig & Åhlström 2012, 9.)

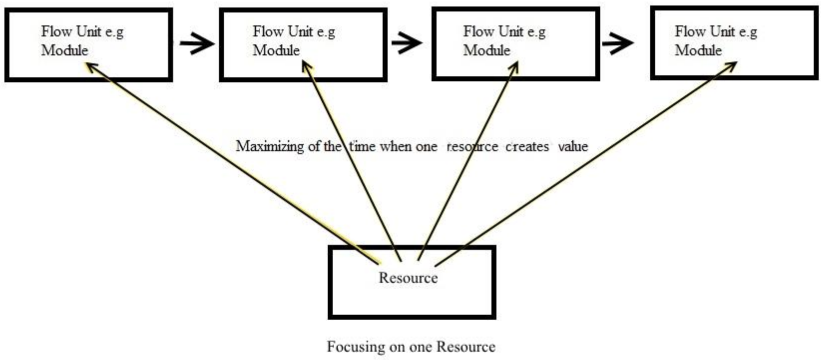

Figure 2. Resource based view of efficiency (Modig & Åhlström (2012, 21).

2.5 Defining of flow efficiency

Flow efficiency is defined to be a new type of way how to conduct the value delivery. Flow efficiency is focusing on decreasing of the total lead in value crating process. In other words the time that takes for the distinct units to pass through the value adding production line. Flow Efficiency turns the attention away from efficient use of resources and sets the provided customer value at the center of the operations. By maximizing the value adding time per flow unit, creates the total product delivery time shorter, see figure 3 below. In the industrial environment these flow units can be products that are processed with value adding actions. It can therefore be assumed that in the context of construction of industrial plant, the flow unit can be the whole plant or one plant module. The level of flow efficiency can be interpreted to be higher in cases of modular construction method in comparison to stick built construction method. The notion of flow efficiency is well known as well in the service sector. There the flow units are usually humans. The measured value adding time ends when the total value demand has been fulfilled. (Modig & Åhlström 2012, 13.)

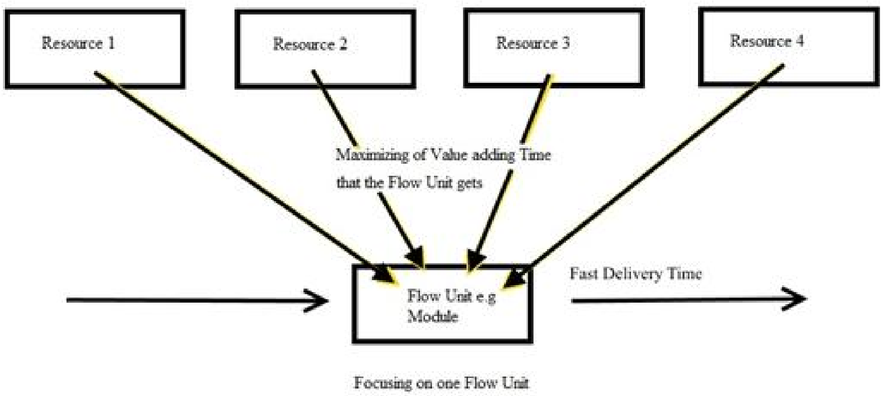

Figure 3. Flow efficiency (Modig & Åhlström 2012, 21).

2.6 What makes the process flow

To understand the system is important to know the laws that affect the process flow. The consequences of these three laws are the same regardless of the type of flow unit or the type of production line. These three laws help to understand why it is difficult to reach a good level of flow efficiency and a good level of resource efficiency at the same time. These three main laws are the following:

1) Little's Law (***L* x *W***)'L' denotes the number of flow units in queue to one production line . 'W' denotes the long-term average time of flow units spend in the production line. In other words that the number of unfinished flow units in queue and the time that flow units spend in the production, affect the total throughput time.

2) The Law of Bottlenecks indicates that every production line has at least one bottleneck that limits the speed of the process flow. The throughput time of the total project depends mostly on the time that takes to pass the bottleneck of the process.

3) The Law of variation says that every system is affected by changes. These changes might be related to resources that perform the task when adding value to the flow unit. This resource can be machines on production line that get bugs. The variation occurs also in cases when different motivated employees take over the conducting of the work. Due to employee change the new resource might need more time to perform the value adding service. The flow units might differ from each other and some of those might be more complicated. The legal conditions and country specific regulations can differ depending on circumstances. The lack of quality in production can affect the throughput time of the flow units. The arrival time of the flow units might vary at the beginning of production line. Such external factors that affect variations for system might occur due to the lack of quality of design. (Modig & Åhlström 2012, 31-40.)

According to Modig and Åhlström (2012, 45) in certain situations the level of these two efficiencies might take opposite directions. The level of the resource efficiency might increase if there is a big number of unfinished flow units because In other words a full workload for resources. To avoid queues and increase the flow efficiency it is essential to reduce the number of unfinished flow units. Shorter throughput times for units reduce the work load and inventory that temporary increase of resources. Standardizations and modularity can be seen to improve the flow efficiency in terms of decreased variety and unpredicted changes. The consequence of these laws makes that the attempts to increase the resource efficiency decreases the flow efficiency.

2.7 Efficiency paradox

Modig & Åhlström (2012, 47) criticize the resource efficiency thinking to causing a failure demands, secondary needs and such problems that do not exist in the flow efficient process. The level of 100% resource efficiency implies that all the resources are fully booked and employers are running with a full speed to keep the time schedule. According to Modig & (2012, 47) the most companies and organizations even today focus only on the resource based on efficiency and pay less attention to flow efficiency. Modig & Åhlström (2012, 48) points out three sources of inefficiency:

1. Long throughput times that cause numbers of secondary needs. In other words material handling and temporary

material inventory that leads to a long chain of work processes which is not the requested primary value

2. A big number of unfinished flow units and long queues at the beginning of production lines cause safety risks and variations. This causes failure demands and extra workload to project team. Big number of unfinished flow units' makes the holistic view of the project unclear and difficult to supervise. The delayed starts of work imply changes in the work process and daily routines.
3. Interruptions in work affect badly the work processes. In practice the works need to be started several times again before the completion. This causes also unnecessary needs to store and search of information. Interruptions in work can affect the chain of secondary needs and changes in resources which can lead to quality losses that imply extra workload to the whole organization.

2.8 How to behave to be Lean

Modig and Åhlström (2012, 88) state that there are different abstraction levels in terms of hierarchy levels where Lean actions can be utilized, see figure 4. Modig and Åhlström (2012, 88) state that the definition of Lean is quite generic on the highest abstraction level and becomes more precise when moving to the lower levels in terms of hierarchy. The highest abstraction level defines the value that aligns that customer preferences should in most cases come first.

The second abstraction level consists of two principles that are "Just-in time", the creation of the flow in production line and elimination of waste. The second principle is “Jidoka” that can be interpreted to mean the awareness and the holistic view of project situation. The good holistic view can be achieved through appropriate knowledge management methods and effective information sharing. The meaning of Jidoka is to make things visible. The barriers of efficient work flow should be easily discovered and eliminated. The four principles of Jidoka are the following:

1. Detect the abnormality.
2. Stop.
3. Fix or correct the immediate condition.
4. Investigate the root cause and install a countermeasure

The third abstraction level defines the detailed methods of how to implement “Just-in-time and “Jidoka” (Modig & Åhlström, 2012, p. 139). In the context of construction of industrial plant “Just-in-time” could be implemented by using modular construction methods and “Jidoka” could be implemented by knowledge management methods e.g. new model of lessons learned and live capturing of knowledge. (Modig & Åhlström, 2012, p. 139.)

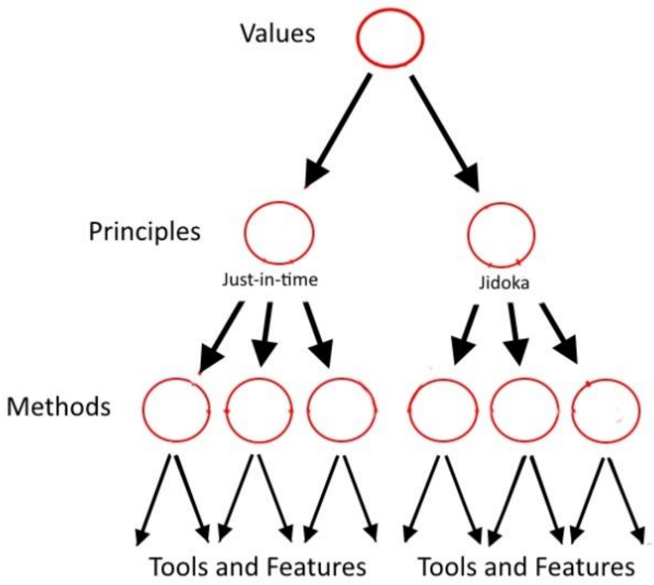

Figure 4. Strategic actions of Lean (Modig and Åhlström, 2012, 139).

According to Modig and Åhlström (2012, p. 88-95) the three common problems in defining lean are : 1), the lack of understanding how lean should be defined in the different abstraction levels; 2) Ignorance and the lack of understanding related to the methods and targets of lean. This can be interpreted to mean understanding conditions where the methods of lean can be utilized. 3) Unclear definitions of lean thinking and insufficient understanding in strategic action that strives to deliberate change in efficiency matrix in figure 5.

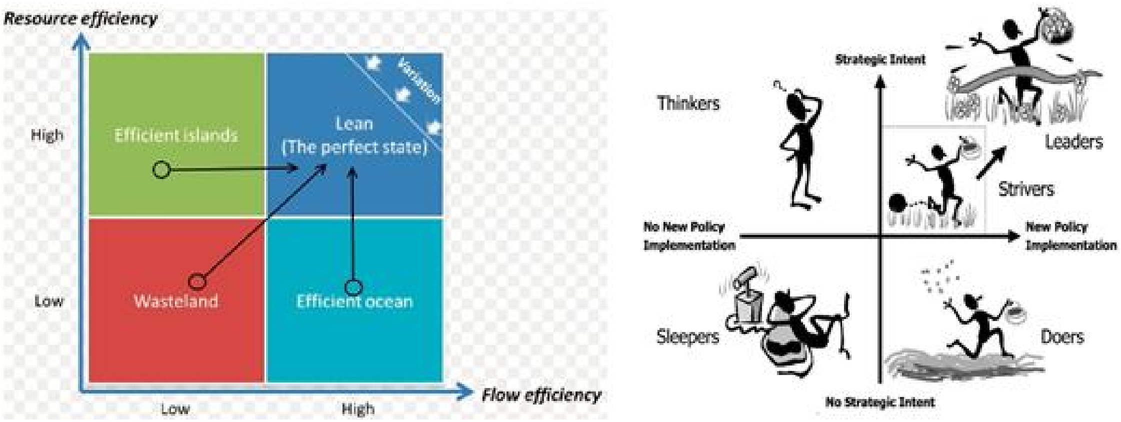

Figure 5. The efficiency matrix (Modig & Åhlström, 2012, 98; Taylor, 2002).

The efficiency matrix above is positioning the company depending on the balance between resource efficiency and flow efficiency. The left corner down of the efficiency matrix in figure 5 describes organizations that have failed to achieve resource efficiency and at the same time have slow work processes. This is not a desired position for the organization because the resources are wasted and the value created to customers is low. The left corner up in figure 5 describes organizations that have achieved resource efficiency but are struggling with flow efficiency. This is not a desired position for the organization because the organization consists of independent parts that might be resource efficient but are lacking for a holistic view that would promote the flow efficiency. The right corner down in figure 5 describes organizations that have achieved flow efficiency but are struggling with resource efficiency. The main focus in the right corner down is on clients but works are not synchronized and optimized on the view of available resources in organization. The desired position for organizations is in the right corner up in figure 5. To be at the same time resource efficient and flow efficient describes the strategic meaning of Lean thinking. Lean can be defined to be strategic action that seeks appropriate balance between resource efficiency and flow efficiency. Variation implies restrictions caused by unpredicted changes that make it almost impossible to achieve the maximum level of resource efficiency and flow efficiency. Variation can be bigger depending on the type of organization and the field of business. (Modig & Åhlström, 2012, p. 98-113.)

2.9 Values and principles of Lean in plant engineering

The starting point in this research defines the strategic actions of Lean the two highest abstraction levels of Lean on the context of the plant engineering project. Modig & Åhlström (2012) state, that only such works and efforts can be defined to bring a core value which promotes the fulfillment of customer demands. The approach of “flow efficiency” puts the value on the center of the operations which are delivered to the customer. Based on the statements of Modig & Åhlström (2012) the strategic actions in the field of the Plant engineering can be defined to be a Lean that seeks the appropriate balance between the resource efficiency and the flow efficiency. It can be interpreted from the nature of Pöyry as a company that such values that promote the customer’s satisfaction and shareholders’ satisfaction are desired. The principles “Just-In-Time” of “Jidoka” in the context of the plant engineering projects could be interpreted to be related to the modularity and knowledge management. The modularity in design and construction promotes the targets of Just-In-Time. In order to mean that the modularity in design and construction reduces the throughput time of the product i.e. the plant project in the context of Pöyry. This eliminates the waste. The modularity in design contributes to a higher level of the flow efficiency and at same time, a higher level of the resource efficiency. It can be further interpreted that the appropriate Knowledge Management practices in the plant projects contribute to a better holistic view and increase the ability to react quickly, which are the main targets of “Jidoka”. Defining of the functional requirements of modularity and the content of the two lowest abstraction levels of Lean in the context of Pöyry are framing the later content of this paper, see figure 6. The defined methods of modularity and knowledge managements will be presented in the result of this paper.

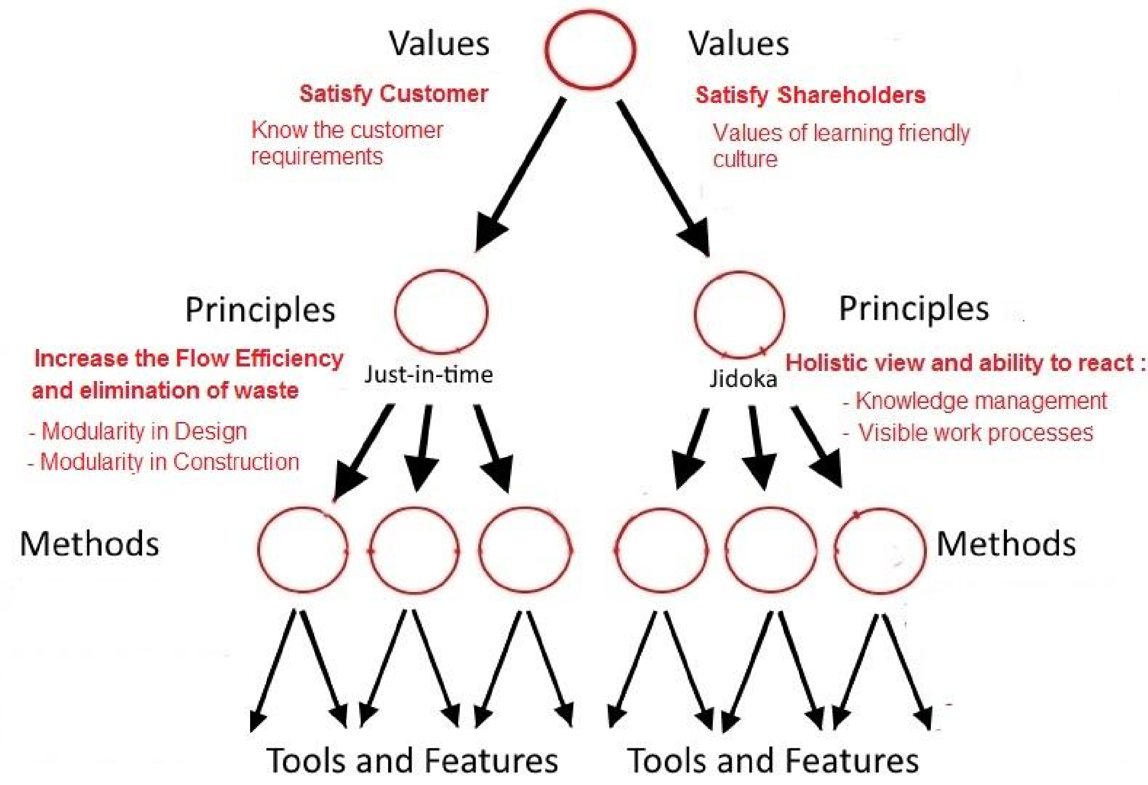

Figure 6. Lean in the context of plant engineering project.

3 DIMENSIONS OF MODULARITY

The dimensions of modularity are defined in this chapter. At first, the general definition of modularity is discussed. Finally the three driver of modularity are presented.

3.1 The definition of modularity

The common understanding of the definition of product modularity according to Jacobs et al (2007) is that the product modularity implies building of block that can be combined in several ways to provide a comparatively large number of product configurations (Blackwin and Clark, 1997; Garud and Kumaraswamy, 1995; Sanchez, 1995; Schilling, 2000). Lomholt Bruun and Mortensen (2012), further specified that a modular structure consists of self-containing and functional units, i.e. modules, with standardised interfaces stably related to the system definition. Figure 7 below shows the simplified idea of modularity.

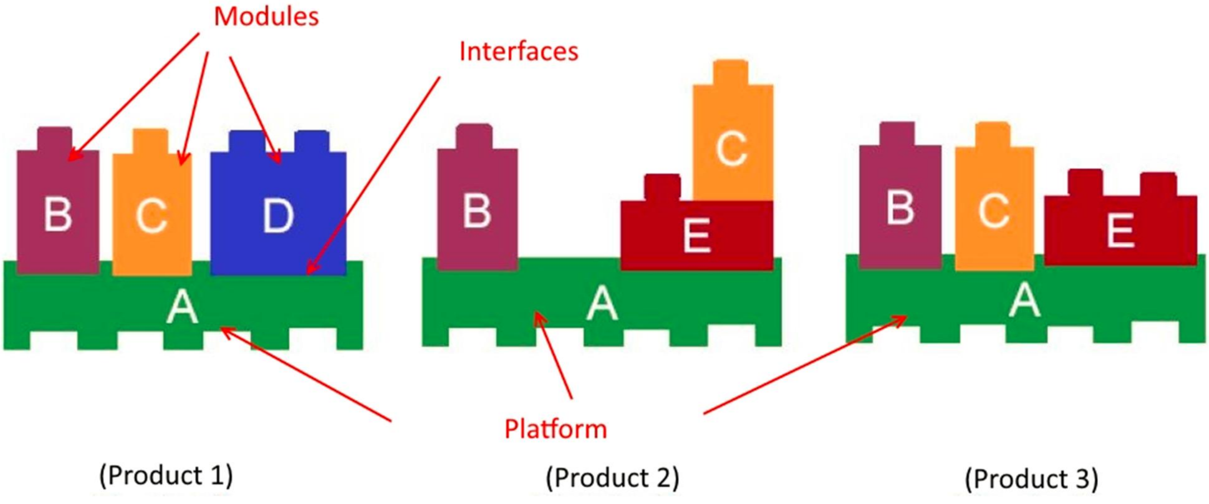

Figure 7. The principle of modularity

Pine et al. (1993) writes that one good reason to utilize modularity is the standardization of both production and products to benefit the economies of scale. Papinniemi et al (2013) statements related to economy of scale are in line with Pine et al (1993) and they point out that the modularity brings benefits in the whole product or project lifecycle that implies production-, implementation-, maintenance phases. Papinniemi et al (2013) are focusing on project requirement information and they suggest that modular business concepts are partly based on utilization similarities between different projects where the same requirement information can be used in several projects even the manufactured machines are unique in other ways.

Papinniemi et al [2013] refer to Briére-Côté et al. (2010) when defining of the life cycle aspect of modules. It may be the case therefore that this aspect indicates how well the module behaves throughout the delivery chain and how it benefits the production or assembly, installation and construction. Papinniemi et al. [2013] pay attention to the modularity of requirement information what implies the connectivity requirements of technologies and the requirement shareability in products and projects. The question related to the degree of the modularity of the requirement information in Pöyry is interesting and it could be discussed during the Master’s thesis work by interviewing of material specialists.

3.2 The three drivers of modularity

According to Hellström (2005) the business concept based on the modularity on a general level seeks answers to what makes sense to be modularized and what is better to keep outside the modules. Hellström (2005) aligns that there are three core aspects that have significant impacts in decisions which need to be taken in account when starting the evaluation of what could be modularized. These three aspects are the following:

1) Manufacturability
2) Serviceability and
3) Recyclability

3.2.1 Manufacturability as a driver

According to Hellström (2005) the manufacturability as a driver of modularity aims to reduce the complexity of the manufacturing process when designing modules. The components should be standardized and classified according to the manufacturing complexity, states Hellström (2005). Thus the procurement of auxiliary equipment should be optimized. Manufacturability can be interpreted to mean the constructability in the context of the Pöyry. Thus, if the driver of modularity is constructability, the design should enhance the possibilities to classify construction works in order to contribute to cost efficiency, fast delivery and easily mounting to its place on building site.

3.2.2 Serviceability as a driver

According to Hellström (2005) when evaluating the serviceability the components or parts of one product need to be divided according to the frequency of service or maintenance needs and the service operation complexity. It could be argued of the statements of Hellström (2005), that in case of a part of products of a high service and maintenance frequency, the design should support the easy replacement of those parts and it could be separated from different modules and the parts of products with a low service frequency. Again reflecting the article of the topic of Master’s thesis can be interpreted that Hellström’s (2005) statements of serviceability could mean the maintenance of an industrial plant in Pöyry’s context. When designing the modules it is important to have an eye on the functionality of the maintenance of the whole plant. The functionality could mean placing overhead cranes and modules so that the product with a high service and maintenance frequency could be easily served.

3.2.3 Recyclability and reusability as a driver

According to Hellström (2005) when evaluating the recyclability the core aspects with impacts on module boundaries are, if the physical part of product can be used again somewhere or how it is scrapped in the end of component life cycle. In other words we are talking about the component life cycle. If the current sub-process have a longer life cycle than the whole plant or for instance mineral deposit, it should be designed as a module with the removable function. The recyclability can be seen to benefit more the process owner than the industrial plant designing company. The figure 8 shows an example of impacts of the recyclability and reusability. In practice the longer lifecycle of modules in terms of reuse those in other industrial plants could have an impact on an investment decisions and bring opportunities to FEL1. Practically this means that the modules would be designed with an eye on transportability and so that the modules would be removable and truckable. In the context of plant engineering, the statements Hellström (2005) related recyclability could be interpreted to mean the reusability of existing design. The reusability and standardized modules in the design phase can be seen favoring a company as Pöyry. The reusability means less tailored design and more effective utilizing of the work which has been done in previous projects.

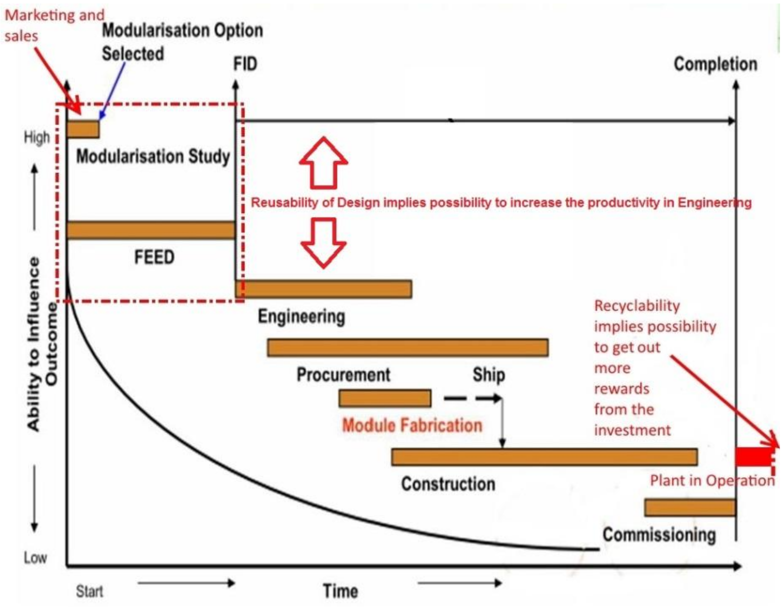

Figure 8. Reusability and recyclability as a drivers

4 PROJECT BUSINESS CONCEPTS BASED ON MODULARITY

The project concepts based on modularity are defined in this chapter. First, the general definition of a project is discussed and the definition of modular project is presented. Then the difference of mass customization of products and the modularity of projects are discussed. Secondly, the continuation of the Lean philosophy, project maturity concept and the functional requirements of modularity are discussed. Finally the most relevant, issue related implementation of modularity in design is presented in this chapter by using product structuring methods that lays ground to product configuration system development.

4.1 The Definition of Project

Industrial projects and multi-project programs are the vehicles for achieving the strategic goals of every complex organization states Tonchia (2008, 1). Tonchia (2008, 1) points out that there are two perspectives of project management which are the strategic perspective and the operational perspective. Strategic management perspective deals with prioritization, selection and allocation of people, money and other scarce resources to the organization's projects at the project portfolio level. This it is usually performed through the strategic management processes in place inside the organization aligns Tonchia (2008, 1).The operational perspective of project with respect to their lifecycles, Turner and Cochrane (1993) stated that a project can be regarded as successful only if it is capable to produce a product that is worthwhile and can beneficially function after the project expiration to return its investment. Plant design project consist about several functions (i.e. time scheduling, engineering, procurement and etc.) and specialist teams that aims to fulfill the targets of a project during a determined period of time (Pöyry Plc, 2016a). According to Humphreys et al (1998) procurement function usually consist about purchasing specialists who have the ability to evaluate the best suppliers in the internal or global market to ensure or achieve quality and cost balance. It can be assumed from Humphreys et al (1998) statements, that purchasing and procurement means the same but purchasing is more specified and means buying.

4.2 Project implementation methods

The project implementation policy or method is a model which describes how a single project will be implemented. Money is the main driver in selection of the implementation method. In the context of Pöyry, the most used implementation method in their client’s large projects is EPCM (i.e. Engineering, Procurement, Construction, Management). In addition to the main project implementing methods (i.e. EPCM, EPC, EPS, OB, ESS, BOO) there are mixtures of all these and also different names given to these mixtures or even to same methods. (Pöyry Plc, 2016a.)

In the view at modularity it is interesting to explore the EPCM and EPC-Implementation methods of a Project.

EPCM-implementation method

Briefly explained, the main characteristic of EPCM-implementation method is that the owner (i.e. client) remains fully responsible for the project. Thus it mean that if Pöyry is the EPCM-contractor, project will be executed on behalf of the owner. EPCM-contractor provides services which support owner in project management and in controlling, supervision of the sub-contractors. Owner has the right and obligation to take final decisions. All contracts (i.e. supplier/vendor/sub-contractor) in the project are signed by the owner. The owner bears all risk regarding schedule and cost, but benefits also from gains. (Pöyry Plc, 2016a.)

EPC-implementation method

The main characteristics of EPC-implementation method is that the EPC-contractor (i.e. Pöyry) carries all the risks and will be full responsible for the project execution through a fixed price contract (Lump sum turn-key contract). EPC-Contractor will include a risk that are related to schedule, budget, performance, operational guarantees and warranty in return provision in his fixed price. All sub-contracts in the project are made directly whit the EPC contractor. Project owner has limited rights to take decisions after signature of the EPC-contract. Engineering, Procurement and Construction (EPC) contracts include the design, procurement of equipment, materials, services, construction and installation, erection and commissioning, testing and hand-over. It can be summarized that the EPC-contract covers risks, but also possible gains are transferred to the EPC-contractor. (Pöyry Plc, 2016a.)

4.3 The Definition of modular project

Papinniemi et al (2013) align that when company operates with Turn-key sales- and delivery projects, the whole project can be seen as “extended product” which could have several repeatable options and features. Each project has its Works Breakdown Structures (WBS) regardless if it modular or not. The budgeting of the total project estimate the material, equipment, labor, engineering tool license costs and engineering hours that are needed to complete the project. Project breakdown structures allow cost monitoring of distinct projects. Marketing and sales have an important role in agreements of engineering scope. Defining the technical realization and finally signing of the contacts has a significant impact on project costs. Projects are able to cut cost and increase productivity due to the repeatability and by using existing design, see table 1. The expertise and concepts which has been intended and designed in earlier projects can be seen to referring to modularity. (Artto et al. 2006, 54-56.)

Economies of scale

When reflecting the statements above to Turner and Cochrane (1993) and Pine et al. (1993) it can be stated that modularity is a standardization of both production and products to benefit from economies of scale. It can interpreted from statements mentioned earlier that the engineering works which has been conducted in one project benefits later projects if it have generic modular features, see Figure 9 below. Grieves (2006, 10) states that the estimated waste for engineering and design functions in normal projects are often cited at 60 percent to

80 percent of total design and engineering costs. Grieves (2006, 10) sees that the time that are wasted in engineering and design functions are usually related to overproduction that means designing of things which are already designed once or several times before. According to Grieves (2006, 10) every repeated work process implies 20 % time savings if appropriate practices to capture and share project knowledge are implemented. Grieves (2006, 10) points out that same kind of cost trend can be achieved in construction if the production and manufacturing processes are repeatable. Hellström and Wikström (2005) state that due to outsourcing and suppliers network the customers are losing the sight of the delivered items. In stick built construction method it is very difficult and time consuming for customers to keep a track on what is delivered and more importantly hat is not delivered. According to Hellström and Wikström (2005) the modular project can better manage this complexity. It can further be interpreted from statements of Tan e al. (2010) that the modular project business concept are related to knowledge management because Modular project business are based on capturing and reuse of earlier project knowledge. It is also notable that Grieves (2006, 12) states that the drivers for this cost reduction shown in Table 1 is not simply the doubling of production but rather the feedback loop when workers and managers perform their work tasks. It can therefore be assumed that knowledge management in form of appropriate lessons learned practices has a big role that lead some organizations and companies to success

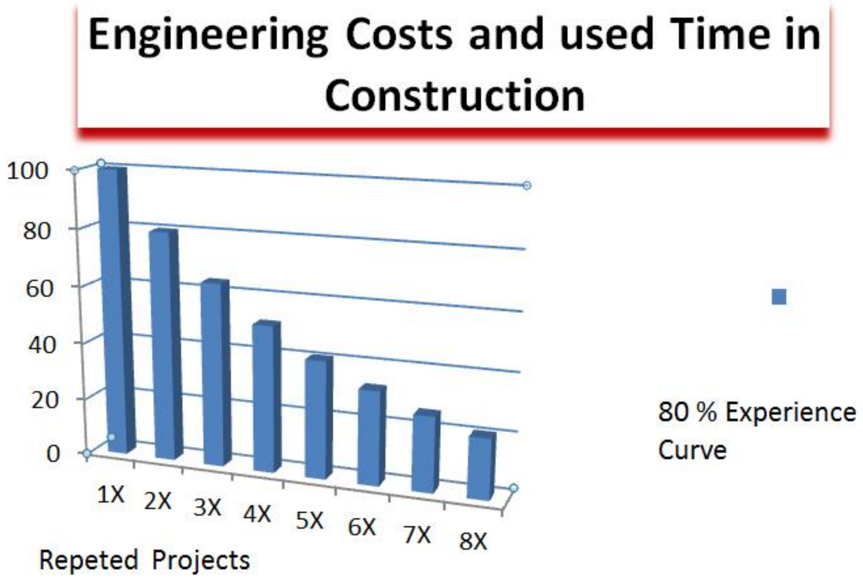

Figure 9. Experience curve of every repeated work process (Grieves et al., 2006, 11).

4.4 Definition of mass customization

To understand modularity it is important to understand also the notion mass customization that can be seen to have the same characters as modularity but the notion is used mostly when mass producing companies strives to move from standardized product toward higher level of customization. Davis (1987) defines mass customization as follows: ‘the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously they can be treated individually as in the customized markets of preindustrial economies’. One popular definition introduced by Tseng and Jiao (2001) is that mass customization implies “to deliver goods and services which meet individual customers’ needs with near mass production efficiency”.

4.5 Engineering-to-Order and mass production companies

Enineering companies can be defined as mass production companies or engineering-to-order (ETO) companies. From statements of Haug et al. (2009) It could be said that Pöyry can be described as ETO-company who delivers products which are engineered according to specific customer requirements. To reach efficiency, the ETO companies strive to transform from producing tailor made products to mass customized products. For the ETO companies the transformation from tailor made products towards mass customized products implies standardization of engineering works and the internal processes need to be more automated. It is obvious that mass customization and standardization implies less flexibility for the ETO companies. When moving towards modularization it is important to find right balance between flexibility and standardization. On general level only a small part of the product portfolio could be mass customized, in the context of ETO companies. By dividing the product to small sub products and work packages it might be possible to completely automate some of them. (Haug et al., 2009.)

Project service companies are facing the challenge how to offer both tailor-made and flexible services. Companies should fit customer’s specific requirements and at the same time they should try to achieve efficiency through standardized processes, explains Rahikka et al.(2011). The figure 10 below expresses the variations between customization, modularization and standardized products.

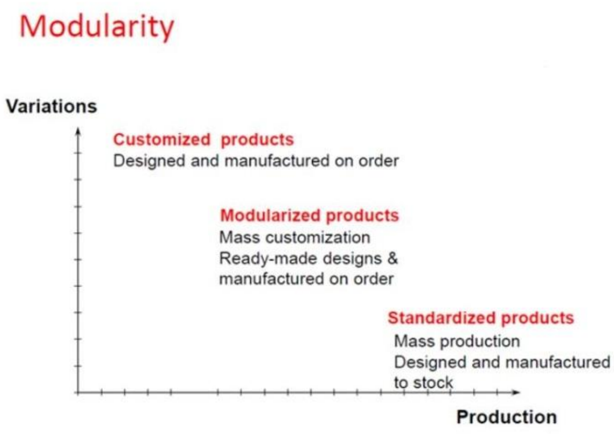

Figure 10. Customized, modularized and standardized products (Haug et al., 2009).

According to Haug et al (2009), the steps and methods differ depending on the type of company when moving towards modularity. Table 1 below; explain the tasks which come in question when a mass production type of company moves towards mass customization. Whereas the table 1 on left, expresses the situation when ETO companies move from tailored products towards modularized products. In comparison to ETO companies, the customer order de-coupling point can be seen to differ in mass production environment, state Haug et al (2009). To clarify, it mean where in the product lifecycle the customer order is linked to the product (i.e. are the products already designed or manufactured when customer orders are taken in). The customization level of a product is scalable depending on the placement of customer order de-coupling point in the product life cycle. It can be stated based on findings of Haug et al (2009) that the customer order de-coupling point is linked to the product already in its engineering phase in the context of ETO.

	Mass production to mass customization	Engineering to order to mass customization
Product variety	Increase variety	Limit variety
Customer view	Create valuable variety	Create adequate variety
Manufacturing costs	Slight increase	Decrease
Business purpose	Increase sales	Optimize processes
Configurator challenge	User interfaces	Knowledge base

Table 1. Transition towards mass customization (Haug et al.,2009).

4.6 Product Lifecycle Management

According to Grieves (2006, 1) PLM is an “outcome of Lean thinking and a continuation of the philosophy that created Lean thinking”. Papinniemi et al. (2013) defines Product Lifecycle Management (PLM) mean an integrative information approach that includes processes, practices and technology from manufacture, deployment, maintenance disassembly and component recyclability. Grieves (2006, 1) summarizes that PLM eliminates the waste and inefficiency in all phases of the project lifecycle and not solely in its construction and manufacturing phase. Grieves (2006, 2) states that PLM strives to find an ability that allows a company to develop and build useful and more creative solutions and products with the same amount of efforts. Grieves (2006, 2) points out that the improvements which are gained through PLM methods are more sustainable for the business in comparison to the traditional way for cost cutting. Grieves (2006, 10) states that every life cycle phase in a project might include certain amount of waste that could be eliminated by implementing the strategic actions of Lean. Grieves (2006, 10) mentions also other sources of waste which are relevant even today such as the waste of that comes due to rework. In practice this means redesigning of parts which cannot be easily manufactured or such types of waste that occurs when sitting in an inefficient meetings and using a lot of time for searching for drawings and documents.

This possibly illustrates that PLM means strategic actions of Lean utilized in the whole project lifecycle. Therefore PLM can be seen to be an appropriate approach for Pöyry in the view at the global competition and increasing demands of clients. The suggestions of improvements mentioned in the study of Pinnock et al. (2012) can be seen to be achieved with help of an appropriate PLM strategy.

4.7 Project maturity

In the project context, the concept of the maturity model assess the capability and capacity of organizations to manage their products of a type of service i.e. projects (e.g., Pasian, 2014). In their study of the projects setting a goal and the definition of methods used to achieve the goal Turner and Cochrane (1993) proposed that these two parameters can be used to obtain the matrix of a 2 x 2 goals-and-methods. Based on the 2 x 2 matrix they further divided the projects into four types of a distinctive category which are the following:

- Type 1 projects: the goals and methods of achieving the project are well defined;
- Type 2 projects: the goals are well defined but the methods are not;

- Type 3 projects: the goals are not well defined but the methods are,
- Type 4 projects: neither the goals nor the methods are well defined.

According to Turner and Cochrane (1993), the industries which have the ability to manage projects successfully fit into the category of “Type-1” with their projects either well-defined or not left to a chance by the goals set for and the methods applied in them (see also Pasian, 2014). From the perspective of organizations the central objective to develop the project processes by minimizing their variation is leading to a greater efficiency and productivity. It is also beneficial for current and potential clients to collaborate with the organizations whose reliability bases on the successful development and management of repeatable processes. Therefore, the repeatability, which is associated with the concept of modularity, is seen to be a measure of maturity in the process (Pasian, 2014). The reliable repeatability of processes is obvious in the case of Type-1 projects, whereas in Type-2 projects where goals are highly defined but methods undefined the repeatable processes are illogical and likely less expected in terms of capability of management. It was also stated by Pasian (2014) that the organizations of the Type-1 projects reliably managed are holding the maturity partly assessed based on their repeatable processes. Moreover, improving the organizational capability of managing is needed to conduct the project will by Pasian (2014) as a result of the increasing maturity yielding to their continuous improvement, the feature which is characteristic to the manufacturing sector and the total quality of management (see Dean & Bowen, 1994; Powell, 1995; Pasian, 2014).

It can therefore be assumed that the project maturity in the context of Pöyry means, how well they know the process and technology and what are the number of similar reference projects that have been conducted.

4.8 The three functional requirement

In the context of mass customization and engineering environment, Blecker and Abdelkafi (2006) presents an effective variety management tactic. Even if this variety of management tactic, specified by Blecker and Abdelkafi (2006) is taken from a mass of customization environments, it might be useful for the context of the plant design. Especially the functional requirements for the modularity can be interpreted to be the same in the mass of customization and approach of the modular project. Blecker and Abdelkafi [2006] are referring to Suh’s (2005) definition of complexity as a measure of uncertainty in achieving the specified requirements for function (FRs). Blecker and Abdelkafi (2006) states that there are three functional requirements 1) FR1 = satisfy customer 2) FR2 = produce economically 3) FR3 = deliver fast, see the figure 11 below.

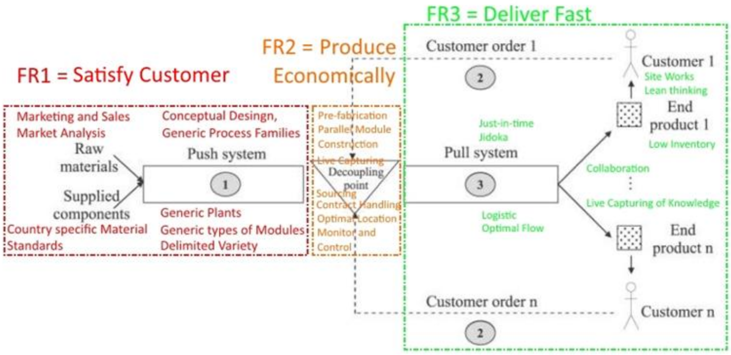

Figure 11. Modular Production System

4.8.1 Satisfy customer

According to Blecker and Abdelkafi (2006) the success of a mass of strategy of customization and modularization starts by understanding the preferences of customers. This implies that the marketing managers should determine the range of attributes and functionalities to offer the market the fulfilment of the need of customers, state Blecker and Abdelkafi (2006). This functional requirement, FR1 = satisfy a customer, can be interpreted to commerce in the Marketing and Sales phase in so called conceptual design and in a pre-designed phase in the context of engineering-to-order projects, see the figure 9 above. Furthermore Blecker and Abdelkafi (2006) argue that the development, research and design should ensure that the requirements of customers are converted into a concrete variety of products.

4.8.2 Produce economically

The FR2 (produce economically) in the figure 11 could be interpreted to mean reusing the existing design in the context of the modular design. To clarify it is avoiding such technical solutions which lead to tailored engineering and extra costs for design. This possibly explains to ensure the achievement of the FR2 in the design phase the appropriate tools for the product structuring management are needed. The product structuring should need to be implemented to facilitate making a decision when evaluating the possibilities of the modularity.

When reflecting the statements of Blecker and Abdelkafi (2006) in the context of the Pöyry, one can notice that RR2 refers to the modular engineering, construction and to the parallel module prefabrication. The appropriate placement of the customer de-coupling point (i.e. when the customer order is linked to the project lifecycle) expressed in figure 9, will be discussed later in this thesis work. Blecker and Abdelkafi (2006) write that the purchasing, engineering and construction managers have to collaborate to get a holistic view project. This implies that the managers need to have the ability of making optimal make-or buy decisions.

4.8.3 Deliver fast

The third functional requirement, specified by Blecker and Abdelkafi (2006) can be interpreted to yield both on the modular construction and the modular engineering. Hvam (2006) explains that there is usually an increasing pressure in the field of plant engineering to deliver the information as fast as possible and to make quick binding quotations. When considering the content of FR3 (deliver fast) in the context of the plant design is obvious that the configuration systems of the product can be used to facilitate a more efficient engineering and sales process, see Hvam (2006). Product configuration systems are defined later in the chapter 4.9.3 of this thesis work.

The third functional requirement is important in the construction phase of the plant project. This phase of project harnesses the Lean philosophy that consists of the principles of Just-in-time and “Jidoka”. In the context of the construction project the principle of “Just-in-time” aims to eliminate the waste and should contribute to a low inventory. These principles can be seen to advocate the target of FR3. The creation of the optimal process flow of modules to the site allows achieving a quick delivery. Blecker and Abdelkafi (2006) argue that in construction phase FR3 requires a close collaboration with the managers of procurement through an appropriate scheduling. It is obvious that if the parallel prefabrication and the module construction are closer to the project site shorter delivery times can be achieved.

As a conclusion, the modularization implies a connected system and any change in one FR that somehow affects the fulfillment of other FRs, states Blecker and Abdelkafi (2006). The decision of the place functional requirements in the figure 9 has been taken in regard to the comments of Blecker and Abdelkafi (2006). Modular plant design implies reusing the documentation and pre-engineered design. Blecker and Abdelkafi (2006) explain that the modular project approach need value adding actions before the customer order arrives. Those actions aim to build such a product in advance that matches the requirements of a customer. In practice it means existing generic lists of materials, standards, equipment, 3D-models, modules that should be available before the order of a customer. If the customer de-coupling point moves upstream in the value chain, the level of customization increases. (Blecker & Abdelkafi, 2006.)

4.9 Product structuring methods

The methods for product family development and product structuring are defined in this chapter. First, the logical sequence for a complexity-based variety management is presented. Then the Product structure management and design reuse mechanism are discussed. It is notable that the definitions of the product family development and Logical sequence for the implementation of the complexity-based variety management are based on the context of mass producing and customizing of products. Finally, at the end of the chapter, the implementations of the product structuring tactics in the context of industrial engineering are presented.

4.9.1 Logical sequence

Blecker and Abdelkafi (2006) attempts to facilitate the identification of the strategies that are adequate and appropriate to tackle the problems and challenges which are caused by complexity. It can be assumed that Blecker and Abdelkafi (2006) declares the complexity of a product to be a barrier of the mass customization. Therefore the product complexity can be seen to be a barrier of modularity even in the context of Plant design projects. Blecker and Abdelkafi (2006), states that the implementation of the variety management and effective strategies at the product and process levels enables the management of complexity and makes the system more decoupled and modular. The Figure 12 below explores the logical sequence for the implementation of the complexity-based variety management where the component families are the starting point.

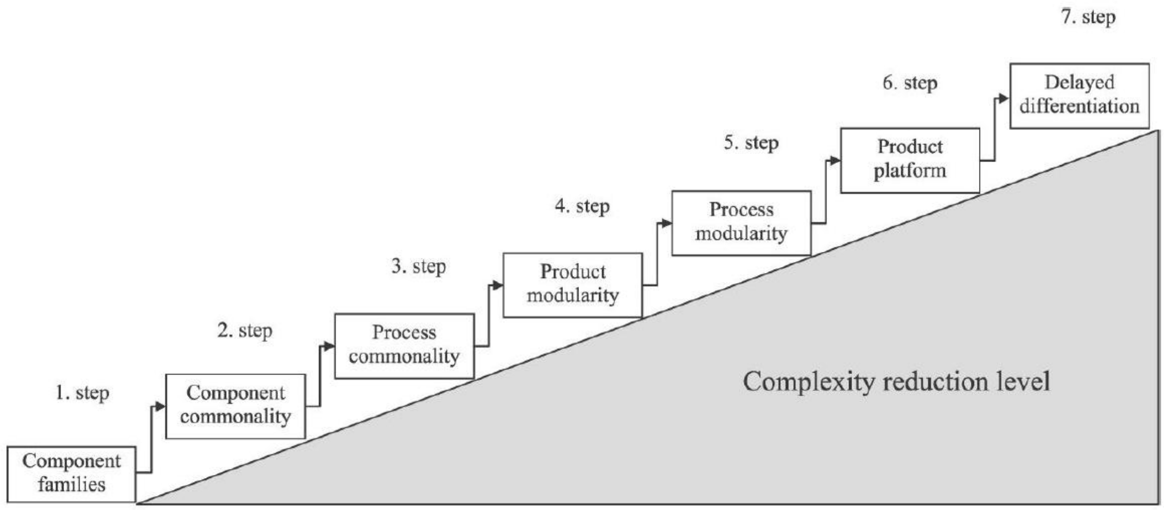

Figure 12. The logical sequence. (Blecker & Abdelkafi, 2006).

The definition of the Component families and Component Commonality in the context of engineering-to-order and plant design could be interpreted to mean standards and specifications. The component commonality strives to use a few components in as many products as possible so long as it is economical by grouping the existing components into the clusters. In practice, the component commonality can interpreted to mean a systematic reuse of material specifications from earlier projects. The notion of component families is also used in connection with the cellular manufacturing. Cellular manufacturing is related to Just-in-time and it aims to increase the similarity of produced products to reduce the waste in production. (Blecker & Abdelkafi, 2006.)

The definition of product modularity in the context of plant design could be interpreted to mean pumps, tanks and vessels. According to Blecker and Abdelkafi (2006) the product modularity is a property of independent and identical products. In context of plant design, the product modularity could be reached in practice by systematical reuse of existing 3D-models of pump, tank and other generic elements from earlier projects.

In the context plant design the definition of platforms could be interpreted to mean such layouts and steel structures which are carrying the modules of an industrial plant. The product platforms can be described as a basic common module that can have several variants. The platforms are cost-intensive and these are developed to work as a basic component for a long period of time. (Blecker & Abdelkafi, 2006.)

The definition of the process commonality in the context of engineering-to-order and plant design could be interpreted to refer to the constructability and work processes in the manufacturing process. According to Blecker and Abdelkafi (2006) the level of process commonality indicates how well the products can be manufactured assembled by a certain number of work processes.

The definition of process modularity in the context of the plant design could be interpreted to means sub-processes that can be manufactured, assembled and tested within processes to decrease the construction and commissioning work throughput times. Baldwin and Clark (2000) refer to process modularity when shaping smaller subsystems of a complex process system. These subsystems can be designed independently but they function together as a whole system.

The definition of the delayed differentiation in the context of engineering-to-order projects could be interpreted to mean smaller one-of-kind modules which need to be tailored and customized to meet specific customer needs. (Blecker and Abdelkafi, 2006.)

4.9.2 Product structuring and design reuse mechanism

The structure management of the product has been widely discussed among researchers and many types of methods have been developed. One common method is defined by Gunnar Erixon (1998). The MFD- tool (Modular Function Deployment) provides the main steps for modular product development project. According to Erixon (1998) the MFD-method and procedure consists of the following steps:

1. Clarify the Customer Requirements
2. Select the Technical Solutions
3. Generate the Concepts
4. Evaluate the Concepts

When defining the model that reduces customer driven design costs and throughput times in ETO based business, Briére-Côté et al. (2010) presents a categorization system that is also interesting on the view of the case Pöyry. This categorization can be seen to be more simplified than the logical sequence in figure 10, defined by Blecker and Abdelkafi (2006). This categorization is threshold and consists of 1) Common features and base product, 2) Parameterized features and reused variants and 3) Special features and new components.

Common features and base product

The Common features and base product group consist of components which shape the product family’s recurring features, which are shared by all projects. In the context of plant engineering these product variants here can be interpreted to mean different types of industrial plants and the base product could be for instance the steel profiles of pipe racks, electrical rooms or other things as generic documents, typical drawings that remain the same in all the projects. The base products could have limitations in terms of weights and material standards. Thus the planning and design of the base product should aim to integration. To repeat, the common features should be implemented in every project with a limited number of base component variants. (Briére-Côté et al., 2010.)

Parameterized features and reused variants

The definition of category group 2) (parameterized features and reused variants) need contextual thinking. The context of industrial plant, it can be interpreted from statements of Briére-Côté et al. (2010), that these modules which have parameterized features, could concern components such as tanks, vessels or sub-processes. The components in group 2 should share the common features but differ from others for instance in terms of size, material and capacity.

Special features and new components

The group 3) consists of individual components which have special features or which are totally new components. Briére-Côté et al. (2010) explains that it is expected that some customer requirements cannot be translated as parameterized features during the sale phase of a product configuration process. These special features are deliberately unique due to a customer’s specific needs and preferences. These new components must therefore be in most cases designed in a project as a part of the sales-delivery process. These modules are called for one-of-kind modules and these are tailored to fulfill the special requirements, explains Briére-Côté et al. (2010). The group category 3 can therefore be assumed to mean the step 7 (delayed differentiation) in the logical sequence for the complexity-based variety management, defined by Blecker and Abdelkafi (2006) in figure 12.

4.9.3 Product structuring tactics

It has been widely agreed among researchers that modularization, product platforms, product families and product configurations are efficient product structuring methods in mass customization context state Lehtonen et al. (2016). In the view at the Pöyry, it is notable that the logical sequence presented by Blecker and Abdelkafi (2006) and the structuring method presented by Briére-Côté et al. (2010) is that those are proposals for mass production environment. The mass customization of mass produced products differs from industrial plant engineering environment, explains Lehtonen and Juuti (2016). Most cases of mass customization focus on products with a rather limited complexity in comparison to cases of engineering of industrial plant, States Hvam (2006). Lehtonen et al. (2016) present a new method that describes how the structuring and rationalization of existing products should be carried out in industrial plant engineering. Lehtonen et al. (2016) presents a design method known as the Brownfield Process. According to Lehtonen et al. (2016) the notion of brownfield implies a reusing of available assets. In the context of plant design the notion of brownfield means re-build project cases which are new parts of an existing industrial environment. This method developed by Lehtonen etal. (2016) is focusing on companies that operate in project based business and produce products in small series or the size of series can be just one. Lehtonen et al. (2016) suggest that the partitioning logic is in key position move towards modularity in the project based business. The partitioning logic implies a description that specifies why a certain design is or should be partitioned on a specific way. To clarify it means a set of modules, architecture, interfaces, and configuration knowledge. For instance, the set modules should have the information whether those can be used in several projects or in just one. The interfaces should have the information of the connecting standards. The modular architecture should have the information of a limited set of layout that can be reached due to use of module configurations and generic elements. The product structuring of modular product family goes out by "identification of the building blocks which can be standard, configurable, partly-configurable or one of a kind", see the figure 13 illustrated by Juuti (2008) below. These generic elements and modules which have no relation to any specific customer needs are a potential for standardization, whereas such modules and generic elements to which several specific customer needs are related, make a challenges on the view of modularity. In the case, presented by Lehtonen et al. (2016) the generic elements were defined by personnel from sales, product development and all the engineering disciplines who participated in a brainstorming session.

According to Lehtonen et al. (2016) generic elements might consist of these five product structuring types:

- Standard parts and solutions without options can be used in all deliveries
- Interchangeable modular solutions without any changes for dimensioning or design
- Interchangeable modular solutions configurable elements with predefined standardized options with layout alternatives
- Parametric solutions including one of a kind elemets
- One-of-kind solutions that require free layout designing with unique options and combinations of these.

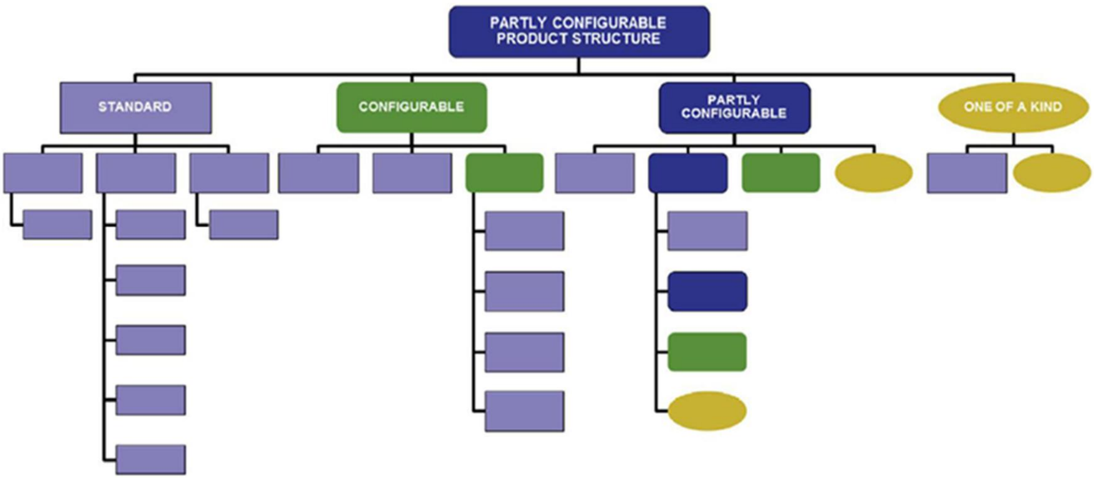

Figure 13. Product structuring (Juuti, 2008).

Lehtonen et al. (2016) explains that it is important to analyze the customer environment if the company wants to change its operating mode from the project-specific solutions to the configurable product delivery mode that consists of predefined modules. The configurable product delivery can be reached only if the generic customer requirements in the business sector can clearly be defined. Lehtonen et al. (2016) continues that the end users and customers of the generic products can be segmented into different market groups based on the same kind of expectations related to the products. Lehtonen et al. (2016) presents a matrix that is grouping the customer needs of the defined generic elements. These customer needs are added in columns and the generic elements are listed in the rows of the matrix in Figure 14. It might be said that the analysis of the relations between the generic elements and different customer need groups, tells what is the real number of generic elements and the type of projects were these can be used.

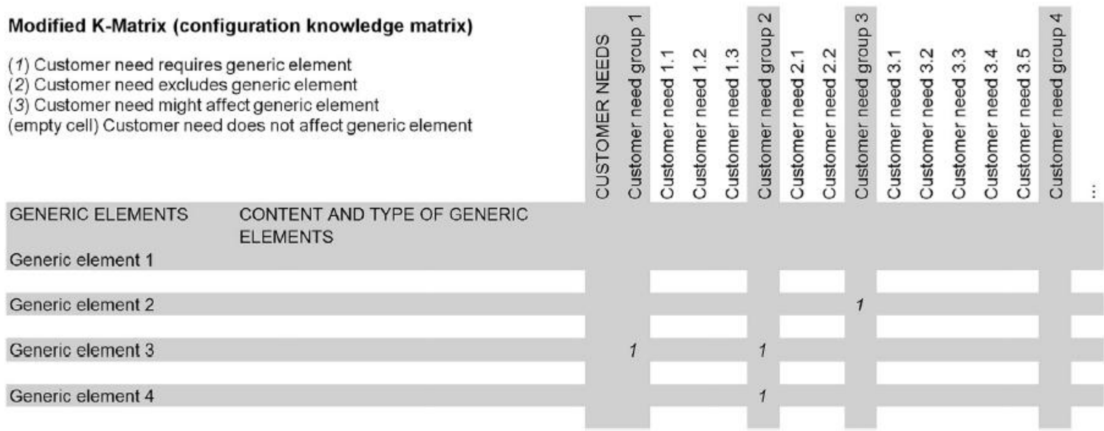

Figure 14. Configuration matrix. (Lehtonen et al., 2016).

An implementation method of a “key engineering concept” was suggested, see appendix 4. The key engineering concept consists of manual classifying work that is divided in to ten steps which can be seen to be crucial in the development of the product configuration system. These steps provide guidance when defining the design information that facilitates the planning of a modular product family. (Lehtonen et al., 2016.)

4.9.4 Product configuration system

In cases where the level of project maturity is high the implementation of the configuration system could be considered. The implementation should take place when the modular structuring and classifying work has been completed. The structuring here means company’s product architecture that was specified in the previous chapter of this paper. It can be assumed from the statements of Lehtonen et al. (2016) that modular project approach can be utilized most comprehensively when the circumstances can be seen to be stable. The configurable plants could be delivered in such a customer environment where the level of the project maturity is continuously on a high level. It can be interpreted from statements of Hvam (2006) that the implementation of configuration systems should be considered especially in business sectors where the prevalent customer requirements indicates that the quick delivery of bidding quotations is decisive for the company to achieve stronger order stock. Such kind of conditions was in force in the case of FL Smidth A/S, presented by Hvam (2006). In other words it mean that before the implementation of configuration system, the employees of FL Smidth A/S was forced to prioritize the customer inquiries due to lack of time to handle them all. According to Hvam (2006) FL Smidth A/S did not answer all the inquiries with a budget quotation and therefore some of the potential orders where continuously lost. The goals for the development of the configuration system are presented below in the table 2. The functional requirement of the configuration system can be interpreted to be “deliver fast”.

	Goal	*Existing performance*	*Gap*
Throughput time	1–2 days	10–25 days	Reduction of about 90%
Consumption of resources	1–2 man-days per budget quotation	About 10–25 man-days per budget quotation	Reduction of about 80%
Percentage of inquiries that are replied to with a quotation	100%	50%	50%
Quality of budget quotations	Homogeneous budget quotations	Great variations	More homogeneous quotations

Table 2. Elaboration of budget quotations. (Hvam, 2006).

In the case FL Smidth A/S the company could finally successfully conduct the structuring of the product. This product structuring worked later as a base for the development of configuration system. The configuration system was developed to achieve a more efficient engineering and sales process. The most important customer requirements were evaluated and the outcome of this evaluation was that the configuration system should need to specify these four things to be able to give binding quotations:

- Price, including financing terms.
- Delivery time.
- Operating costs.
- Energy consumption and environmental impact (emissions)

Development of configuration system

The development of the configuration system was based on the application of the generic modules of the cement plant that determine 80% of its total price. These generic base modules consist of detailed drawings and lists of the auxiliary equipment which belongs to it. The interconnecting modules connecting the base modules to each other (i.e. belt conveyors, cyclones) was not included in the cement plant configuration because it was not seen to be decisive for defining the price or capacity of the cement plant. In the addition to the base modules, the different capacities of the cement plant, were limited to options e.g., 2000, 3500, 5000, 7500 tons per day see figure 15 below. The additional price and weight curves were calculated based on the previously manufactured main equipment.(Hvam,2006.)

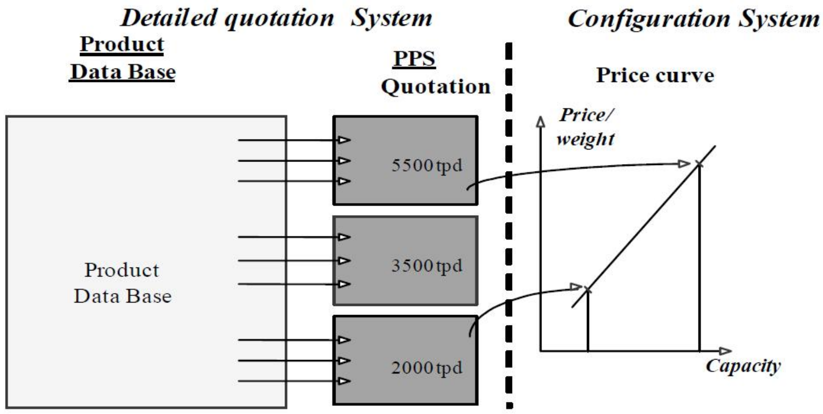

Figure 15. Price and weight curve (Hvam, 2006).

The Configuration system enabled F.L.Smidth to reduce resources for the preparation of the quotations by 50%. F.L.Smidth could respond all the requests with quotations and the time from client request to the signing a contract has significant decreased. An important functionality in the configuration systems is that the customers can be led to select F.L. Smidth’s standard solutions instead of customized and specialized solutions. (Hvam, 2006.)

It is important to notify that in the context of ETO companies’ modularity and the mass customization implies the postponement of a customer de-coupling point which can lead to many positive impacts. In other words the postponements can lead to benefits such as reduced delivery times, reduced specification costs, less training needed for sales personal and more precise cost calculations. (Haug et al., 2009)

5 PROJECT KNOWLEDGE MANAGEMENT

This chapter presents the dimensions of Knowledge Management. Then the definition of Product Data Management systems is discussed and the modern technology related to Big Data and Machine learning is briefly explained. Finally, at the end of the chapter, the issues related to capturing of Project knowledge is presented in general state. As discussed earlier in chapter 2 of this paper, it was interpreted that the Knowledge management can be seen to fulfilling the requested targets of “Jidoka”, that is a one curial principle of lean management.

5.1 Strategy of knowledge management

Knowledge is the most valuable and strategic resource for organizations and they must clearly and prominently manage their intellectual capabilities and resources. It is essential for the organization to form its knowledge strategy in relation to the measures needed for increasing understanding of the contents and processes of organizational learning among members of the organization. Relationship between knowledge management and business strategy has been widely ignored in practice, regardless that it's often talked about. Many executives are fighting to put in words the relationship between their organization's competitive strategy and its intellectual resources and capabilities. (Zack, 1999.)

Ståhle (2002) defines that knowledge management as systematic action that aim to increase the intellectual capital inside an organization. Knowledge management has been explained from several perspectives according to Tan et al. (2010) and it appears they see it important to think what perspectives are relevant to each contexts before utilizing its outcome. Figure 16 below by Jashapara (2005) explains the interdependencies and dimensions of knowledge management.

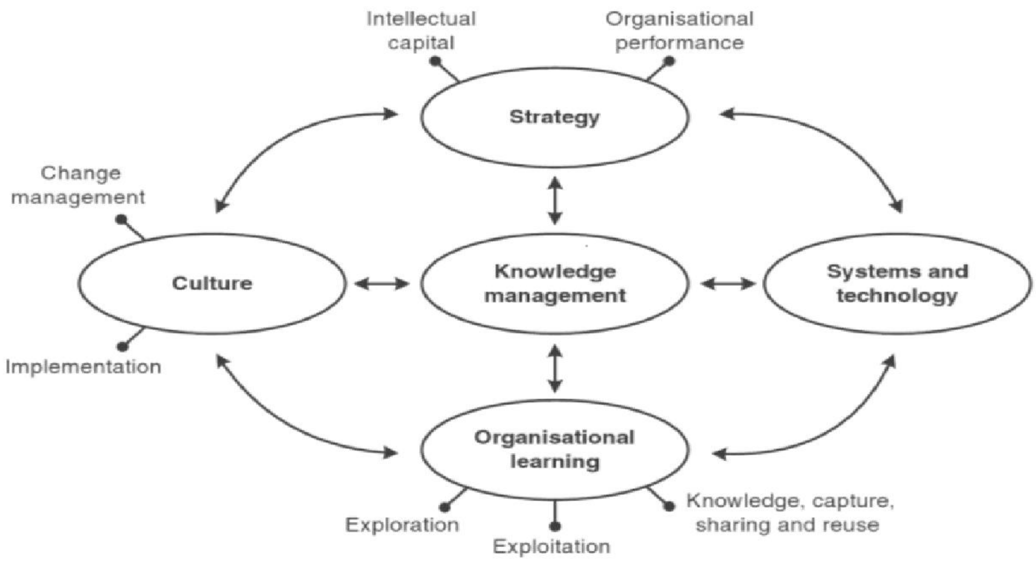

Figure 16. Dimensions of knowledge management (Jashapara, 2005).

In context of project work, Tan et al. [2010, 9] sees it important to understand the subjective perspective of knowledge that is defined by Schultze (1997) in following form: Knowledge is continuously shaping and being shaped by communities and social practices and can therefore not be located in any one place because it cannot exist without human experience and social practices of knowing. Grover and Davenport (2001) state that all knowledge management perspectives does not see the technology and information systems as solution by itself, but rather support the social and human activity in sharing of knowledge. Grover and Davenport (2001) explain that the functional perspective of knowledge depends heavily on technology and database-led activity. According to Grover and Davenport (2001) the functional perspective of knowledge implies employing accounting methods, structures and codification to exploit knowledge.

5.2 Intellectual capital

It's agreed among researchers that the most important asset of organizations is knowledge in the knowledge-based economy. During the last decades has the role of intellectual capital (IC), significantly increased as a success factor and source of sustainable business advantage. (Tan et al., 2010; Barney, 1991; Zack, 1999; Marr & Roos, 2005; Marr, 2008; Drucker, 1988.)

According to Ståhle (2002) IC is described as value adding assets and property for an organization that can be increased and refined by methods of knowledge management (KM). Zack (1999) also stated the knowledge supposed not to be treated as ‘static’ meaning that knowledge regarded as innovative today will likely become the core knowledge of tomorrow. Tan et al. (2010, 7) defines knowledge in terms of hierarchy to be on higher level than data and information Tan et al. [2010, 8-9] are referring to Schultze (1998) when they are defining the objective perspective of knowledge and explains that it can exist in variety of forms which are explicit or tacit knowledge. It can therefore be assumed that the explicit knowledge in Pöyry’s context means documented and decoded information that exists in specifications, standards drawings, project tools (I.e. Pro-elina), guided work processes. To understand the content of these specifications, standards and drawings requires that the reader possess tacit knowledge that is practical and experience related.

5.3 Organizational learning and culture

Organizational learning is a process itself and characterized by the exploration of knowledge, where new learning is connected to earlier. The exploitation of knowledge and already learned is utilized by finding a balance between and eliminating things that creates tensions in organizations (see March, 1991). Discipline, support, trust and stretch are four elements are crucial in establishing a framework needed for supporting learning, creating commitment, imbuing confidence, enabling execution and inspiring collaboration (Leatt et al., 1997). Interestingly, the statement by Leatt et al. (1997) on the essential role of core values in forming learning-friendly frameworks are directly related to discussions by Schein (1996) on the cultural aspects of learning. He sees that managing and understanding the organizational culture and its subcultures is a necessary for learning. Schein, (1993) argues that organizational learning will ultimately depend upon cultural understanding and that in building such higher level of consciousness, a dialogue is a central element of all models designed for organizational transformation (Schein, 1993). In dialogue, the aim is to confront own and others' assumptions, reveal feelings and, finally, build a common ground (Schein, 1993). Ineffective senior management teams, unclear strategies and conflicting priorities, top-down or laissez-faire senior management style, poor vertical communication, poor coordination across functions, businesses or borders, and inadequate down-the-line leadership skills and development were specified as likely killers of strategy by Beer and Eisenstat (2000).

The framework by Crossan and Berdrow (2003) for organizational learning and strategic renewal is as follows:

1. Organization should recognize how to learn something new and how to reuse the old one.
2. Organization should check the levels of learning (individual, group and organizational) and their relationships.
3. Organizations should identify processes and their links to the levels of learning.
4. Organizations should link these processes to restructuring.
5. Organizations should understand that organizational learning requires an interaction between action and cognition.

5.4 Product Data Management systems

In order to increase the understanding related to functional perspective of Knowledge Management it is necessary to broach the notion of Product Data Management (PDM) that Grieves (2006) defines as an information system with a systematic set of tools and guided processes for the storing and sharing of information between project stakeholders. Grieves (2006) explains that Information systems of PDM and also wider frame oriented PLM systems could be based on a data model which enables updating, accessing, reasoning and manipulating about product information that is being produced. In the context of the Pöyry, the Product Data Management system can be defined to be Sharepoint, Dochotel or JP-Doc depending on the project.

5.5 Big Data and Machine learning

Big data and Machine Learning can be seen to represent a functional perspective of knowledge management that focusses on systems and technologies. The volume of data in the world is rapidly increasing and it is expected that by 2020 there will be more than 16 Trillion GB of useful data state Becker, Tilman et al. (2016). According to De Mauro at al. (2016) the information is the fuel to the current Big Data phenomenon. Big Data can be defined as technology for analyzing and identifying the various processes involved in cataloguing library assets of a big amount of data. It extracts quickly the information that is requested to aid in the knowledge management of an organization or society. Unfortunately, a specific competence about the potentiality and limitations is not yet adapted for use in the job market, state Tilman et al. (2016). The ability to efficiently extract the necessary knowledge is seen as a key competitive advantage. Big Data technology implementations within industrial sectors are not very high tech but nowadays rather a necessary need for most companies to survive and gain a competitive advantage. Big Data has come as a new factor of business and production where it is essential to have the appropriate structure and technology to exploit this data which creates value. Big Data solutions will enable Europe to increase its competitiveness by delivering value through adding tools, services and applications. It is expected that by 2020 the potential of big and open data will improve the European GDP by 1.9 %. (Becker, Tilman et al., 2016.)

Machine learning is defined as an analytical method of Big Data. Machine learning means data analysis that automates analytical model building. Machine learning uses algorithms that iteratively learn from the data. Machine learning allows computers to find hidden insights without being explicitly programmed where to look for them. (De Mauro at al., 2016.)

This kind of new technology could find similar objects from Pöyry’s project databases even though the objects may have different type of naming and position numbers.

5.6 Capture and reuse of knowledge

According to Tan et al. (2007) the importance of reusing and sharing the knowledge of earlier construction projects are undermined mainly due to the lack of important insights and knowledge. Tan et al. (2007) state, that the reason for the challenges in knowledge management beside the employee turnover is the time lapse in capturing knowledge and the people’s lack of willingness to share knowledge. Tan et al. (2010) claims that only a small fraction of the knowledge gained in the construction project phase is captured. Tan et al. (2010) continue that even smaller fraction of gained project knowledge is reused. Tan et al. (2010) explain the statements mentioned above to be a result from the fragmented nature of construction projects. The fragmented nature here implies a variety of disciplines and organizations who take the part of construction projects. According to Tan et al. (2010) the reason for these challenges can be found in long chains of suppliers, suppliers' suppliers and their conflicting interests. Tan et al. (2010, 20) state that the contractors and suppliers who are collaborating in one project can be competitors in others which explains the conflicting interests in sharing all of useful knowledge.'

5.7 Insufficient knowledge management practices

A significant reason behind an insufficient knowledge management lies on the common practices when capturing, sharing and reusing knowledge. The sufficient knowledge of management practices is essential when seeking improvements of the profitability in constructing a project in a type environment.
The common knowledge of the management practice "lessons learned" has been only marginally successful because of the time lapse in capturing the knowledge. The major limitation on the approach of lessons learned is the following; it takes place long after the learning event occurs in projects which means that many details and subtleties are not captured. It is also difficult for the project participants to fully recall and utilize the details of the knowledge in that context where it is learned. The members of projects can only see bits of the whole story that are related to their work. The project knowledge is scattered in the minds of various team members in

projects and most of the knowledge is not shared and will therefore be lost. (Tan et al., 2010.)

Post Project Reviews

Some companies have implemented Post Project Reviews (PPR) in order to tackle the problem of the lost project knowledge. PPR is often undermined and insufficient because of the lack of time of conduct it by the project team members. When the PPR in terms of lessons learned takes place after the completion of a project the members are usually already involved in other projects. Therefore an appropriate mechanism and formats for representing the knowledge and sharing information across the project is important. (Tan et al., 2010.)

5.8 “Live” capturing of knowledge

To reach the functional requirements of the modularity which are presented in the chapter 4.8 of this paper is essential to get the knowledge captured “live” in a collaborative environment while the project is being executed. Development of modular construction requires effective knowledge transferring to design phase to maintain continuously improvement. It is also important to present the knowledge in such a format that it facilitates reusing it during and after the project, state Tan et al. (2007). It is also important to have incorporating mechanisms to hasten the validation and dissemination of the knowledge at once an important information has been found, writes Tan et al.(2007). To address this, the main issues needed are the following:

- Web-based knowledge base e.g. Sharepoint and Doc-hotel that Pöyry have. Knowledge network aided by custom-designed IT-systems for project people to communicate with each other and share their knowledge.
- An integrated workflow system
- Project knowledge manager as an administrator

Three main functions of knowledge capturing

Tan et al. [2007] writes that knowledge capturing consist about three main functions which are:

- Identifying and locating knowledge
- Representing and storing knowledge
- Validating knowledge

Identifying and locating knowledge. To mean in practice an identification system that classifies knowledge and specifies the location of learning situations. It defines where the new knowledge is created and the people who have and might need the knowledge (Kamara et al. 2003). The case studies of Tan et al. (2007) indicates that reusable project knowledge often exist as a mix of explicit knowledge which is documented and tacit knowledge that is stored only in memories of project members.

Representing and storing knowledge. In order to save the knowledge in an appropriate standard or format specified with the details required the tacit knowledge can be supplemented and enhanced by video clips to capture the detailed explanation of the originator of learning. The tacit knowledge of a project should be decoded into an explicit form as far as possible because it is easier to be transferred and shared. The remaining tacit knowledge that is difficult to translate in an explicit form of documentation could be linked to people (e.g., contact details) by building up a network of people for sharing the tacit knowledge.(see Robinson et al. 2002; Rollett, 2003; Markus 2001; Davenport and Hansen, 1999.)

A validating knowledge mechanism is required to ensure that the entered knowledge is accurate and complete with all the details required. This can be interpreted to mean revision making, finalizing and updating of knowledge to ensure the credence of knowledge to avoid copying mistakes to following projects. This implies also that the captured knowledge is stored with the all relevant contextual details and in the format required.(Tan et al., 2007)

5.9 The methodology and process of knowledge capture

The process starts by learning the situations in a project which create a new piece of knowledge that can be captured in the Block 2 meaning group meetings and reviews.

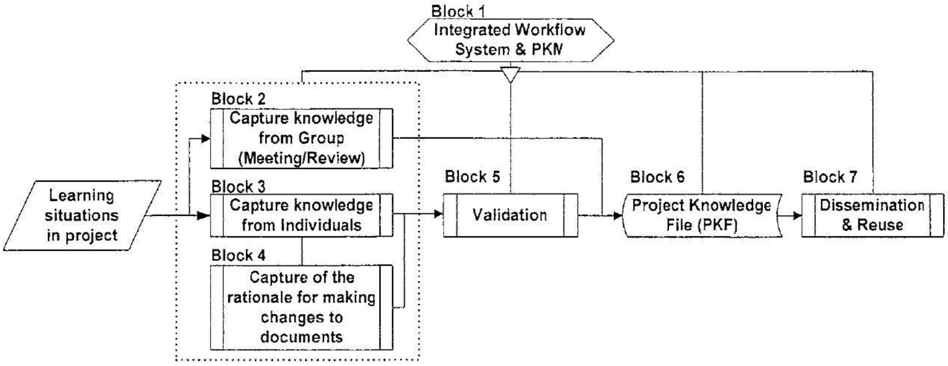

Figure 17. Live Capture of Project Knowledge (Tan et al., 2007).

Block 3 in Figure 17 implies that once the knowledge is gained or identified, all knowledge workers in the project should be involved in the knowledge capturing and storing. The users should have usernames and passwords to access the work flowsystem. Block 4 implies appropriate revision management and an access to previous revisions. The project documents should need to be checked by the knowledge manager in predetermined intervals. The block 5 implies the validating of the process that means the making of the final decision of the outcome in learning situations. Validation of gained knowledge can be rating based, majority opinion-based, comment-based options. Bypassing the validation mechanism should also be an option. The new knowledge should be discussed in next meetings and reviews using a web-based user-interface to avoid traveling. The block 7 implies the final validation and dissemination mechanism of the project information. The validation in the final step should release the information and the knowledge gained for reusing in new similar projects in order to optimize the design that should contribute to increasing the safety, faster delivery and construction. (Tan et al., 2007.)

Based on Tan et al. (2007) investigation there are some main factors that have to be resolved before implementing the new information of the capturing and sharing practices which are the following:

1. The Costs of live capturing and reuse of knowledge should not incur a significant additional cost to the collaborating companies in project.
2. The methodology developed should not create significant additional workload to the collaborating companies in project in view of their existing heavy workload.
3. Facilitating the capture and reuse of project knowledge by guided work processes. Project knowledge should be captured as soon as possible once it is created or identified.
4. Legal issues. Some companies prohibit their employees and collaborating companies from to share out the information and knowledge learned to other companies that are not involved in the project. A solution is required to ensure that the sharing, capturing, and reuse of project knowledge are not restricted by conditions of contract and the copyright.

6 UTILIZING METHODS AND SYSTEMS IN DEVELOPMENT PROCESS

This chapter aims to clarify how the semi structured research was implemented and how the research construction was shaped. The procedure to shape the construction follows the guidance of Erixon (1998) MFD-method that suggests: clarifying the customer requirements, selecting technical solutions, generating concepts and evaluating the concepts. First, Pöyry’s Project Management Guideline PM0 (modularization ‘constructability’ study guideline) is introduced. The content of PM0 was inspected by the author of this paper before preparing the suggestion of framework for modularity guidelines in project based business. Finally, the suggestion of framework was shaped based on literature review of and internal project management guideline material from Pöyry.

6.1 Modularization ‘Constructability’ studies

The Modularization ‘constructability’ studies guideline PM0 can be seen the starting point for the investigation the utilization of modularity in the project. It is notable that the modularization ‘constructability’ studies are placed as one early phase step in the suggestion of framework for modularity guidelines. The PM0 aligns that modularity in project based business implies upfront decision making that affects especially the Engineering, Procurement and Construction phases of the project. The ability to influence the outcome of project is relative high in the early phase of the project but decreases exponentially with respect to time according to Pinnock et al. (2012), see figure 18. To mean in practice the decision, whether to utilize modularity in projects or not, is taken during the conceptual design phase FEL1. It should be issued between Gate 20 – 40 in the Proposal phase, see appendix 2.

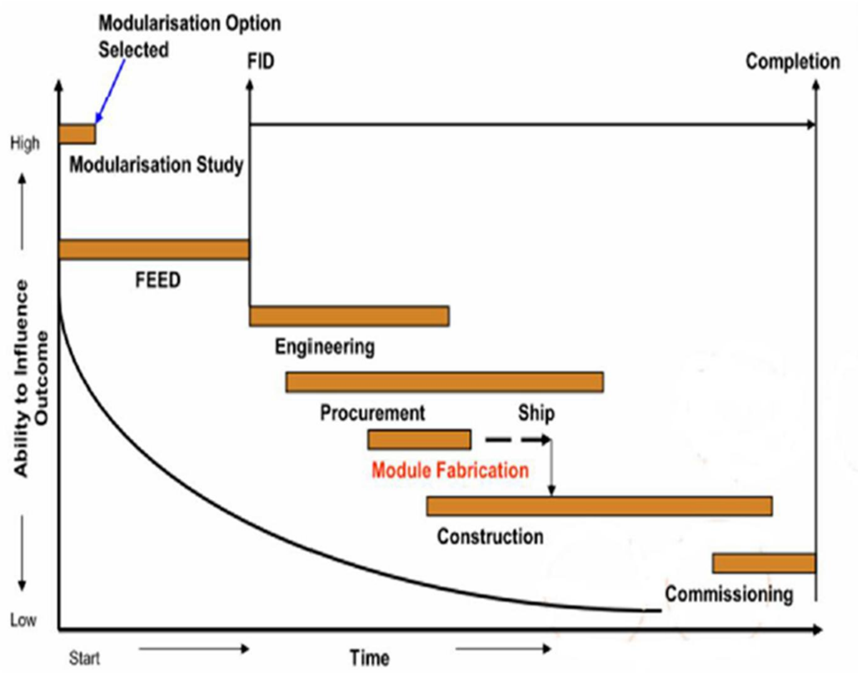

Figure 18. Modularization study. (Pinnock et al., 2012).

“Simply put Constructability focuses on (1) safety , environmental and risk prevention, (2) construction driven schedules, (3) simplified design configurations, (4) standardization of elements, (5) modular and preassembly designs which facilitate fabrication, transport and installation, and (6) accessibility and adverse weather” (Pöyry Plc, 2016a). The constructability study reseaches the prevailing conditions in the area where the plant is planned to be built. Thus the impacts of the area specific logistical conditions are evaluated. PM0 aligns that early phase decision should be taken related to the appropriate module sizes. The constructability study finds also about the prevailing conditions related to the country specific laws and regulations. The constructability study explores these factors that have an impact on the design and specifications. It can therefore be assumed that the constructability study explores the project specific possibilities to utilize modularity in design that means the re-use of existing design. Modularization 'constructability' studies are vital to define how detail engineering will be executed. (Pöyry Plc, 2016a)

6.2 Concept for testing

Due to lack of scientific references from exactly similar cases where an ETO-project based business move towards modularity, a framework was established which shows the suggestion of main steps towards modularity in the context of plant engineering at Pöyry. Based on findings of Lehtonen (2016) and Hvam (2006) which are presented in chapter 4.2 of this paper, the modularity in designs requires foundational work that consists about product structuring and evaluation of existing design with an aim to identify the generic elements and the type of project where these can be used. The foundational work should aim to serve all plant projects in the future and it would form the basis for the framework.

The framework of suggested steps towards modularity at the context of plant engineering was formed in the guidance of scientific models specified by Blecker and Abdelkafi (2006) combined with information and internal project management material from Pöyry Plc (2016a). Figure 17 below shows seven suggested steps of complexity reduction framework that have an iterative nature. This framework will be tested by an interviewee group in forms of interview questions with an aim to identify what is the correct order of this process flow e.g. which has the largest influence. The interview questions are presented in Appendix 5. The qualitative action research method with semi-structured interviews is focusing on the steps 2-6 that is presented in the Figure 17. To mean in practice, that the step 1 and step 7 are mainly excluded due to delimitation of this study.

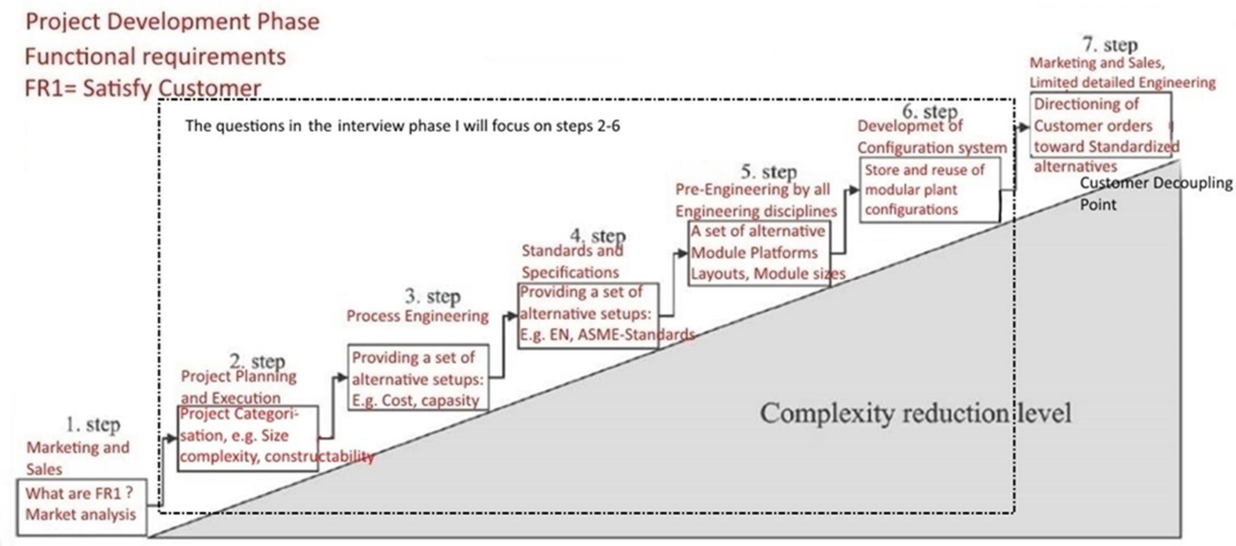

Figure 19. Complexity Reduction concept

Step 1

The excluded step 1 in the framework in figure 17 implies business sector specific market analysis that would evaluate the generic market trends, needs and the generic customer requirements. Defined by Lehtonen (2016) and Hvam (2006), the aim of this step is to lay ground to the foundational product structuring work of generic elements that takes place in the early phase of modularization.

Step 2

The step 2 in the framework in figure 17 implies project categorization in form of Modular Constructability study. As presented in the chapter 6.1 this evaluates the modularity in the view at one distinct project and in the view at project maturity level. The notion of project maturity was defined in chapter 4.6 of this paper. To repeat the project maturity in the context of Pöyry means, how well they know the process and technology and what are the number of similar reference projects that have been conducted. The categorization classifies the projects in the view at project size, standards, location and country specific law and regulations.

Step 3

The step 3 in the framework in figure 17 implies evaluation of the process engineering in the view at modularity. The process engineering can be seen to be a kind of foundational engineering that specifies main equipment, auxiliary equipment, datasheets and other used technology in the plant (Pöyry Plc, 2016a). The names specified in this phase are related to thousands of objects in the plant. The aim of modularization of the process engineering is to evaluate the possibilities to increase the reusability of existing works. The modularization of plant processes should be conducted together with other engineering disciplines. Practically it means evaluation of the possibilities to shape generic equipment datasheets, lists of equipment and specifications. Modularity in process engineering should find out the possibilities to split the sub-processes of the plant to such entities and sizes that it could be prefabricated, commissioned and tested before sending to the site.

Step 4

The step 4 in the framework in figure 17 implies evaluation of the prevailing standards and specifications. The material standards and specifications can be seen to be a kind of foundational input material for all engineering disciplines (Pöyry Plc, 2016a). Differences in project specific requirements related to standards in comparison existing design might prevent the possibilities to reuse of design. Step 4 should find out what are the factors related to specifications standards that would facilitate the reusability of design in future. It is notable that the constructability study provides project specific input data for standardization.

Step 5

The aim of this step is to develop and shape industrial plants that consist of physical modules that could be used in several projects. The primary drivers of modularity, presented in chapter 3 of this paper, can be interpreted to be the Reusability and Constructability. Thus it in the field of mechanical engineering means design that aims to build module platforms and transportable modules that are of pre-determined size. The possibilities to build multi discipline modules should be considered which means structure and equipment installed within the modules. It is notable that the constructability study in step 2 of the framework gives the input data related to project specific requirements of possible module sizes. The design should contribute to fast delivery and easily mounting to its place on the site. All engineering should be conducted with the aim to increase its repeatability in future projects.

Step 6

The primary aim of step 6 is to find solutions on how to facilitate the storing, sharing and searching of reusable modular design across project boundaries. This implies evaluation of the needs and the currents possibilities to utilize new technology or to develop a product configuration system. The evaluation should be done based on findings from the foundational structuring work and in the view of the information from previous steps presented in this framework.

Step 7

The primary aim of step 7 is lead the customers to select the standard solutions instead of customized and specialized solutions. In practice it means that the gathered information (e.g. physical modules and specifications) from earlier projects are used in the second “Customer de-coupling point” to learn and lead the customers in new projects. This final step can be seen as essential in the view of increased productivity because it allows the direction of customers towards the preferred standard solutions outlined by the developed modules.

7 RESULTS AND DISCUSSION

The results of the qualitative study discussed in this chapter aim to answer the main research question. Firstly, the dimensions of Lean in the context of Plant Design projects are presented. Then, the effects of modularity to the customer project life cycle are analyzed from base of the literature review and internal project management guideline material from Pöyry. Third, recommendation on how to capture and reuse project’s knowledge are given based on the interviews and on the literature review. Fourthly, framework for modular guidelines based on result of the semi structured research is presented. The contents of these steps were tested by internal interviews and the answers are presented stepwise in this chapter. Finally the impacts of modularity to the current level of productivity in the plant project business are discussed.

7.1 The dimensions of Lean in the context of plant design projects

Lean can be defined to be the umbrella term for the activities that this paper recommends to implement in the Pöyry, see Figure 20 below. As a result of this study the content of strategic actions of Lean in the context of the Pöyry was defined. Results are shown in Figure 20 below which is based on the statements of Modig & Åhlström (2012)and the interviews.

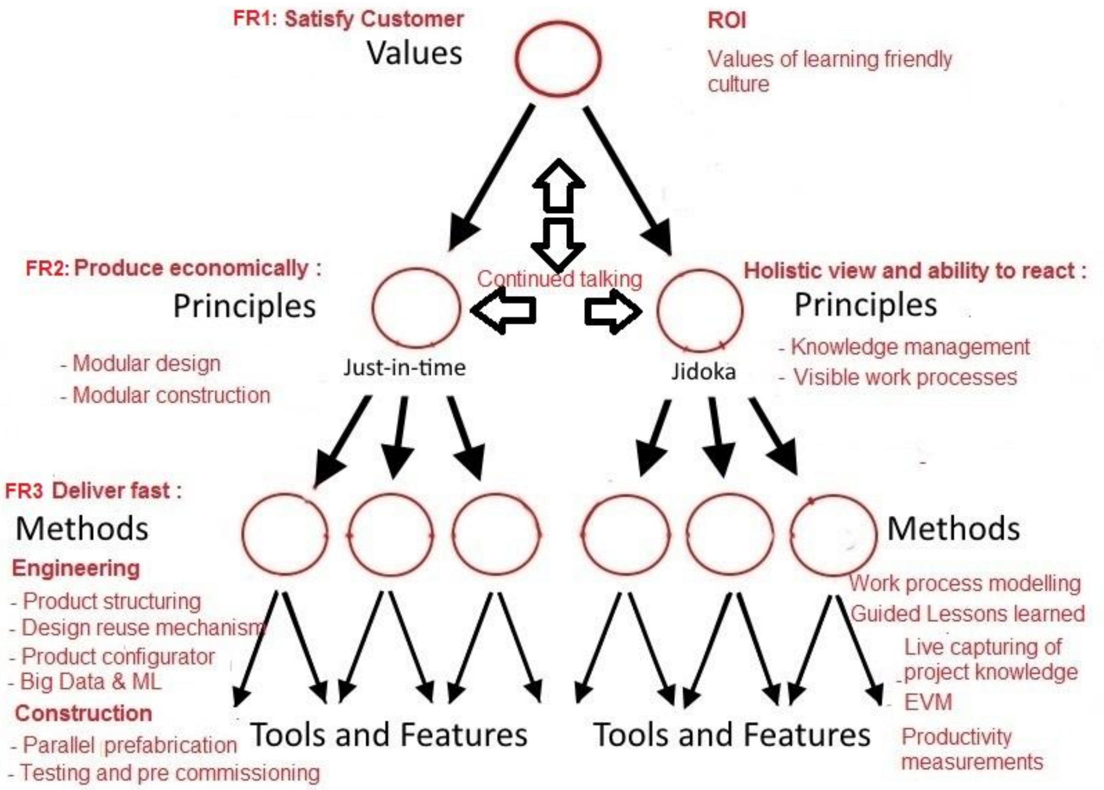

Figure 20. Lean in the context of Plant engineering project

The primary value in the context of Pöyry

Starting point for defining the dimensions of Lean in the context of plant design projects was to define the content of the two highest abstraction levels of Lean. Modig & Åhlström (2012), state that only such works and efforts can be defined to bring core value which promotes the fulfillment customer demands. In the view at this statement the value “Satisfy Customer” by delivering smart solutions through connected teams was placed on the highest abstraction level of Lean management. By satisfying customers the company can get the business to grow that can be seen to contribute to satisfied shareholders (i.e. to bring ROI). When the consensus of most important value on the highest abstraction level has been achieved, the company gets the answers on how to act in every situation.

The Principles of Lean in the context of Pöyry

The second abstraction level consists of two principles with an aim to fulfill the value that is requested on the highest abstraction level. Based on the vision and strategy of Pöyry and statements from the supervisor of this work, the value in the context of Pöyry, implies such actions that contributes to 1) efficient delivery time, 2) reduced cost, 3)promotes the level of quality and 4)allows reaching an increased level of safety in the Project Execution phase. As a result of this study, it can be stated that these mentioned actions are in alignment with a modular project approach. According to Modig and Åhlström (2012), the approach of Lean and the principle of Just-In-Time (JIT) put the “creating of flow in production system through elimination of waste” at the center of the operations when producing of value which is delivered to the customer. Based on findings of the literature review it can be stated that modularity in plant design and construction can be seen to promote the targets of JIT especially in the final erection of the plant construction. There are cases where it is needed to purchase something very early , only so that other processes can continue and data is available. The second principle in this abstraction level is “Jidoka” that is defined to be the other side of the same coin that complements the JIT. Modig and Åhlström (2012) defines that “Jidoka” implies a good holistic view, ability to react fast, see the players and targets, see the time that is left in the project. As a results of the literature review and the interviews, “Jidoka” can be interpreted to mean appropriate knowledge management practices and modelling of visible work processes in term of monitoring and measurement.

The methods of Lean in the context of Pöyry

Based on the literature review and interviews of this study, the methods of Lean are defined in the Figure 18 above. As a results of this research, it can be stated that the degree of business sector specific project maturity has an impact on the modularity methods that make sense to implement in order to achieve better level productivity. The functional requirements of modularity based on statements of Blecker and Abdelkafi (2006) can be seen framing the content of the defined methods In the view of the internal Project guideline material and the literature view, it can further be interpreted that the dimensions of Knowledge management and use of Earned Value Management (EVM), fosters the ability to reach the targets of "Jidoka" in the Pöyry. EVM gives a realistic feedback on the progress of the project and it enables Pöyry to plan corrective actions early enough in order to complete the project with expected delivery time , see figure 21 below.

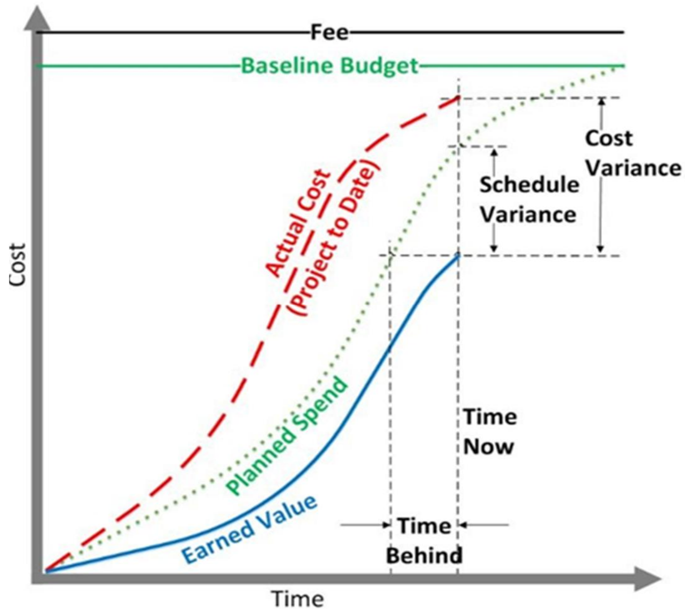

Figure 21. EVM, earned value of your project Pöyry Plc, 2016a).

7.2 The impacts on customer project lifecycle

This chapter aims to briefly present the results of the research in the view at the customer project lifecycle, see figure 22. It was found that the features of modularity need to be utilized in the whole lifecycle of the customer project. When considering the definitions of Lean management and PLM as continuation of the philosophy, it can be assumed based on statements in the literature review that the project can be seen to be a kind of product that is enhanced by modular features during its lifecycle (see, Grieves ,2006, 1; Papinniemi et al.,2013; Modig & Åhlström, 2012. It is important to notify that the implementation of modularity plant engineering projects requires lots internal foundational work that is not in the scope of works of the project.

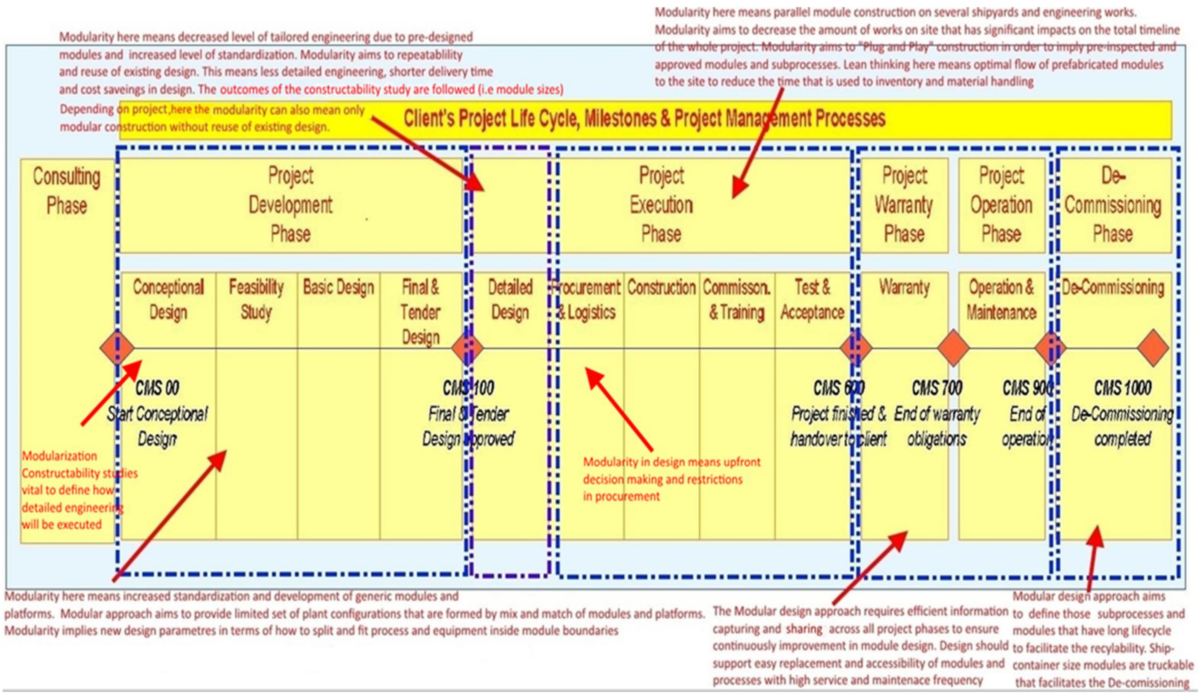

Figure 22. Clients Project Lifecycle

Project conceptual design phase

Regardless if the project approach is modular or not, project Conceptual Design phase should start whit a constructability study that clarifies the limitations and understanding what factors can influence the successful construction of the project. In the view at the findings of literature review and the interviews it can be stated that modular features can be utilized both in cases of EPCM- and EPC Projects. To benefit from the gains of modularity it was suggested by the interviewees that it could be considered in Project development phase to split the bigger EPCM projects to smaller EPC deliverable entities.

It can be summarized based on empirical research of this paper, the recognizable difference between the traditional project approach and modular approach is the upfront decision making related for instance to the use of engineering strategy, specifications and standards, module sizes, procurement, automation technology and etc, explained in chapter 6.1. In case modular approach is used the scheduling of procurement would need to be reconsidered and possibly changed. The different drivers of modularity explained in chapter 3 of this paper need to be identified in early phase e.g. to could benefit from them in project Execution, Warranty, Operating and De-commission phases.

Feasibility Study and Basic Design

The results of empirical study of this work indicates that the most recognizable difference between approaches of traditional project and a modular project is the upfront design, early phase commitment to limited number of suppliers, standards and specifications. Feasibility Study and Basic Design establish the cost level, evaluate and select the technical solutions for the project. Based on statements of Hvam (2006, it can be interpreted that this is the stage in Pöyry’s Clients’ Project Lifecycle, when the customers can be led to select standard solutions, instead of customized and specialized solutions. This would be ideally already in the conceptual phase of project. According the findings of Literature review the development phase of modular project should be carried out by mixing and matching of existing generic modules. The results of the empirical research of this thesis work indicates that in the field of energy plant engineering the plant sub-processes consist of already modularized equipment that are supplied by external vendors on EPS or EPC basis. Thus, the question is mainly how Pöyry can modularize the Balance of Plant engineering (BOP). As the main equipment are in most cases project specific, the BOP requires tailored work that cannot fully be modularized, except such modularity that is related to the modularization of work processes. Modular design in such projects mentioned above, means rather interconnection design between the main equipment and sub-processes supplied by the external vendors. There are still many types of projects (i.e. energy, chemicals, pulp and paper, mining and metal) conducted by Pöyry where the scope of work in not only balance BOP. In the context of Pöyry, modularity means decisions of how to modularize the pipe racks, distribution and collection manifolds, piping utility stations, pump beds, pump units, electrical rooms and etc. Modularity means also establishment of generic valve and equipment list that should rather be specified based on dimensional series instead of the accurate supplier. This maneuver would allow Pöyry conduct a competitive bidding without changes orders and new revisions of drawings.

Detailed Engineering

Based on literature review the modular approach in Detailed Engineering phase should aim to conduct these customized works that remains after project the Development phase. These works consist about tailored engineering works need to be done in every project e.g. creating of works drawings. Specified in chapter 4 of this paper, in the logical sequence of complexity reduction it can be assumed that the detailed engineering of modular plant refers to the “Delayed differentiation” phase. The amount hours that are consumed to complete the Detailed engineering phase might vary depending on the project maturity and the possibilities to use modular.

The result gathered through interviews indicates that due to the traditional role of Pöyry that means design of the BOP, most projects are of such kind that the number of generic elements is relative low and the customization level is high, except small EPC-delivery projects. It was suggested that the dimensioning principle related to the work drawings i.e. isometric drawings

Construction and commissioning

The findings based on the literature review empirical research shows, that modularity affects the construction and Commissioning & Training and Test & Acceptance with aim to move works from the building site to better conditions. In order to mean that modules should be prefabricated and commissioned to the maximum extent before the transporting to the site. If needed the module prefabrication can be done in parallel to catch up with the schedule or because of other reasons. It is obvious that modular approach affects the time scheduling of whole project in comparison to traditionally customer project lifecycle. In order to prefabricate modules of certain size requires upfront decision making and engineering. Thus, the optimal module sizes have to be frozen in constructability study phase and a procurement study need to be conducted to be sure that the selected materials and equipment can be used and are available.

Project Warranty, Operation and De-commissioning phases

Based on the definitions of Hellström (2005) modularity brings opportunities for improvements that could be utilized in Project Warranty-, Project Operation- and Decommissioning phases. The opportunities are related to the drivers of modularity i.e. serviceability or recyclability i.e. maintenance and recycling aspects was sawn as attractive focus points by the interviewees. These Drivers should need to be identified in Conceptual Design phase and in the design of generic elements based on generic customer requirements. Serviceability as driver of modularity facilitates the maintenance and easy replacement of parts that have high service frequency.

Recyclability as main driver of modularity brings opportunities in terms of reuse of sub-processes in cases were the equipment lifecycle is longer that the plants. Recyclability as driver of modularity implies design of modules in eye on transportability and so that modules would be removable and truckable. Recyclability as driver of modularity allows the owner of the plants to gain more benefits from the investment.

7.3 Suggestion for modular project management

This chapter discusses the outcome of the testing of the framework for modularity guidelines in project based business. The result has been gathered trough the empirical research. The findings indicate that the variety of project conditions where modularity can be utilized is large and the ways how to utilize it are many. The results indicate that features of modularity can be utilized most comprehensively in small size EPC-projects where the scope of engineering is not only BOP but the whole project scope. To clarify the features and as a results of the research, figure 23 below presents a concept for complexity reduction in EPC-project based business.

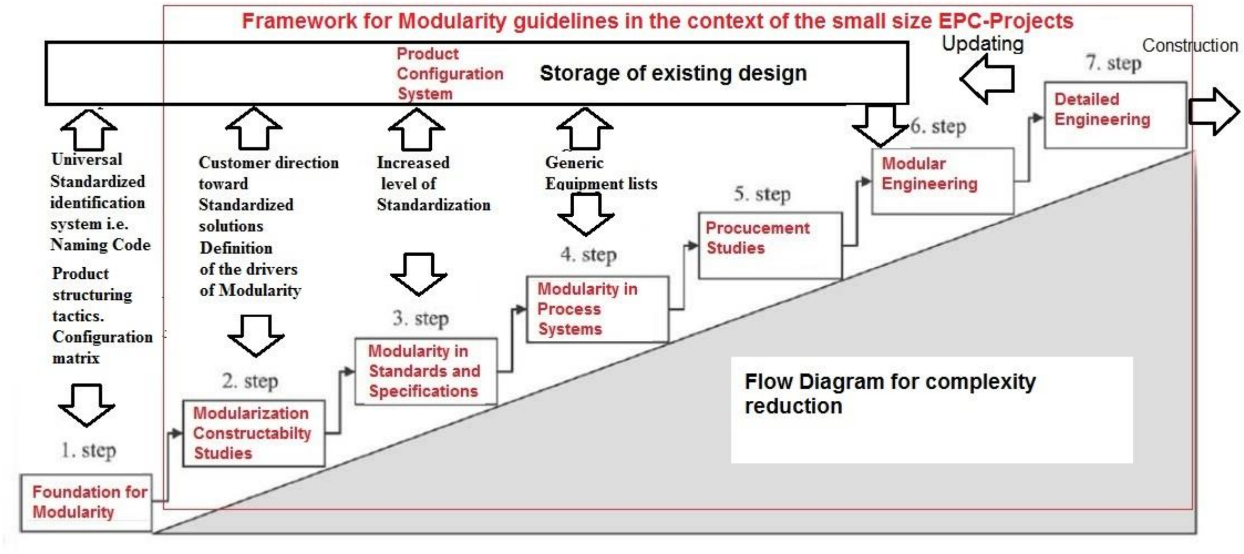

Figure 23. Re-engineered concept for complexity reduction

7.3.1 Project categorization

Based on the empirical study it can be stated that the actions to increase modularity in a project are scalable according to project scope, size, implementation method, and the selected driver of modularity. When examining the results of this study it is important to note that Pöyry operates in many types of circumstances. To repeat the features of modularity can be utilized most comprehensively in small size EPC-projects depending on the decision parameters i.e. who has the main process core knowledge and if there are previous experiences of similar size projects. It was found consensus among interviewees that due to the high overall costs a big and medium size plant projects, the time is not mature for bigger EPC deliveries conducted by Pöyry. EPC-contract covers risks, but also possible gains are transferred to the EPC-Contractor whereas in EPCM, all contracts in the project are signed by the owner (i.e. Client). I cases of EPCM-contracts, all project stakeholders are acting on behalf of owner and the main technology is usually supplied by external vendors. Thus it is obvious that modularization conducted by Pöyry would focus on narrower sectors in EPCM projects unless situations where Pöyry can convince and explain to client why they should select modular approach. Then the client can force all stakeholders to follow modular approach. The interviewees suggest that Pöyry should identify those smaller sub-processes and stand-alone departments of big and medium size plant projects that could be implemented trough modular EPC-implementation method to benefits also from gains. Modularizing of sub-processes and generic elements reduces the overall risk due to the repeatable nature and better validated design. Once or several times constructed and assembled modules provides transparency and predictability in terms of construction costs. Thus it means that modular design approach reduces risks and increases the possibility to sign more small EPC-contacts and benefit from its gains.

The scope of Pöyry can vary depending on the project and the type of project implementation method. In large pulp and paper and bigger energy projects the scope of Pöyry - in addition to the other EPCM services - is to do the engineering for the Balance of Plant (BOP) so that the BOP constitutes together with the main equipment a well-designed entity according to the customer’s requirements. As stated earlier BOP requires in most cases tailored work that cannot be normally modularized because of the project specific already modularized equipment and other processes that are supplied by external vendors on EPS or EPC basis.

Pöyry is also conducting BOP-engineering in small and medium size EPC-projects that consists about modularized equipment packages and plant sub-processes supplied by external vendors on EPC basis. According to interviewees the engineering conducted by Pöyry makes only 2-3% of the total project costs of such EPC-projects. The engineering of these projects are quite simple and straight forward where optimization and modularization of engineering would not bring Pöyry any significant advantage. The optimization of the purchasing by making the packet as cheap as possible was seen most important in EPC-projects that mainly consist of packages delivered by third parts.

Reusability as a driver of modularity

The different drivers of modularity was discussed and accepted among the interviewees. Three main factors that have impacts on the ability to reuse of design which are following: 1) scope of supply, 2) repeatability of projects 3) Project maturity that means how well known is the used processes and technology.

Constructability as a driver of modularity

Constructability is such driver of modularity that can in most cases be utilized to some extent in all projects. Interviewees pointed out that modularity can increase the quality of work and provide stability against industrial action as labor strike. No clear consensus among the interviewees could be found when discussing the impacts of modularity to the total project timeline. It is obvious that parallel prefabrication of modules decreases the construction timeline but when considering the total project timeline it rather depended on the main equipment delivery times which are not normally in scope of Pöyry. Delivery times of main equipment are still the same in modular projects as in stick built project. The benefits that are gained due to modular approach are rather related to the possibility to transfer works from challenging conditions and such areas that lacks skilled and cost effective labor. The decision to utilize modular approach need interests of the client and not only concern Pöyry’s own scope of supply. Turner and Cochrane (1993) states that project based categorization should be implemented i.e. classification according to the degree of complexity from the modularity point of view. According to the interviewees a features of modularity could be utilized on following ways in the listed types of projects:

1) Small size Greenfield EPC-projects where scope of supply includes total MEI and detailed engineering of plant processes. Modularity should be utilized to the maximum extent possible at the all levels.

2) Small size Brownfield EPC-projects where scope of supply includes the total MEI and detailed engineering delivered plant processes. Modularity is limited due to existing technology, standards and other plant specific requirements. Modularity should be utilized to the maximum extent inside these requirements.
3) Small size EPC-projects that consist equipment packages supplied by external vendors and only engineering for the BOP is conducted by EPC contractor. Modularity in terms of reusability in design would not bring Pöyry any significant advantage but constructability should be the driver of modularity i.e. “Plug and play” modular construction and prefabrication.
4) Big and medium size EPCM-projects with high level of project maturity. Modularity is limited because the owner has the right/obligation to take final decisions. If possible Pöyry need to convince the client that they choose a modular approach in construction. If possible Pöyry should aim to split the project to smaller EPC deliverable entities in order to increase the level of modularity and benefit from the gains. The reusability of existing design should be observed due to the high level project maturity. Reusability and Constructability should be the drivers of modularity.
5) Big and medium size EPCM-projects with low level of project maturity. Modularity is limited because the owner has the right/obligation to take final decisions. If possible Pöyry need to convince the client that they choose a modular approach in construction. Actions that enhance the reusability in future should be adapted. Constructability should be the driver of modularity.

7.3.2 Foundation for modularity

In terms of Reusability of design being the main driver for modularity, the interviewees in the field of engineering work processes did not see it as being very straight forward in the case of Pöyry. The results indicated that foundational work should be conducted in terms of product structuring and evaluation of the existing design with the aim to identify the generic elements and the type of projects where these can be used. According to the interviewees modular approach in the foundational level requires senior management commitment and development budjet.

It was widely agreed among the interviewees that to reach modularity in design in terms of better reusability of existing design should require a universal standard for the Nomenclature which is a system of names or terms, or the rules for forming these. The system would facilitate the structuring of generic elements. The lack of universal standards and specifications in many areas hinders the modularization at the reusable design level. To clarify, one industrial plant consists about thousands of objects which have names and one change in nomenclature implies big amount of tailored work. Standardizing this would involve implementing and developing technical standards based on the consensus of all parties including firms, users, interest groups, standards organizations and governments. The interviewees take the KKS-standard as being an example of that type of standard. It was also noted that in the field of Pulp and Paper industry the naming of different plant departments can be seen to be followed allover in the projects but the naming of sub-processes and equipment remains individual and project specific. According to the interviewees currently, there are no generic internal standards inside the organizations of Pöyry. The interviewees doubt the possibilities to launch one naming standard that cover all industrial sectors. The aim within Pöyry should still be that the most common naming specification could be implemented. In practice it means setting the standard when naming the pumps and other equipment which then can be used in other instances to ensure that the same principals are followed in all the Projects that are conducted by Pöyry. To advocate its adoption and implementation among other project stakeholders, it was proposed that Pöyry could publish a system standard as open data on Pöyry’s web sites. The interviewees point out that the launching of guidelines and standards that support modularization is not enough to reach the targets. It should be even ensured that these standards are also implemented and followed worldwide at Pöyry. Nomenclature is named as one issue in Pöyry’s project specific check list for constructability review and analysis.

The interviewees point out that modularity in design requires evaluation and decision making related to appropriate engineering tools that supports integration. Integration would allow Pöyry to better utilize a readymade engineering and design work across organization borders in different projects. It was noted that reusability faces challenges that are related to different versions of software that have been used in past and in the technological development of 3D-plant design tools. The interviewees explain that the compatibility of different types of software requires that same standard is used and it might not be possible for the Pöyry to influence this. It was agreed among interviewees that an increased level standardization is key to reaching higher level of reusability of design.

Additionally it was noted that it might be necessary to launch a company standard that specifies the work process for a modular project and shows the principles of some details. The aim of this thesis work is to give good a starting point for the development of modular company standard by providing a framework for modularity guidelines. The interviewees suggest also that the company standards should specify how generic documents, specifications, typical and other generic lists should look like.

7.3.3 Product configuration system

In terms of reusability of design, the interviewees in the field of project tools and IT applications see that product configuration systems is not far from that reality where Pöyry operates even if this cannot be used so extensively in all types of projects. Storing of modular design was discussed in terms of establishing a master database with a web-based user interface that ensures fast and easy access to any information. According to the interviewees the master database should be established with aid of modern technology (i.e. Big Data tool and Machine Learning) to avoid the use human resources for updating and maintaining work. The interviewee sees that the use of special resources would cause risks in the long run that are related continuously updating and managing of the modular data and to the normal employee turnover. The development of modularization tools should aim to have an easy user-interface so that the managing and updating work could be done by ordinary engineers besides other operational project works. This would require organizational learning within Pöyry. It was pointed out by the interviewees that Big Data technology has taken huge steps forward during the last years. The interviewees in field of project applications see that Machine Learning and Big Data tool could help find reusable designs at Pöyry. Implementation of configuration systems would firstly require manual system standardization as explained in previous chapter.

7.3.4 Modularization Constructability studies

It was widely agreed among the interviewees that the primary aim of Modularization Constructability studies is to provide the best possible starting point for modularity in a project level. The opinions of interviewees are mainly aligned with the content of the Project Management guideline PM0. There was consensus among the interviewees that the constructability studies are in a crucial role when seeking answers to into what degree it makes sense to utilize modularity in the context of one distinct project. When reflecting content of PM0 to the statements of Hellström (2005, it becomes clear that modular guidance in PM0 focuses more on the constructability of plant than the reusability of existing design. The internal study of Pinnock et al. (2012) concluded that the ability to influence the outcome is relatively high in the beginning of the projects. Therefore also the aspects related to the reusability design should be taken into account at an early stage. The

interviewees gave a clear message that indicates that the reusability of design should be improved at Pöyry.
When reflecting these results to the statements of Blecker Abdelkafi (2006) and Hvam (2006), one can notice that Modularization Constructability study phase in a project can be seen to be as the Customer Decoupling Point, defined by Blecker and Abdelkafi (2006). Thus, in practice this might be the first and maybe also the best chance to lead the customer to select standard solutions instead of customized and specialized solutions. To calcify, in the case where the driver of modularity is the Reusability should the modularization constructability study advocate the reusability of existing design and this should be clearly articulated in PM0 document. Making of separate reusability study in an early phase of project should also be considered as an alternative.

The results indicate that drivers of modularity might differ depending on the project type, the industrial sector, and the scope of work. When reflecting these results to the statements of Pasian (2014) and Turner and Cochrane (1993), the project specific drivers of modularity should be defined during the Modularization Constructability studies by specialists from all engineering disciplines and a project categorization should be conducted based on maturity level.

It can be summarized that the idea and the opportunities of modular solutions should need to be declared to the client in early phase of collaboration in terms of better quality and increased efficiency and safety. This would facilitate the implementation of modular project and make the later engineering work more trivial. It was also seen to be important to present several options and setups of plants within the frames where the modular plant configurations provide i.e. a product configuration system development could be considered in future in the Pöyry. The decision /agreement made together with the client should steer the entire design towards selected module options.

7.3.5 Standards and specifications

The statements of interviewees are discussed in this chapter in the view of selected drivers of modularity because the empirical research shows that the project specific drivers have an impact on the actions that should be to be taken. The opinions of interviewees are mainly aligned with the content of the Project Management guideline PM0. The primary aim of modularization of standards and specifications is to limit the variety, provide needed input data for the other phases i.e. process engineering, procurement studies modular engineering and detailed engineering that takes place later, see the concept complexity reduction in figure 21. Standardization phase should further develop the generic design across boundaries of different projects that have been processes on the foundational level by product structuring tactics, explained in chapter 4. It can be summarized from statements of interviewees that when evaluating the appropriate standards for modular plant engineering with the reusability as a driver, these things that are listed below have to be taken in account:

- The business sector specific policies related to the standard

- The location of the plant and country specific policies related to the standards
- The existence of specification and standards

Laws of pressure vessels

When considering the legal issues related to laws of pressure vessels in the environment of country specific differences, the interviewees state that all projects need to be treated separately with an aim to fulfill the country specific laws and regulations. In the view at reusability of design and in order to decrease the variety and complexity of modular projects, it would be profitable to have both the PED and ASME approval for the designed pressure vessels, as it covers many countries. These country specific inspections and validations of pressure vessels are conducted mainly according to Pressure Equipment Directive (PED) that belongs to EN-standards or similar based on ASME-standards. The interviewees estimated that the PED covers over 50% of the worldwide market share in the field standards. The interviewee refers to statements European commission (2016) that defines the objective of PED. The objective of PED is to guaranty free movements of equipment in the internal market and ensuring high level of safety by providing guidelines and frameworks for commissioning. The interviewees point out that even in the context of repeatable projects there might be sometimes needs to select other standards. This makes it impossible to utilize existing design if standards are different.

Area specific seismic design parameters

In the context of reusability of design as a driver of modularity, the interviewee see that the impacts of the area specific seismic design parameters should be observed in the designing of generic modules. Categorization should provide guidance to the seismic considerations in relation to the siting of industrial plants into the areas of design and qualification. Input data for stress analysis might not differ in case of the small and low modules. The seismic categorization could come in question in case of high module structures e.g. reactors where the gravity point is at a higher level from the ground. It is obvious to meet safety requirements in some areas requires stronger or more flexible steel structures. The interviewees suggest implementing of an investigation that would find out an appropriate categorization system to avoid too high material costs. Interviewees suggest that the outcome of the investigation could provide guidance in order to specify the needed amount of different type of modules or reactors to cover the needs of different earthquake areas in the world.

Plant process specific generic lists

Reusability as a driver of modularity the interviewee suggest launching a generic valve lists that are specified related to plant process fluids. In comparison to the common valve specifications, the change in modular project approach is that it aims to increased reusability. To avoid struggling with the work processes in the modular engineering, Pöyry should launch such generic lists of valves and equipment that would be specified based on dimensional series standards instead of the accurate equipment supplier, see figure 24 below. This change can be seen a significant because it affect positively the reusability of existing design i.e. 3D-models and isometric piping drawings. This maneuver would give needed flexibility to Procurement and it implies that several suppliers can still supply the valve or equipment if it suits in in the asked dimensions. This would allow Pöyry to conduct a competitive bidding without changes orders and new revisions of drawings.

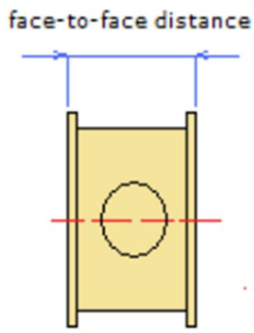

Figure 24. EN-558-1 Face-to-face Dimensional series.

Automation and electricity

It was noted that the complicity reduction and limitations in the field of automation standards and technology is more advanced work but still possible in comparison to mechanical e.g. steel structures and piping material. Frequency of new innovations in the process automation technology is namely much higher than in the field of mechanical equipment technology. In cases of Brownfield plants the automation field equipment need to share the same technology that is used overall in the plant. There are some country and industrial sector specific differences related to automation technology and electricity. Therefore the reusability of standardized options has to be based on evaluation of the appropriate automation technology to fit in this environment where the most of the project cases are located. The interviewee in the field of automation and electricity suggest that business sector specific market analysis should be conducted that seeks answers in questions that are related to the selection of most reusable automation technology.

Constructability as a driver of standardization

In cases were constructability is a driver of modularity, the standardization work should contribute to increased level of safety, fast delivery and easy mounting to its place on building site. There was consensus among the interviewees that that outline dimensions of modules should be standardized. The use of shipping container sizes was discussed and it was agreed that ISO 668 - Series 1 freight containers sizes could be a good starting point for modular design, see appendix 5. Decisions to freeze the module sizes need to be taken in Modular Constructability study phase. The modules need to be designed in the view at transport that means temporary supporting of equipment in side modules. According to statements of interviewee from shipbuilding industry, the standardizing and the recyclability of temporary supporting of the generic elements should be considered in some cases. Also the design of super modules should be standardized to meet the requirement that comes due capacities and dimensions of special vehicles that are developed to heavy equipment transport, see figure 25 below.

Figure 25. Super module transport (Pöyry Plc, 2016a).

7.3.6 Modularity in process systems

When considering modularity in the context of repeatability the interviewees suggest that modular process engineering should further develop the generic design across boundaries of different projects that have been processes on the foundational level by product structuring tactics, explained in chapter 4 of this thesis. Process engineering should provide the needed input data for procurement studies and modular engineering in form of generic datasheets and equipment lists that belong to the generic modules and sub-processes. Interviewees point out that Pöyry’s role in process engineering might differ depending on the project type and size. Thus, in practice, this mean that in a big EPCM-project the process engineering is usually controlled and conducted “on behalf” of the project owner. The ability to influence the outcome is relatively low in cases where the process core knowledge is owned and supplied by other external vendors. Therefore it is obvious that the natures of the project have an impact on the possibilities to develop repeatable and modular process systems. Evaluations have to be done case by case. Process engineering acts as input data for the automation and mechanical engineering and it takes place in the early phase of projects. The interviewees in the field of Automation and electrical engineering state that the possibilities to utilize repeatable solutions in in the field of process automation require project maturity. To clarify, it means that the plant processes need to remain the same in project after project. It was noted that one change in plant processes e.g. piping connection lead to further changes in process automation and increases the amount of tailored engineering. To summarize the results it can be stated that to could provide repeatable modular solutions in the field of automation, it requires concentrating to a limited number of automation technologies and “frozen” P&I-diagrams.

Constructability as a driver

When discussing Process engineering from the viewpoint of constructability it was noted that the P&I-diagrams give the coded names for all equipment. These naming codes are needed to be able to extract module specific part lists in the Detailed engineering phase. The module specific part lists are essential for material handling in cases of parallel module prefabrication where several engineering shops might be used.

7.3.7 Procurement studies

The statements of the interviewees are discussed here in the view of selected drivers of modularity. In order to increase the reusability of design, the primary aim of procurement studies is to check the availability of specified materials and auxiliary equipment that belong to the generic modules, see the concept in figure 23. Delivery time of auxiliary equipment might differ depending on the order stock of suppliers. As mentioned earlier, to allow procurement to conduct a competitive bidding without project change orders and new revisions and drawings, the generic lists of equipment and valves should be specified based on dimensional series, selected automation technology, and material standards that cover many countries. Procurement decisions are finally taken in agreement with the client and in the view of prevailing standards and specifications. Therefore the issues related to procurement should be taken into account already in the Modularization ‘constructability’ studies. The Procurement study is considering the availability of a limited variety of technology in the view of the project timeline.

The outcome of the procurement study should provide the needed information to evaluate the possibilities for the use of generic elements and ready-made modules in next phase of the modular project. The outcome of procurement study should also provide an indication of the amount of tailored engineering hours that need to be consumed later in the detailed engineering phase. In the modular design approach, the purchasing orders of the auxiliary equipment and materials take place at the end of Detailed engineering phase when work drawings and equipment lists can be exported from the design tools, even though the contract is made earlier.

Procurement and contract handling in modular construction

According to interviewees, the procurement and contract handling differ quite significant in modular construction in comparison to the traditional stick built construction method. Possibilities related to parallel module prefabrication close to the location of building site need to be checked in Constructability study phase. Trials of appropriate engineering shops and shipyards should be carried out. Launching of specific internal guidelines for contract handling in the view of wide scale prefabrication would be considered.

7.3.8 Modular engineering

The statements of interviewees are discussed in the view at the selected drivers of modular engineering because these have an impact on the practices and principles that should be followed. The primary aim of modular engineering is to ensure that it continuously contributes to an increased level of quality, fast delivery and fewer hours consumed in engineering.

Reusability as a driver

Modular engineering is developing and utilizing such generic design across boundaries of different projects that have been processes on the foundational level by product structuring tactics, explained in chapter 4 of this thesis work. The generic elements should be easily found from the master database and selected for reuse in new projects. To repeat, in a modular project approach, the modules should be designed to support easy transport and mounting. In the context of Pöyry, the interviewees define readymade generic design and design templates to be:

- Sub-processes of a plant
- Piping systems i.e. distribution manifolds,
- Typical pipe bridge frames
- Ventilation rooms
- Standalone departments
- Big modules (e.g. Towers that are 10 000 m3) can be transported to the site and assembled as one or two modules
- Tanks and hoppers

Constructability as a driver

The results of empirical study indicate that in cases of one-off projects when the driver of modularity is only constructability, the primary aim of modular design is to ensure that the outcome from the constructability study is captured and implemented in the design. Modular engineering should aim to fit the design inside these frames and dimensions that have been defined in Modular Constructability study phase or in the Standardization phase. In the context of the projects that are conducted by Pöyry, no clear consensus among the interviewed experts could be found when discussing the possibility to use modular construction approach when it comes to building the entire plant of various sizes of modules. This decision is project specific and comes from the constructability study. There was still a clear consensus among the interviewees that ship container size modules should be used as frames especially in the design of pipe bridge profiles, electrical rooms and smaller sub-processes that could be skid-mounted, tested and commissioned to the maximum extent before being sent to the site. To summarize the result, modular engineering means that modules are designed in the view of the information that is gathered trough the constructability study.

7.3.9 Detailed Engineering

The statements of interviewees are discussed in the view of selected drivers. When reflecting the result to the statements of Lehtonen et al. (2016), it becomes clear that current engineering work processes regarding the plant engineering project need to be reorganized and to be moved upfront if possible. To repeat, in a modular project approach the primary aim of the Detailed engineering phase is to fulfill the customer specific requirements by conducting these tailored work and the one-of-kind modules that remain after Modular engineering phase, se in figure 23. Secondly, the new validated design and the new modules that are designed in detailed engineering phase should be stored in the product configuration system or master data base in order for them to be ready for reuse in a new project. In the long run the amount of new modules would decrease due to continuously growing amount of stored design that has been processed by suturing tactics on the foundational level explained in chapter 4.9 of this paper.

The empirical research indicates that the overall level of modularity in terms of reusability might be generally quite low at Pöyry in comparison to the Cement Plant case of FL Smidth A/S, presented by Hvam (2006). According to the interviewees, the plant engineering at Pöyry in the context of big EPCM-projects means often BOP-engineering.

The modularization and standardization of the project work processes was seen as very important among the interviewees. Plant engineering project can be seen to as a production system that produces 10 000 documents in average per one industrial plant that are needed for permits, construction and in the operation. Struggling with the work processes affect the throughput time of the project and leads to failure demands, secondary needs that do not bring the core value that the customer asks for. In other words Pöyry is providing their expertise in form of tested and validated work processes to be used in their clients' project organizations in order to find together out the most cost efficient and best available technological solutions for their unique investment project.

It can be summarized from the statements of the interviewees that the amount of engineering works which are conducted in the Detailed engineering phase can vary depending on the drivers of modularity, industrial sector, scope of works, engineering discipline, project implementation method, project size and Project location. The iterative nature of the modular project approach decreases amount of tailored work. Furthermore, the implementation of a configuration matrix which classifies the generic elements to customer groups decreases the amount of detailed engineering in the long run and contributes to increased level of productivity.

7.3.10 Impacts of modularity to the level of productivity

This chapter aims to briefly clarify the impacts of modularity on the level of productivity. Firstly, the impact of modularity on the productivity of engineering in the context of plant design project conducted by Pöyry is discussed based on both literature review and the empirical research. Finally the impacts of Modular Construction to the level of Productivity based on both literature review and the findings of the empirical research concerning the Ship Building industry.

Partial productivity

As stated chapter 2.1 of this thesis the Partial Productivity in the context of engineering refers to the engineering hours which are consumed to produce drawings during a determined period of time. Bernolak (1997) defines, “If we produce more or better goods from the same resources, we increase productivity. Or if we produce the same goods from lesser resources, we also increase productivity”. There is a plausible link that modularity in terms of reusability of validated design increases the partial productivity of engineering. The impact of modularity on the partial productivity depend of the number of generic elements which can be used in a project. It was estimated by one interviewee that use of design template which consist of readymade and validated design i.e. generic element could reduce the engineering work of several weeks into lasting only couple of days.

Total productivity

It can be further interpreted based on the literature review of this thesis that the total productivity of modular in design depends on the number of generic elements that can be used in several projects, and also on the costs which come due to the foundational work i.e. product structuring, standardization, implementation and maintaining of master database. The impacts of modularity in design on the total productivity can be calculated by using PBBS benchmarking when assuming that the consumed engineering hours, produced drawings, cost of the foundational work and the number of projects that utilizes the generic elements are known during a determined period of time.

How to increase the profitability and performance

As stated chapter 2.1 of this paper, profitability can be defined as the ratio between revenue and cost while performance includes the overall economic and operational aspects. When the business logic of modular project approach (i.e. reusable generic elements, readymade modules and design templates) was discussed, a suggestion was provided by the interviewees. In order to increase the profitability the interviewee suggested that the generic elements should have their own WBS while the foundational modularization work should have its own PcBS and it should be linked to the business management system. Thus, in practice this means that the generic elements should imply a certain number of indicative engineering hours. When the designer reuses generic elements, the customers should be charged according to these indicative engineering hours instead of these exact hours which have been consumed for the re-use work. Making an agreement of fixed prize for the provided intellectual property could also be considered. However, this must be transparent to the customer i.e. based on open communication and acceptance made in advance with the customers.

The impacts of Modular construction to the productivity

The results of empirical research indicate that Modular construction have significant impacts on productivity in Shipbuilding Industry. Based on the literature review of this thesis it can be stated that the findings of empirical study are aligned with each other when it comes to considering the results related to the classification of construction work explained by Hellström (2005). Referring to statements of Modig and Åhlström (2012, 47), there is a plausible link between the Modular construction and the targets of Lean in the ship building projects because these aims to eliminate the waste and secondary needs of a production system. The interviewed interviewee from Shipbuilding industry explains that the ship construction has utilized the modular approach for a long time. In practice, the ship has been divided into bigger ship sections and smaller modules which can be built off-site or in engineering shops and to be finally transported to the construction basin of the shipyard. In the past the all works phases was conducted in the basin of a shipyard which it in the context of plant design concerns conditions are close to the same as in the stick built approach of construction. This meant that modular construction was not utilized in terms of off-site prefabrication of sections and modules. The interviewee explains that nowadays modular construction approach allows the ship building industry to achieve 2,5 times shorter throughput time in comparison to the traditional “stick built” approach in construction.

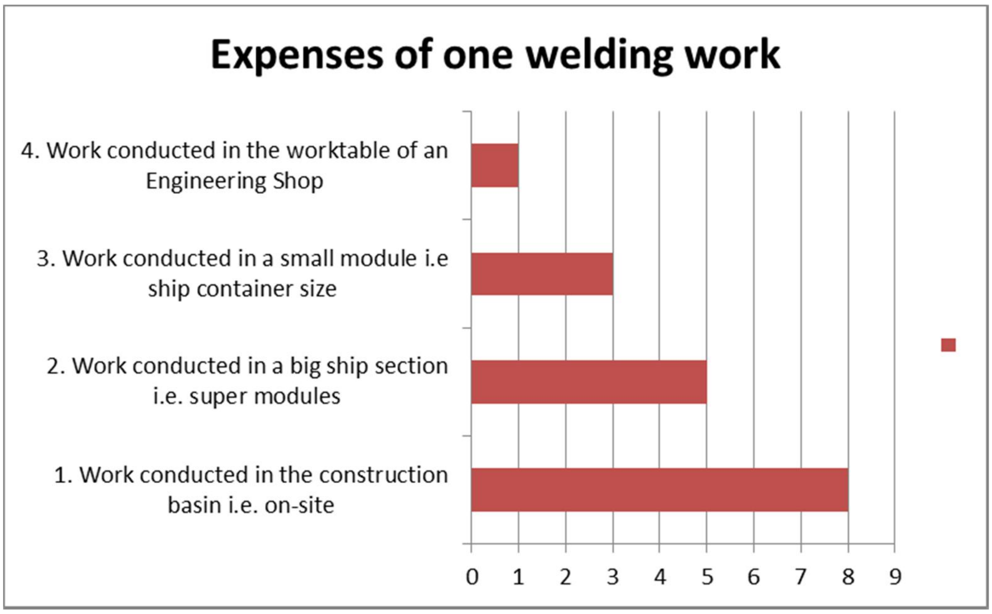

Table 3. The impact of different conditions to the expenses.

The table 3 above explains in a simplified manner the impact of different conditions to the expenses of conducted welding work in Ship building industry.

The bar 1 expresses work which is conducted in the basin of the shipyard. This might cause challenges for the employees to find the location where the work need to be performed and transporting of equipment e.g. welding apparats is also time consuming. The work might need scaffolding and permitting before it can be started and completed. The work can be seen to evoke lots of other secondary needs defined by Modig and

Åhlström (2012, 57), which don’t bring the value what the final customer asks for.

The bar 2 expresses work conducted in a big ship section i.e. super module and might need extra efforts to be competed. Thus it might need scaffolding which refers to difficult working positions/conditions where the work is performed.
The pillar 3 expresses work that is constructed and mounted to its place in a module. In other the working conditions are quite good whereas the working positions might not be ergonomic.

The bar 4 expresses work that is conducted in good and ergonomic conditions and which is performed on the work table of an engineering shop. These conditions can be only maintained with the help of advanced tools and equipment which can usually be found in engineering shops.

It can be summarized from the findings of the literature review and the results of the empirical research of this paper that construction works need to be classified in order to reach increased level of productivity. It can be further interpreted that although the table 5 presents the work expenses from Shipbuilding industry, the same type of classification is still relevant and adapted partly in the context of construction of an Industrial Plant. The class 4) includes type of precision demanding work i.e. welding and NDT-tests that should be conducted in engineering shops. The class 3) includes the module assembling works i.e. equipping of modules and pre-commissioning. The class 2) includes the super module assembling works. In other words these concern works such as interconnecting and placing of the small size modules to the super modules and pre-commissioning. Last class 4) includes works that can only be conducted in the site conditions or require a mechanical and electrical completion. In practice, these works concern the interconnections of super module on site, final commissioning and testing of e.g. automation technology that remains after pre-commissioning from earlier phases.

Work transfer

In the view of total productivity of construction the interviewees explain that there is room for improvements in the construction work practices. Thus it means in practice that these works which are conducted later in project execution phase can sometimes be moved to earlier phases. The interviewee explains that the monitoring and calculations conducted by in Ship building industry indicates that this kind of work transferring increases the productivity on the construction work by 20%-30% in average. The interviewee states that when considering the costs and time schedule pressure which the shipbuilding industry faces in the daily business, they have no other choices than the modular construction method.

The results of the empirical research shows that in the context of Pöyry such work transfer means that the more work will be transferred from the on-site conditions to off-site conditions, the more it reduces the overall cost. Thus, in practice this means that work transferring reduces the construction risk, the delays, the variation orders, the standby time, increases the quality and most importantly the safety. It was stated by the interviewees that modular construction increases the flow efficiency because it allow multiple trades working at the same time in same work areas. When reflect these results to the statements of Modig and Åhlström (2012, 37), one can notice that the modular approach in construction have a positive impacts on the Law of Bottlenecks. Thus, in practice this means that modular approach opens up work fronts in parallel that normally cannot be done during stick building. This also guarantees progress (i.e. process flow efficiency) when things do not go according the plan due to variation that have negative impacts.

7.3.11 Project Knowledge Capturing

It was clarified in the literature review of this thesis work that the project knowledge capturing is in an essential role when striving to reach higher level of productivity. When reflecting the results to the statements of Tan et al. (2007), it becomes clear that construction project knowledge capturing is important especially in maintaining of continuously development of engineering activities. It was suggested by the interviewees that Pöyry could have more representatives on site during the project execution phase to ensure efficient knowledge capturing and sharing. Enhanced communication and knowledge shearing between engineers that conduct construction management activities in different projects at Pöyry was also suggested.

It came up that Pöyry do not have any guided systematic approach for construction project knowledge capturing. The results of empirical research showed also that due to lack of time, the adaption of appropriate lessons learned practices to capture knowledge from al project organization levels was often ignored. It was stated that trying to capture lessons learned at the end of the project is too late. An effective knowledge management is team working and side by side working but this takes time. The challenge is to share knowledge over a short period of time. It is also hard to transfer knowledge to those who were not involved in earlier project. Also legal issues which being open might sometimes restricts knowledge sharing especially in cases when there are unresolved disputes. In practice it can mean that your own lessons learned can be used against you in court. It was agreed that the construction project knowledge capturing requires incorporates mechanisms to hasten the validation and the dissemination of the knowledge. To summarize the interviews, there are good intentions and hence promising prospects for improvement in the sharing project knowledge within Pöyry.

8 CONCLUSIONS

In this chapter the main findings of this Master's Thesis will be presented. Then an assessment of the limitations will be discussed and finally future implications of the study will be provided.

Main findings

This Master's Thesis concentrated to define the framework for modularity guidelines in project based business in certain industrial sectors. The primary aim for the modularity study was to explore appropriate methods for the productivity intervention in projects. Lean and PLM based strategic actions were selected. The values, principles, methods, and tools of Lean Management, that was examined, could also be defined to the circumstances where the Pöyry operated. The primary value found satisfy customers by delivering smart solutions through connected teams. The principles of JIT and Jidoka were considered reachable by utilizing the methods of modularity and knowledge management. The content of these methods framed the later research of this work.

This Master's Thesis showed that when considering the opportunities of modularity in project based business it is essential to define what the project type specific drivers of modularity are. From the view of Lean management literature it can be concluded that the constructability of an industrial plant and the reusability of design are essential drivers on modularity when striving to increase the project flow efficiency. These drivers can be seen to fulfill the value request of customers and at same time increase the level of productivity. Furthermore, the approach of Modular Construction can in most cases be utilized to at least some extent regardless the type of project. The interviewees gave a clear message that indicates that the reusability of design should be improved at Pöyry. All in all, the iterative nature of modular project approach increases the level of productivity of plant engineering projects in the long run.

The empirical research examined the impact of modularity to the customer project lifecycle and showed that the variety of different types of projects conducted by Pöyry makes it difficult to provide one solution to cover all the possibilities to utilize modularity. Thus, it is important to conduct project categorization and define the project type specific drivers of modularity. In addition, it can be stated that features of modularity can be utilized most comprehensively in small size EPC-projects. Master’s Thesis provided concept for complexity reduction that shows the causalities of the different phases of modular project approach. Detailed information was provided in order to give guidance when considering modularity from the views of constructability and reusability.

To summarize the results of this thesis work that, the increased standardization and product structuring tactics are in key position move to towards modularity on all levels. Therefore, when it comes to standardization, it should be based on dimensional series instead of accurate supplier dimensions, Pöyry should emphasize limited types of automation technologies and flexible designs. This would allow the procurement to conduct a competitive bidding without changes orders or new revisions of drawings when striving to increase the reusability of design. Frequency of new innovations in the process automation technology is namely much higher than in the field of mechanical equipment technology. High frequency and new innovations might be a barrier for modularity in terms of reusability as a driver. However, some industrial sectors that are more conservative in adaption of new technologies are seen as exceptions here.

The results of this paper allow one to assume that the answers to the questions which lead the organization to tomorrow's success are often likely to be found in the organization itself. The interpretivist perspective of knowledge management was seen essential when seeking these answers. When optimizing and developing a modular construction concept in pilot projects, Tan et al. (2007) underlines the importance of the model of “construction project knowledge live capturing”. However in terms of modularity Pöyry should need to establish the knowledge capturing. The empirical research showed that due to lack of time, the adaption of appropriate lessons learned practices to capture knowledge from al project organization levels was often ignored. When evaluating the results from a functional perspective of knowledge management, the reusability of the existing design could be enhanced in future with the help of Big Data and Machine Learning to avoid the use human resources.

As final conclusion it can be stated that modular project approach can be seen to partly challenging the traditional way of thinking at Pöyry. In addition, Pöyry is conducting EPCM services in some industrial sectors by providing tailored BOP engineering i.e. project optimizing, interconnecting of modularized equipment supplied by external vendors in “one-of-kind” type of Projects. It is important to note that Pöyry conducts projects also in many other industries where this is not the case and therefore modularity could be a differentiation factor that helps Pöyry to win projects they currently lose. Despite some experts’ doubts, the results of this paper show that the modular methods can still be utilized to some extent in most cases. To benefit from the possible gains of reusability and constructability, a new way thinking is required as well as team work by all engineering disciplines within Pöyry. It became clear that the modular project approach implies one step away from the traditional tailoring.

Limitations of the study

This Master’s Thesis was focusing on the constructability and reusability drivers of modularity. Thus the serviceability recyclability was mainly excluded.

Future research topics

From the base of this research a couple of suggestions for future research can be made:

This Master’s Thesis examined the modularity from a quite broad perspective. To adapt modularity in terms of reusability would require further investigations related to IT applications, Big Data and Machine learning.

Additionally there might be room for a business sector specific market analysis that would evaluate the generic market trends, needs and the generic customer requirements that would serve the modular design approach.

In the view of development of an automated productivity measurement it might be room for future research that examines the possibilities of OEE, (Overall Equipment Effectiveness) in the context engineering companies.

To adapt modular features in a project of the Pöyry, further internal investigations and developments projects should be done that examines the company specific product structuring tactic and the configuration knowledge matrix

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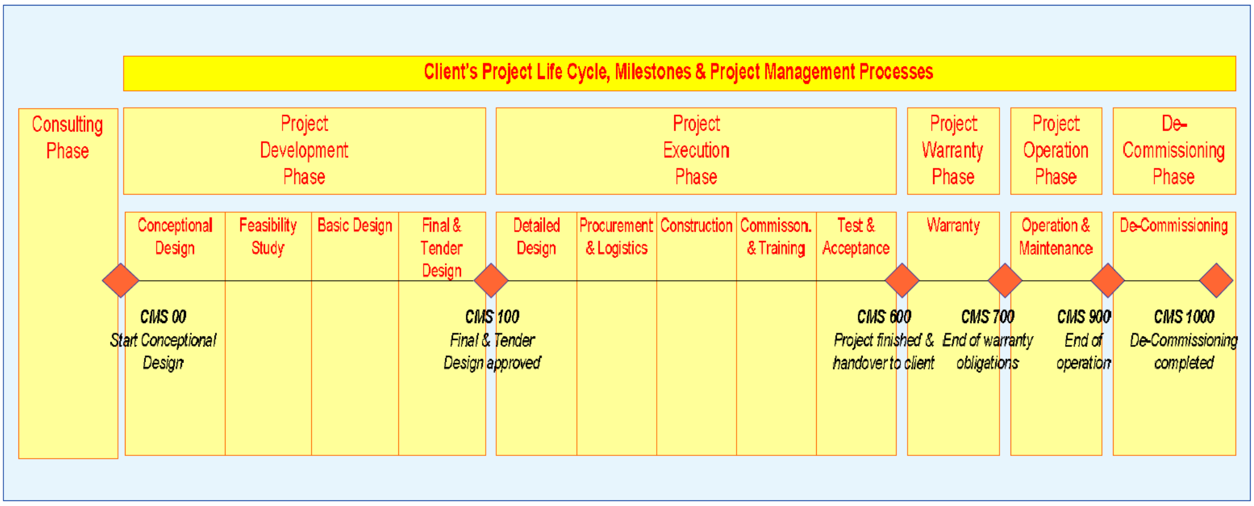
LIST OF INTERVIEWEES

Representatives	**Company, Title, Location**
Bachofen, Andy	Pöyry Plc: Senior Project Manager, Thermal Staff CH - Zurich
Kaila, Hanna-Maria	Pöyry Plc: Vice President, Global Procurement, Project Managers, CA - Montreal
Jaaskelainen, Heikki	Pöyry Plc: Director, Electrical & Automation, Pulp and Paper, FIN - Helsinki
Peltopuro, Jani	Pöyry Plc: Director, Mechanical & Piping, Chemicals and Biorefining, FIN - Helsinki
Paasonen, Jorma	Pöyry Plc: Senior Project Control Manager, Industry Project Mgmt. Serv., FIN - Helsinki
Kovanen, Kovanen	Pöyry Plc: Senior Vice President, Energy Projects, Project Mgmt., FIN - Helsinki
Mäkinen, Mika	Meyer Turku Plc: Head of Department, Standards and Design Solutions, FIN - Turku
Leinonen, Silvo	Pöyry Plc: Senior Advisor. Mechanical Engineering, Pulp and Paper Finland, FIN - Helsinki
Olsen, Theresa Anne	Pöyry Plc: External - Vice President Global Construction Management, Global Sales and Project Management, LPCC, CA - Montreal
Syrjanen, Timo	Chief Architect, Engineering Systems, Industry Technology Services, FIN - Helsinki

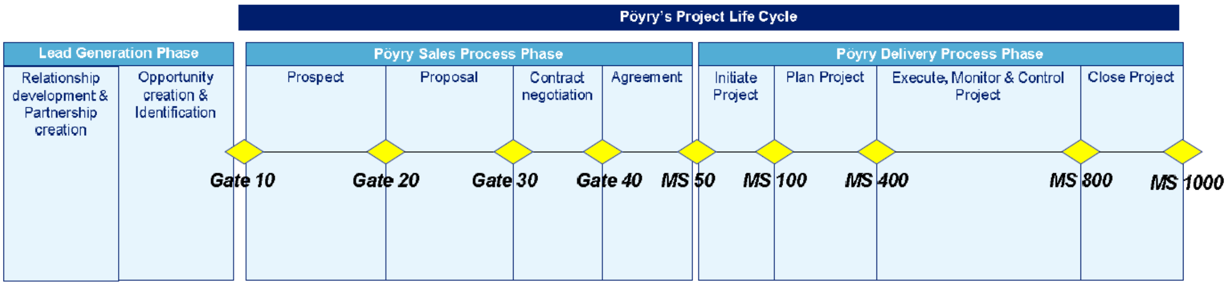
Appendix 1. PM 001, Clients project life cycle (Pöyry, 2015).



Client Project Life Cycle can be divided into five major phases:

1. **Project Development Phase:** The feasibility of the project is analysed and a pre-design and basic design is established. This should be established in conjunction with the client's business case for the total project. The project development phase outlines the project's economic value, taking into consideration constraints, such as environmental impact, sustainability and technical issues. The project development phase ends in final and tender design.
2. **Project Execution Phase:** The actual product/facility is designed,procured, constructed, tested, commissioned and handed over to the client.
3. **Project Warranty Phase:** During this phase, warranty issues are handled with the various contractors and suppliers if and as they occur.
4. **Project Operation Phase:** The Client is fully responsible for the facility, however, an O&M service provider may manage the operations under an operation and maintenance management contract.
5. **De-commissioning Phase:** The facility is taken out of production and eventually dismantled or sold.

Appendix 2. Pöyry’s project life cycle (Pöyry, 2015).



Gates are specific decision points where a formal decision is taken to continue into the next phase or not by a clear defined approval matrix and project categorisation.

Milestones (MS) are defined as having achieved a specific state, e.g. all planning activities are done and a Project Management Plan has been issued and agreed. A milestone does not in itself require any duration or take any resources, but the activities leading up to it do.

Appendix 3. Pöyry’s project guidelines (Pöyry, 2016).

References to Pöyry PM Guidelines

PM 0 **-** Constructability Study Guidelines and Definitions

PM 002 - Service Types

PM 003 - Project Contract Management

PM 004 - Integration and Control Management

PM 005 - Scope Management

PM 006 - Time Management

PM 007 - Financial Performance Management

PM 008 - Quality Management

PM 009 - Project Human Resource Management

PM 010 - Communication and Reporting Management

PM 011 - Risk and Opportunity Management

PM 012 - Project Closure Management

PM 013 - Engineering Management

PM 014 - Procurement Management

PM 015 - Construction Management

PM 016 - Commissioning Management

PM 017 - Test and Acceptance Management

PM 018 - HSE and Security Management

PM 019 - Training Management

PM 020 - Warranty Management

PM 021 - Project IT Management

Appendix 4. Key engineering concepts (Lehtonen et al., 2016).

> “The goal of these steps is to define design information that relates to the suggested key engineering concepts in designing of a modular product family that supports product configuration”. (Lehtonen et al., 2016.).

1. Manual definition of the Company Strategic Landscape
2. Manual planning applying the generic element definitions of Generic element model of the module system.
3. Manual definition of architecture of generic elements and interfaces.
4. Target setting based on customer environment through Manual definition that finds out customer needs from the variety perspective.
5. Preliminary product family description Manual definition using the modified Product Family Master Plan.
6. Configuration knowledge: generic elements and customer needs Manual definition using the modified K-Matrix.
7. Modular architecture: modules and interfaces Manual definition applying the principles of partly configurable product structure, space reservations and interface standardisation
8. Configuration knowledge: module variants and customer needs Manual definition using the modified K-Matrix
9. Product family documentation Manual description using the Product Structuring Blue Print
10. Business impact analysis Manual estimation using the BIA approach

Appendix 5. ISO 668 - Series 1 freight containers — Classification, dimensions and ratings:

ISO designation *	Common Name	External dimensions			Minimum internal dimensions			Maximum Gross Mass
		Length	Height	Width	Length	Height	Width	
1B	30 foot	9.125 m / 29' 11.25"	2.438 m / 8' 0"	2.438 m / 8' 0"	8.931 m (29' 3.6")	2.197 m (7' 2.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs ***
1BBB	30 foot high cube	9.125 m / 29' 11.25"	2.896 m / 9' 6"	2.438 m / 8' 0"	8.931 m (29' 3.6")	2.655 m (8' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs ***
1BB	30 foot standard	9.125 m / 29' 11.25"	2.591 m / 8' 6"	2.438 m / 8' 0"	8.931 m (29' 3.6")	2.350 m (7' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs ***
1C	20 foot	6.058 m / 19' 10.5"	2.438 m / 8' 0"	2.438 m / 8' 0"	5.867 m (19' 3")	2.197 m (7' 2.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs ***
1CC	20 foot standard	6.058 m / 19' 10.5"	2.591 m / 8' 6"	2.438 m / 8' 0"	5.867 m (19' 3")	2.350 m (7' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs ***
1D	10 foot	2.991 m / 9' 9.75"	2.438 m / 8' 0"	2.438 m / 8' 0"	2.802 m (9' 2.3")	2.197 m (7' 2.5")	2.330 m (7' 7.73")	10160 kg / 22400 lbs
1EEE **	45 foot high cube	13.716 m / 45' 0"	2.896 m / 9' 6"	2.438 m / 8' 0"	13.542 m (44' 5.15")	2.655 m (8' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs
1EE **	45 foot standard	13.716 m / 45' 0"	2.591 m / 8' 6"	2.438 m / 8' 0"	13.542 m (44' 5.15")	2.350 m (7' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs
1A	40 foot	12.192 m / 40' 0"	2.438 m / 8' 0"	2.438 m / 8' 0"	11.998 m (39' 4.375")	2.197 m (7' 2.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs
1AAA	40 foot high cube	12.192 m / 40' 0"	2.896 m / 9' 6"	2.438 m / 8' 0"	11.998 m (39' 4.375")	2.655 m (8' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs
1AA	40 foot standard	12.192 m / 40' 0"	2.591 m / 8' 6"	2.438 m / 8' 0"	11.998 m (39' 4.375")	2.350 m (7' 8.5")	2.330 m (7' 7.73")	30480kg / 67200 lbs
1E ****	6½ foot	1.968 m / 6' 5.5"	2.438 m / 8' 0"	2.438 m / 8' 0"		2.197 m (7' 2.5")	2.330 m (7' 7.73")	7110 kg / 15700 lbs
1F ****	5 foot	1.460 m / 4' 9.5"	2.438 m / 8' 0"	2.438 m / 8' 0"		2.197 m (7' 2.5")	2.330 m (7' 7.73")	5080 kg / 11200 lbs

**** Six and a half and five foot containers (type 1E and 1F) are not in the current edition ISO 668 standard, but were standardised in previous editions,[3] and are still manufactured.[4]
The so-called *width* of these small-size containers may be perceived as their *length*, as it is their greatest horizontal dimension, and their doors are typically in the short end(s).

*** The maximum gross mass rating of twenty and thirty foot units was updated with Amendment 1 of 2005.[1] Until then, the MGW for 20-ft units was 24,000 kg / 52,900 lbs, and for 30-ft units 25,400 kg / 56,000 lbs.

** Forty-five foot containers were added to the standard per Amendment 2 of 2005.[2]

* The standard also recognises containers less than 8 feet in height, under the designations **1AX**, **1BX**, **1CX** and **1DX**, with specifications the same as other containers of their length.

Appendix 6. Interview questions 1-57:

1. What key decisions need to be made differently, and when, in order to increase modularity in projects? (Eg purchasing, design freeze, implementation method)

2. Figure below provides suggestion of main steps toward modularity in plant design, do you agree or not? If not how would you change it?

3. How to facilitate the way toward modularity in project planning and constructability study level?

4. Modular construction ideally leads to project costs savings – either through faster implementation, reduced site man-hours, increased quality etc. How to assess the benefits of modular construction and how should it be declared to the client? What would be the affect of decisions to utilize modularity in one off projects vs repeat projects? Eg would we need additional engineering hours / materials in a one off project in order to achieve the modular time schedule?

5. The effect of modularity on the time schedule and are there needs for timing of certain decision making that is needed for a modular approach?
6. What kind of categorization could be used when evaluating of factors that have impacts on the ability to utilize modularity and reusability in project?

Appendix 6 (cont'd)

7. What key questions need to be asked at what decision points? – What is the order of the questions that then define the approach e.g.:
   - location
   - infrastructure at location
   - resource availability at location
   - investment value – e.g. is it worth chartering own ship with super module? Etc.

8. In cases of smaller EPC projects, the modular design can be seen to decrease the total timeline of project development phase. Do you agree with this and what are your opinion of risk factors that should be taken in account when utilizing modularity?

9. How to decide when to use super modules constructed on / off site or then container based approach, or another modular approach?

10. How to decide how many disciplines are pre constructed/pre erected in modules – e.g. only equipment and steel structures or total MEI?

11. How to facilitate the way toward modularity in process engineering level?

12. Could we provide P&I-Diagrams with limited set of processes alternatives in cases of smaller EPC projects? (e. g. different capacities, operational costs and energy consumption)

13. Could we make plant process specific generic specifications that specify the naming of process equipment, process fluids, pipelines and plant departments?

Appendix 6 (cont'd)

14. Could we prepare generic list of process equipment with dada sheets?

15. Would it be possible to shape smaller subsystems of the complex plant process system so that those could be built assembled, tested to reduce commissioning works?

16. Considering the complete project – what scope of engineering work does Pöyry need in order to design for modular implementation e.g. do we need to control engineering for all discipline for all areas of the plant?

17. How could we benefit from recyclability of physical processes and products?

18. Could sub-processes be designed as modules such that they can be relocated after a plant is shut down – which ones?

19. What are the things that can be done to reduce complexity and facilitate the way toward modularity in the view at standard and specifications?

20. How to enchase the reusability of technical specifications and standards in the environment of country specific differences?

21. Could we use limited set standard alternatives? (E.g. ASME and EN-standards)

22. How to tackle the legal issues related to laws of pressure vessels in environment of country specific differences to decrease the variety and complexity

Appendix 6 (cont’d)

23. How to observe the impacts of area specific seismic design parameters when designing of generic modules? The input data for

24. stress analysis might different. Is there need for seismic categorization for module structures?

25. Could it be possible to make (plant process specific) generic lists of hand valves with limited options?

26. Could it be possible to make a generic tank and insulation specification for tanks and process fluids?

27. How to facilitate the way toward modularity on the level of basic engineering and pre-design? (Repeat projects versus one off projects)

28. Could we define limited set of standard alternatives of module platforms? (e.g. truckable modules, ship container size modules and super modules)

29. Should we aim to provide a limited set of alternative plant layouts in cases of smaller EPC projects?

30. Limited types of module interfaces and connection methods – eg how to decide if modules should be fully pre-constructed with all disciplines - steel structure, equipment, piping, electrical etc. or steel structure and equipment only?

31. What kind of module interfaces support recyclability of sub-processes and modules (all engineering disciplines)?

Appendix 6 (cont'd)

32. Should we need Engineering tool that allows extracting of module specific material lists? (Modules can be parallel manufactured in several shipyards). should We should consider to selection of appropriate 3D plant design software to facilitate the modularization and constructability (ability to evaluate the module weight)

33. Evaluating of the optimal time to export work drawings and specifications. Evaluating the possibilities to use of existing stress analysis of pipes and steel structures of modules?

34. Could we make a generic process equipment lists and automation valve lists to facilitate the reuse of design?

35. Could we classify the modules already in basic engineering phase in the view at constructability to reduce variations in one production line?

36. What is your opinion about possibilities to utilize shipping container building philosophy in plant design?

37. How to facilitate the way toward modularity by developing of existing product data management systems?

38. How could modular business processes be supported with a product configuration system?

39. How to enhance the direction of customers in sales phase towards the preferred standard and modularized solutions that are defined during the complexity reduction steps , 2, 3, 4 and ? (E.g. selling small repeatable EPC projects)

40. What are the current possibilities to use existing product data management systems to store and reuse of standadised and modular

Appendix 6 (cont'd)

41. solutions (Existing systems means here 3D plant models and Sharepoint or Dochotel)?

42. Would modularity mean increased engineering and material costs in one off projects that are not repeatable?

43. Would it be reasonable to conduct generic causality analysis of things what can be changed and what cannot be changed to avoid unpredictable changes and to decrease the workload in detailed engineering phase?

44. Would it be necessary to provide learning for Marketing and Sales department to get understanding of how different kind of changes affect the workload in detailed and tailored engineering processes ?

45. When should the detailed drawings be extracted and stress analysis calculated in cases of repeatable modular EPC projects. Could it be possible to utilize existing calculations and work drawings?

46. How to make a such modular generic plant 3D-model that the selected module sizes can easily be converted out from the model?

47. Pöyry are mostly doing EPCM type of projects in many business sectors where the role are different than in smaller EPC type of projects. Could we seek collaboration and partnership with clients (E.g Kemira, Omya, Outotec) that are selling EPC type project to their end clients and provide them modular plant design?

48. How to minimize the number of unpredicted changes in module prefabrication and modular construction?

Appendix 6 (cont’d)

49. What are the appropriate work routines to avoid unreasonable interruptions in work?

50. How to get optimal flow of plant modules to the building site?

51. What are the appropriate work routines to enhance the modular construction and prefabrication of modules?

52. Identify and list works that can only be done after the assembly in building site phase?

53. Should parallel module construction need additional general guidelines that are related to appropriate methods of sourcing and contract handling?

54. How to utilize the cellular manufacturing in module prefabrication and modular construction?

55. How to increase the module prefabrication speed and the level of quality?

56. How to arrange the development and monitoring of bottlenecks to achieve continuously improvement in flow efficiency?

57. How to capture, store, and use lessons learned in order for the organization to move into modular implementation?

58. The possibilities to utilize existing Web-based knowledge base e.g. Sharepoint and Doc-hotel as tool for integrated workflow system and knowledge capturing in modular construction projects?

59. What are the impact of modular plant construction concept and how differentiates it from normal stick built concept in the view at: