Master Thesis

Time, Cost, and Quality Impact of Modularization on Alstom Combined Cycle Power Plant (CCPP) Projects

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Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, 27.01.2014 ALEV BOYRAZ

Abstract

Modular Product Architectures are being used in different sectors in order to customize the products according to the customer needs with lower costs and with shorter response times. Modularization is seen as a bridge between mass production and mass customization, which has the ability to focus on economies of scope as well as the economies of scale. Many companies are benefiting from this innovative production concept which has brought great flexibility to the manufacturing processes, while also enabling them to gain customer satisfaction and stay competitive on the market.

Like in many other sectors, also in power generation sector, modules are being used as well to reduce the costs and to shorten the lead time of a product or project.

However, it should stay in mind that modularization of a power plant might carry a different meaning than the modular production in literature.

This research will focus on the modularization concept in the combined cycle gas fired power plant projects of Alstom Power. Modules are used in the Power Island of the combined cycle power plants, and they are expected to bring significant benefits to the company in terms of cost reduction, increase of probability to achieve the target lead time of the projects and increase the quality.

When the idea of modularization first rose, the main objectives of Alstom Power were to improve the productivity to avoid the project delays, to reduce the reworks on site, to reduce the complexity of the works and to assure that the highest quality is achieved by shifting the man-hours from site to shop. Today, it is also about reducing the costs of the projects, since the market is getting more aggressive, prices are dropping down more and more and it is getting hard to stay competitive.

All those initial objectives and also the aim to reduce the costs pushed modular installation concepts. Number of modules from the first time they have been used to today have increased from three to eleven and these modules need an intensive evaluation in terms of man-hours reduction on site, cost impact and quality. This research is done to prove that modular installation shortens the project lead times of Alstom combined cycle power plants, improves the quality and even though they might be more expensive, it is less risky and a more robust way to pre-fabricate modules instead of a stick built solution.

Abbreviations

ADV	Atmospheric Drain Vessel
BDT	Blow Down Tank
BoP	Balance of Plant
CCGT	Combined Cycle Gas Turbine
CCPP	Combined Cycle Power Plant
CCW	Closed Cooling Water
EHS	Environmental Health and Safety
EJ	Ejector Skid Area
EPC	Engineering, Procurement, Construction
ERS	Experience Response System
FF	First Fire
FWT	Feed Water Tower
GT	Gas Turbine
HRSG	Heat Recovery Steam Generator
LTR	Lead Time Reduction
MCT	Main Cable Tray
MCW	Main Cooling Water
MPR	Main Pipe Rack
NCR	Non Conformance Report
NG	Natural Gas System
NTP	Notice to Proceed
OTC-CV	Once Through Cooler – Control Valves
PAC	Provisional Acceptance Letter
PI	Power Island
PT	Power Train
RoP	Rest of Plant
RR	Reliability Run
SPR	Small Pipe Rack
ST	Steam Turbine
WSC	Water Steam Cycle

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1 Introduction

Companies within power sector, like the ones in other sectors, are also faced with the challenge of reducing production costs as well as project lead times. Decades ago it was much easier for the companies to stay competitive with high quality and relatively higher prices, however, today customers of this complex and highly important projects are seeking for lower prices.

It is essential for the companies to lower their production costs, and shorten the project lead times -as less time spent on site leads to huge cost savings- while also not ignoring the quality and safety. Due to high costs on site, timely delivery of a power plant project is highly important.

Nowadays, Alstom Thermal Power is faced with low-cost production of the Asian market as well as of the European competitors. Alstom Power aims to reduce the costs on one side via technical developments on, for instance, machining processes and design renovations etc. and on the other hand via increasing the robustness of project lead times.

Statistics of the last Combined Cycle Gas Turbine turnkey projects show that the company could never achieve its 22 months schedule, which was planned; moreover, the projects lasted much longer than the market requirements. Late completion of a power project can have various reasons; these reasons can be either project specific or country specific. As the project specific issues highly depend on the customer and sub-contractors, which are different in almost every project; it is difficult to find standardized solutions or precautions to eliminate them for the next projects.

On the other hand, country specific issues can be estimated according to the previous project experiences or with detailed researches about the conditions and regulations of the project country.

However, if the construction works done on site are reduced, these possible issues of both categories will incrementally reduce as well.

Modularization came up as an innovative solution, which thought to be contributed to both, cost reduction and timely delivery of Combined Cycle Power Plant (CCPP) turnkey projects. The idea is to spend as less time as possible on site, to increase the productivity, to reduce various risks, to increase the quality, to avoid the subcontractor issues, and so on. For that reason, man-hours are shifted from site to shop; components are pre-assembled in a workshop and finished parts of the power plant are transported from workshop to site via air, road or sea transport depending on the module sizes.

In this research, firstly, there will be a literature review about the history of manufacturing and todays manufacturing strategies, the raising need of modular production and modularization in construction sector. After the literature review, there will be an assessment of modules in Alstom Power and their effects on construction works in terms of time reduction on site, cost, productivity and quality.

1.1 Objectives

The goal of this research is to give a broad description about the modular installation concept in combined cycle gas fired (CCGT) power plants of Alstom Thermal Power.

The company has started to pre-fabricate modules for the several sections of the power plant. Instead of building the whole plant on site, some sections are pre-fabricated in a workshop in order to reduce the site activities and shift the man-hours from site to a workshop. Module construction is done by another company and Alstom transports the finished modules from the workshop to the site.

Modularization of the power plant is thought to bring several benefits for the execution of the combined cycle power plant full EPC (Engineering, Procurement and Construction) projects. During an EPC project, Alstom Power does the engineering, procurement and commissioning works and makes an agreement with one or several other companies for the construction works. These companies who undertake the construction works will be called as ‘contractor’ or ‘sub-contractor’ further on this research, since for Alstom Power they are simply the contractors, while for the client Alstom is a contractor and these companies who undertake the construction works are the sub-contractors.

During the construction activities of the contractors on site, Alstom Power supervises them and steers their works with the experienced engineers. Depending on the project location, there might be a shortage of experienced people for the construction works. In that case the contractors need more observations and there are more reworks occurred on site which leads to the time loss. This is one of the reasons that reducing the construction activities on site will also reduce the time loss and risks.

The concept of modular installation in Alstom Power started mainly with the purpose of having fewer interfaces with the contractors, avoiding poor work of the unexperienced contractors and thus having a better quality in a more controlled environment than on site.

Modules are also expected to reduce the costs, since there will be less reworks, better productivity and less expensive labour than on site. These factors also avoid the time loss and increase the probability to meet with the estimated lead time of the project.

This research aims to assess the modular concept in Alstom Power with the data of the currently available modules. Firstly, the past turnkey projects are assessed in order to have an idea about the current situation of the company in relation with the theoretical schedule of the EPC projects. This evaluation of the past EPC projects is expected to show if the company really needs such a new concept. Then the currently available modules will be assessed in terms of man-hours, to find a statement if the man-hours reduced on site are enough to reduce the project duration in order to meet with the target project duration of the company for the Combined Cycle Gas Turbine (CCGT) turnkey projects.

Modules might be more expensive than the stick built solution in some countries, however, it might be still worthy to modularise the plant to benefit from the time and risk reduction on site. If the benefits of shifting the works from site to shop are compensating the possible cost increase, modular concept is still worthy to build.

1.2 Scope

Scope of the research is KA26-1 (KA26-SS) full EPC (Engineering, Procurement, and Construction) projects.

KA26-1 is used to show combined cycle gas (natural gas) fired single shaft power plant configuration. The abbreviation ‘KA’ stands for ‘Kombi Anlage’, which is the German translation for ‘Combined Cycle’.

‘26’ indicates Alstom Gas Turbine type ‘GT26’, which has a sequential combustion and more than 60% efficiency with gross electrical output of 326MW.

‘-1’ or ‘SS’ are used to show that the plant has single shaft configuration, which means one generator is used for both steam turbine and gas turbine.

This research is focused on Mechanical & Electrical Erection works of Alstom KA26-1 projects and also effects of modularization on commissioning works are taken into consideration. Material procurement phases as well as the civil construction works are excluded.

Power plant is mainly divided into two parts which are called 'Power Island (PI)' and 'Rest of Plant (RoP)'.
This research excludes the Rest of Plant equipment and works; and focuses on Power Island erection and commissioning works.

1.3 The Alstom Group

Chaired by Patrick KRON, Alstom is a world leader in rail transport and energy infrastructure. The company is composed of four sectors, Alstom Transport, Alstom Grid, Alstom Thermal Power and Alstom Renewable Power with the following activities; power generation, power transmission and rail transport. It is present in close to 100 countries and employs more than 93'000 people. According to the 2012/2013 financial year the sales of the company is 20.3 billion Euros and the order intake is 23.8 billion Euros.[1]
Figure 1 shows the sales of each sector for the 2012-2013 financial years.

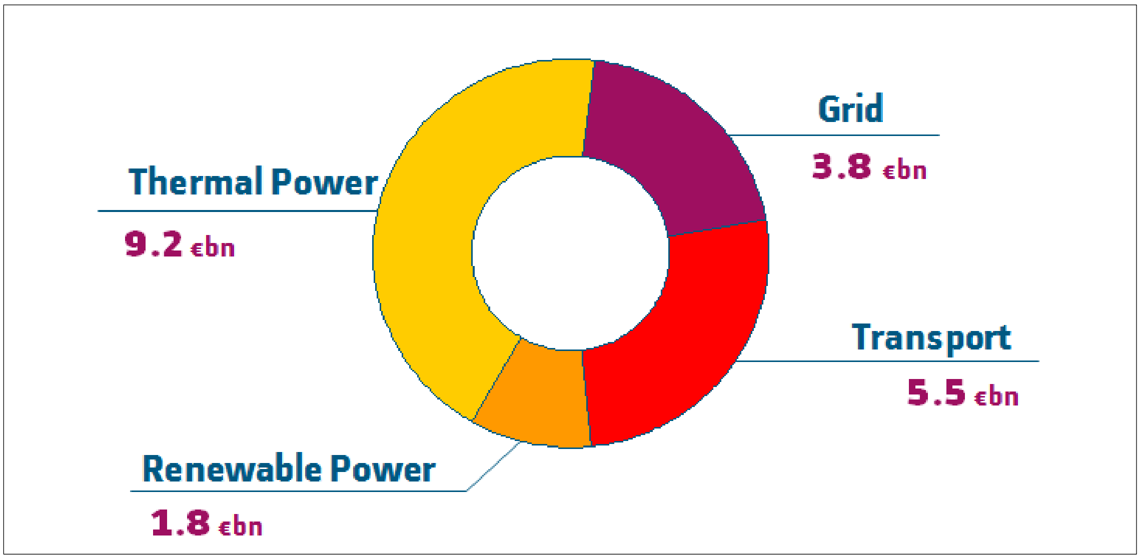

Figure 1: Alstom Group Sales 2012/13, 20.3 € bn[2]

Figure 2 shows the solutions that Alstom Thermal Power offers for its customers:

- Steam, Gas & Nuclear Power Islands,
- Steam, Gas & Nuclear Turnkey Solutions

[1] Alstom (2011), p.3

[2] Alstom (2013), p.5

- Steam, Gas & Nuclear products - all major plant components are in-house equipment
- Power Automation & Controls Products
- Thermal Services - a complete portfolio from maintenance to performance improvement

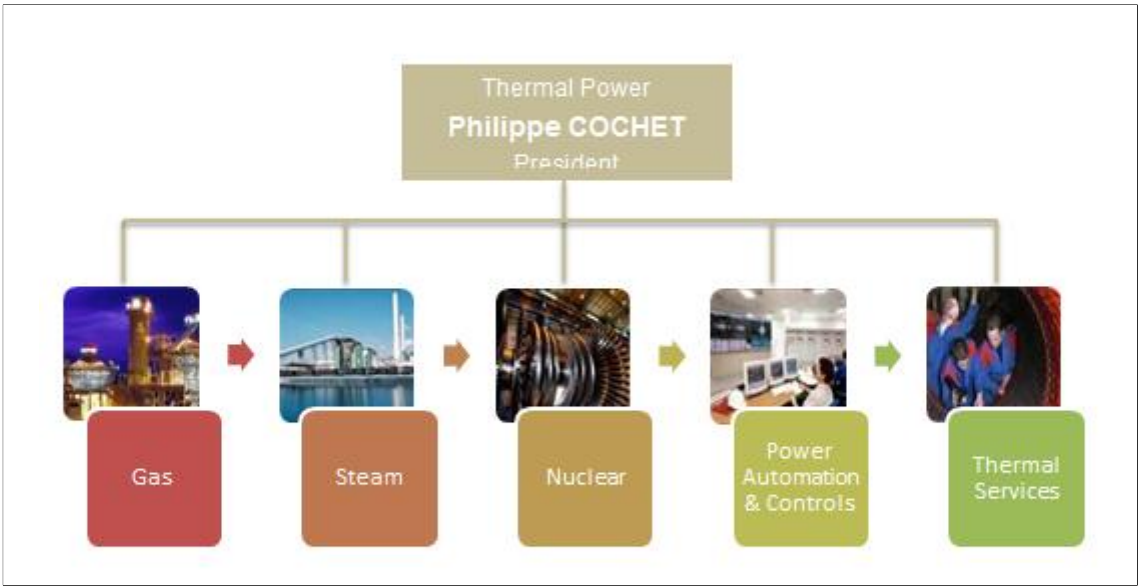

Figure 2: Alstom Thermal Power Sector[3]

Alstom Thermal Power has the leader position in the market with its: [4]

- combined-cycle power plants,
- energy production services,
- environmental control systems.

1.4 Initial Situation

Alstom used modules in Power Island first time on a large scale in 2009 in the UK project named ‘Pembroke’. The main objective of the company modularizing the Power Island is to meet the overall target project duration, since the past projects of the company lasted longer than expected because of several reasons.

In theory the project duration of a full EPC Alstom KA26-1 plant is 2+22+2 months. The 2 months in the beginning is for pre-engineering and the 2 months

[3] Alstom (2013), p.22

[4] Alstom (2013), p.4

at the end is the allowance for project float. However, this 22 months schedule has never been achieved so far.
Average duration of the last 10 projects, in total 20 units (a unit consists of a gas turbine, a steam turbine and a generator) was over 30 months which also exceeds the market requirement. The best achieved duration of a unit was 24 months.
Late delivery of a project obliges the company to pay 'liquidated damage', which is calculated according to the electricity price of the project country and the duration of delay. In case of early delivery of a project, it is sometimes possible to get bonus from the customer if it was included in the contract. Late delivery of a project also restricts the resources for other projects of the company.
The first concern of the company is to finish the projects on the contractually agreed date and secondly, to reduce the project duration in order to offer better prices to its customers. Alstom Power currently has a project called 'Lead Time Reduction', which aims to reduce the 22 months schedule to 20 months.
Even though it is a big challenge to achieve 20 or even 22 months schedule, the company can have high robustness and achieve the KA26-1 projects in at least less than 30 months. For this reason, man-hours should be shifted from site to shop, to have higher productivity and better quality than on site with a shorter lead time, which brings the idea of modularization.
Besides the modules which were already used in Pembroke and later on a few other projects, there are now new modules developed. With the new modules, man-hours shifted to shop are almost doubled.

1.5 Approach

First of all, it is important to understand the concept of modular product architecture independent from the Alstom approach. Literature side of the research is firstly focused on manufacturing history, mainly the evolution of mass production, the need of mass customization, and main differences between these two manufacturing systems. Since modularization rose as a significant solution of customizing with lower costs, after mass customization, the research will give a detailed description of modular product architectures.
Secondly, there is a section about the modularization in the construction site, and the history of modularization and pre-fabrication in this sector.
Lastly, the Alstom approach to modularization is analysed. Currently available modules of the company will be assessed in terms of their contribution to man-hours reduction on site, cost and also quality. Before this evaluation, some

insights are given about the structure of a typical EPC (Engineering, Procurement, Construction) project and the also EPC projects in Alstom.

Cost assessment is carried out at the last stage within the case studies. In these case studies, different countries have been assumed as project country and for each project country other countries are assumed as packager location, where the modules are pre-fabricated. Cost estimations include the module transportation to site location, which significantly raises the overall costs of modules. At the end of each case study a comparison is made between the costs of modular installation and stick built solution.

Besides its advantages and contribution to man-hour reduction on site, modularization has some critical points which are needed to be evaluated.

Since some of them have huge weight/volumes, transportation is a big challenge. For those modules, it might not be possible to transport via road or air. In that case marine is the only way to transport, which means the location of a project and a packager, their distance to a harbour are highly important. Transportation should be considered in the very beginning, even before the selection of the packagers. It actually should be one of the main criteria during the packager selection process, in order to avoid any issues that can occur later on regarding the high costs and reaching to the harbour.

Packager selection is another factor of concern. As the company is shifting a big amount of man-hours to shop, it is crucial to have packagers which are suitable to Alstom criteria and also have sufficient production volume available at a required time.

The packagers have to be evaluated carefully and during the construction of the modules, it is beneficial to have someone from Alstom Power side in the packager’s workshop to observe the construction process and to check if the works are done as agreed.

The evaluation of the modules in this research is done for all the modules available in Alstom Power. In order to get the highest benefit from the modules, they all should be implemented together and preferably the more sections of the power plant should be modularized. Constructing only one module per project will not give as much benefit as gives when they all are constructed together. The more modules constructed and implemented together, the higher benefits they will bring.

2 Literature Review

The literature review of the research consists of three main parts. Firstly, an overview about the manufacturing history is given; evolution of the manufacturing from the single unit production to the mass customization. Secondly, an overview about the different types of product architectures as well as the modular product architectures will be given. Finally, the last part will focus on the modularization and pre-fabrication on a construction site.

2.1 History of Manufacturing

Types of different manufacturing processes before and after industrial revolution are analyzed under the following headlines. Development of the new manufacturing processes changed the characteristics of the markets and the demands of the customers as well. Changing demands then triggered the need of new processes and improvements of the manufacturing. Companies have been looking for innovative ideas to serve the customers better, to align their portfolio with the customer needs and expectations as well as to stay competitive on the market.
Before the industrial revolution, since centuries, manufacturing was based on the skills, talents and availability of skilled individuals like tailors, shoe makers, etc. who had materials, tools and skills about a particular area and turned these raw materials into finished products by themselves. This traditional type of manufacturing simply was dependent on what these “skilled individuals” could achieve. Quality of the work, as well as the style, variety and amount of products were upon their effort, knowledge, and time they could spend on their work, since they mostly used to work on their own and also did all the organization needed for their work alone. Tools they used during manufacturing were a few and they were not complex at all.
This Craft Production lasted with its original definition till Industrial Revolution. With Industrial Revolution the mechanization started, and totally changed the traditional way of manufacturing. It is stated that Industrial Revolution evolved in two different paths.
The first path was focused on enhancing the craftsmen’s production by utilization of the machines rather than having the simple traditional tools only,

and doing everything by hands. This machinery utilization enabled craftsmen to manufacture their products easier, faster and with a higher volume than before.[5] The second path focused more on to produce the products with lower costs by utilizing only the machinery instead of human skills.
Nowadays the distinction between these two paths is much clearer than before, since in the beginning of the revolution high skilled stuff were simultaneously used with the machines.[6]
This chapter will focus on the evolution of manufacturing after the industrial revolution till today's innovative way of manufacturing; customization of goods, which emerged the modularity of products.

2.1.1 The American System

With industrial revolution, the mechanization of the manufacturing started in the US, Great Britain and the other newly industrialized countries of Europe. This new manufacturing system is also known as 'factory system'. Since this factory system was developed faster and wider, more dominantly in the US, it is simply called the American System. This factory system was triggered the development of US and helped out US to become an economic power.[7]

THE AMERICAN SYSTEM
• Interchangeable parts
• Specialized machines
• Reliance on suppliers
• Focus on the process of production
• Division of labor
• Skills of American workers
• Flexibility
• Continuous technological improvement

Table 1: Characteristics of the American System[8]

The American System of manufacturing was differed from both the single-unit production and European way of factory system with eight characteristics.

[5] cf. Pine II (1993), p.10

[6] Ibidem

[7] Ibidem

[8] Pine II (1993), p.11

These eight characteristics of the Amerıcan System of manufacturing are listed in Table 1.

Characteristics of the American System

The first characteristic of the American system was the *use of interchangeable parts*, which means that each part of a component or a product had the ability to fit in the other piece of the same component or product. Interchangeable parts reduced the time, effort and labor during the production process. It also made ease of repairing the defected parts of a product.[9]

The process of interchangeable parts has to be supported with the special machines for the production process to have the right quality. It is not possible to produce interchangeable parts with the right precision by only means of human craft or skills, since it is important to meet with the exact tolerances; special machines for the production process are essential to standardize the parts.[10] Another important point is the volume of production; use of specialized machines also shortens the production time and increases the production volume.

The need of specialized machines brought the *reliance on suppliers*. In the very beginning machines were produced in-house, however, soon producers left this work to the machine tool industry. This approach of outsourcing their machines firstly reduced their work load and created more time slot to concentrate on their products and production processes, secondly it allowed the machine tool industry to develop easily. During the development of the American System, American companies had more success and improvement than the British ones. A reason for that is that they built better relationships with their suppliers than their British colleagues.[11]

As during the mass production, the production got more complex, and the volume became higher; it was essential to *focus on the process of production*. Each different part of a component or product might require a different machining process, which means a different working step. Having a well-planned production process is necessary to manage the production properly and to benefit from the advantages of mass production.

[9] Pine II (1993), p.11

[10] cf. Ramsauer (2009), p.13

[11] cf. Rosenberg (1976), p.162

Moreover, one of the most important characteristics of the American system is the *division of labor*. This principle focuses on dividing the works between workers and having them focused on only one task. Workers have only a simple and repetitive task which is much faster to perform than in the case of having a more complicated task, while also the learning period is relatively shorter.[12] Since the production process was more standardized and routinized,[13] it brings higher efficiency if each worker has a specific task to accomplish.

The American system, the first phase of mass production continued till late nineteenth century as a successful manufacturing method, however, with this successful system, companies, markets and demands changed and lead to the second phase of mass production.

2.1.2 Mass Production

This second phase of mass production is widely called ‘Mass Production’, or also as ‘Taylor system’, ‘Taylorism’ and ‘Fordism’.

In the twentieth century the American System was not sufficient anymore; companies strived for higher efficiency and lower costs of production. The new system which went further on lowering the costs and managing the production with better organization and higher efficiency was called Mass Production but also Fordism and Taylorism since Frederick Taylor and Henry Ford were the pioneers of the system.

Mass production took the four principles of the American System and added eight new principles on them.

Table 2 shows the principles of Mass Production.

[12] cf. Ramsauer (2009), p.12

[13] cf. Pine II (1993), p.13

FROM THE AMERICAN SYSTEM
• Interchangeable parts • Specialized machines • Focus on the process of production • Division of labor
ADDITIONAL PRINCIPLES
• Flow principle • Focus on low costs and low prices • Economies of scale • Product standardization • Degree of specialization • Focus on operational efficiency • Hierarchical organization with professional managers • Vertical integration

Table 2: Principles of Mass Production[14]

Mass Production Principles

The defining characteristic of mass production is the *flow principle*, which means the flow of work to the worker. It aimed to increase the productivity and output by eliminating the time consuming activities like searching for a tool or materials or moving of a worker from one point to another. Instead of a worker moving to do the work, it was much faster if he/she stayed at a certain point and a line slowly moved in front of him. The tools needed for the work were located near the worker, and all needed to done was to wait for the flow to bring the work, perform the work and pass to the next one.[15]

Flow principle was applied fully by Henry Ford and his production engineer Charles Sorensen with the assembly line of Ford Model T. In this assembly line each worker assembled a part and the line flowed to the next worker. It equalized the speed of the workers, made the slow one faster and the fast one slower. Flow principle enormously reduced the production of Ford cars. In the following six months after the introduction of flow principle, labor time spent to

[14] Pine II (1993), p.15

[15] cf. Ramsauer (2009), p.17

complete a single car dropped from 12 hours 8 minutes to 2 hours and 35 minutes.[16]

Second principle mass production followed was the f*ocus on low costs and low prices,* which actually created the need of flow principle. Number of people buying a certain product depends on the price of that product. The lower the costs are, the more that product can be sold. Since the companies started to reduce the production time and increased their output, they were able to lower the costs and the prices as well. When the prices of goods decreased, more people could buy them and more people demanded, so the companies increased the production slot and even lowered the costs further.[17]

Economies of scale derived from faster production with high output and lower costs. If the scale of manufacturing increases, high number of finished products shares the production costs so that the cost per produced good would be less expensive.

Product standardization is another important aspect, since a change in product would need changes or at least slowdowns in production line. If the offered product is only one type, the production process can only focus on production and assembly of this particular product and productivity can be very high.[18]

Mass production decreased the prices of the goods and dropped the barriers between people and the products, since it increased the amount of products available on the market with lower prices. The number of people who can afford these products enormously increased and a homogeneous market was created. However, because of several reasons, this homogeneous market has changed and became heterogeneous and turbulent, which obliged companies to do innovations, and find other ways to make customer buy their products. Mass production is now changing to Mass Customization; customization of the products according to the individual needs of the customers.[19]

2.1.3 Mass Customization

Decades ago, companies aimed to decrease their production costs and increase the output of production. Idea was to enable as many people as possible to buy their products. Over the years market changed slowly from

[16] cf. Pine II (1993), p.16

[17] Ibidem

[18] cf. Ramsauer (2009), p.17

[19] cf. Pine II (1993), p.16

being stable and homogeneous to heterogeneous and turbulent, since the demand of the customer has changed.

In today's market the issue for the customer is not being able to afford a product any more. There are a high number of companies, big enterprises with huge production capacities. Customers can choose the products they want, from various companies, and brands with any price range they demand. The new challenge for the companies now is something else than lowering the costs and prices, increasing the output. Now the challenge is to serve better to the customer, to produce products in a way exactly how customer wishes.

Demand fragmentation started with the customer seeking for something new about the standard products they used to buy. This fragmentation started to change the large homogeneous markets to heterogeneous markets and the niches turned to be the market.

Companies started to change their production strategies to be able to follow this demand of product variety. This requires changes in the current production processes as well as the setup of a flexible new production processes. In that sense, mass customization unlike mass production, focuses on production processes rather than the products. In mass production it was the product which designed first and later on, the process suitable for this product was created. Mass customization focuses on the process first and makes sure that a change on the product will not affect the process; hence the process is capable to support the possible product variety.

As the markets became smaller, unstable and demands fragmented, companies can only survive by producing the great variety as quick as possible. Response time for the customers has to be shorter than ever, since customers are not willing to wait for long deliver times anymore.[20]

Table 3 shows the main differences between the mass production and the mass customization in terms of the key factors they focused on, the goal they followed, and finally the key features of each of these manufacturing strategies.

[20] cf. Pine II (1993), p.45-46

	MASS PRODUCTION	MASS CUSTOMIZATION
Focus	Efficiency through stability and control	Variety and customization through flexibility and quick responsiveness
Goal	Developing, producing, marketing, and delivering goods and services at process low enough that nearly everyone can afford them	Developing, producing, marketing, and delivering affordable goods and services with enough variety and customization that nearly *everyone finds exactly what they want*
Key Features	○ Stable demand ○ Large, homogeneous markets ○ Low-cost, consistent quality, standardized goods and services ○ Long product development cycles ○ Long product life cycles	○ Fragmented demand ○ Heterogeneous niches ○ Low-cost, high quality, customized goods and services ○ Short product development cycles ○ Short product life cycles

Table 3: Mass Customization Contrasted with Mass Production[21]

In order to achieve low-cost production while also responding the customization of products for individuals there are five methods to follow: [22]

- Customize services around standardized products and services
- Create customizable products and services
- Provide point-of-delivery customization
- Provide quick response throughout the value chain
- Modularize components to customize end products and services.

Last method, modularization of the components will be explained in detail under the headline ‘Product Architecture’.

[21] Pine II (1993), p.47

[22] Pine II (1993), p.171

2.2 Product Architecture

Today's huge and complex market obliges companies to a higher competition. As the industry is highly developed and market offers various products with high availability, type of the competition between companies is also changing. Companies are competing to serve customers better, to fulfill their needs completely with a shorter lead time, while also trying to keep production costs as low as possible. Customers on the other hand have higher awareness than before, and they demand more than what is already available on the market, which leads companies to this new type of competition.

In order to gain customer satisfaction and/or to have their attention, companies started to offer products which are more unique to the individual; they allow customers to choose the products of their own desire.

Idea is to customize the products, to focus on economies of scope while also not ignoring the economies of scale.

Before talking about the different product architectures and especially the modular product architecture, it is necessary to give some important definitions like 'product platform', 'product family'.

Product Platform

Product Platform is defined by Meyer and Lehnerd as: *'a set of common components, modules, or parts from which a stream of derivative products can be efficiently developed and launched'*[23]

This set of common components increases the product variety. By applying a platform on the production line, it is possible to produce different products with higher flexibility. Product platforms have a certain number of components or parts, whose combination makes it possible to produce a great variety of finished products with much lower costs.

Ulrich K. on the other hand has a more general definition of the product platforms. Besides the components and parts he also considers the assets like processes, knowledge, services etc. as a group which can be shared between the products.[24]

Once the product platform is set, there can be different *product families* derived from these existing platforms. Various groups of related products, which

[23] Meyer et al. (1997), p.7

[24] cf.Ulrich et al. (1998), p.20

companies can form by using their product platforms, form the product families. Product families then are used to fulfill the customer needs and to satisfy the market niches. Using product platforms enables companies to share the components across the product platforms; so that they can easily develop new products. This ease of producing new differentiated products increases the flexibility of the companies' production, shortens the response time and takes the market share from the competitors who don't have this flexibility and have difficulties to produce a new product. [25]

Product platforms reduce the response time of companies to the customer needs and create flexibility by enabling companies to produce great diversity of products with lower costs. This flexibility, short response time, and low production costs ensure companies existence in the market and create a difference with the ones that don't have this flexible manufacturing process.

Product Family

Once the product platform is set, there can be different *product families* derived from these existing platforms. Various groups of related products, which companies can form by using their product platforms, form the product families. Product families then are used to fulfill the customer needs, satisfy the market niches.

There are two types of product families; *modular-based product family* and *scale-based product family*. Scale-based product family is usually seen as a subcategory of modular-base product family.

Scale-based Product Family

The main idea of scale-based product families is to 'shrink' or to 'scale'[26] a product according to the customer needs. Some examples of scale-based product family are:

Honda developed such a platform. The existing platform of Honda was enough to satisfy the Japanese and the American markets; so the company came up with a different platform strategy which made it possible to stretch the length and the width of the car according to the customer wishes.[27]

[25] cf. Ulrich et al. (1998), p. 20

[26] Simpson (2003), p.7

[27] cf. Simpson (2003), p.7

Another example can be the case of Boeing aircrafts. The commercial airplanes of Boeing have the scale based product families and according they can be stretched to the larger sizes when needed. When there is a need of carrying more cargo, having more passengers etc., the aircraft can be stretched. [28]
As Figure 3 shows, the scale-based product family structure exists in aircraft engines of Rolls Royce as well. The 'RTM322' model aircraft engines of Rolls Royce have the scale factor of 1.8, and then these two different scales of engines further broken down to the different types according to the horse powers they have.[29]

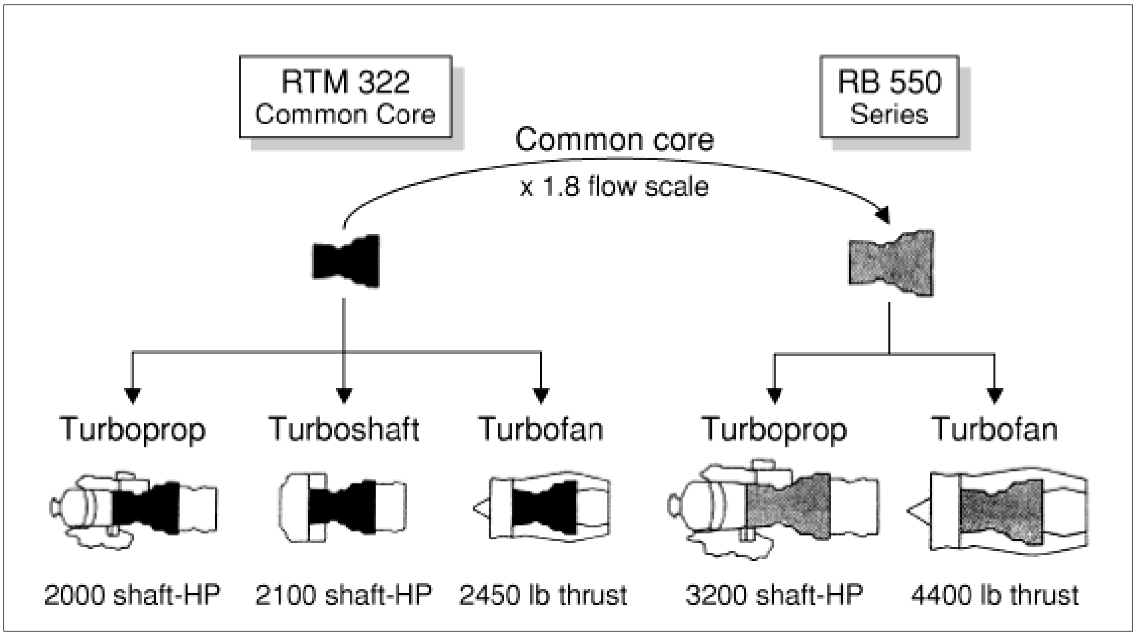

Figure 3: A Family of Scale-based Aircraft Engines[30]

Product architecture

The architecture of a product is defined by Karl Ulrich as: [31]

- 'the arrangement of functional elements;
- the mapping from functional elements to physical components;
- the specification of the interfaces among interacting physical components'.

[28] cf. Simpson (2003), p.7

[29] Ibidem

[30] Simpson (2003), p.7

[31] Ulrich (1995), p.420

Development of product platforms is crucial for modular product families. There are two different type of product architecture exist in product families; modular and integral.

2.2.1 Different Product Architectures

There are two types of product architecture existing; modular and integral product architectures. The features of modular architecture and the differences between these two will be given under the following headline.

As can be seen in Figure 4, modular architecture is then further divided into three different types called *slot*, *bus* and *sectional* which are described in the next chapter.[32]

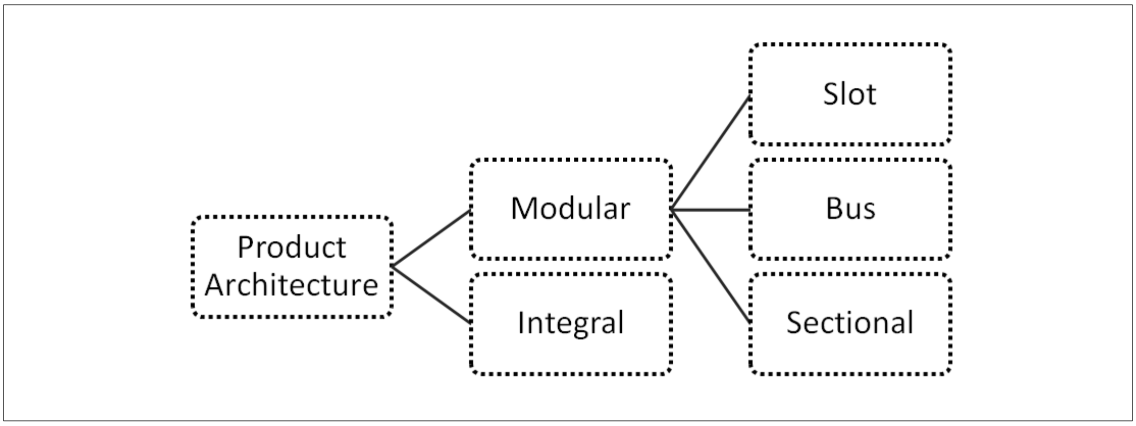

Figure 4: Classification of the Product Architecture[33]

2.2.2 Modular Product Architecture

Trailer example of Karl Ulrich explains the differences between the modular and integral product architecture in a simple way.

Figure 5 and Figure 6 show the integral and modular design of a trailer, on which the distinction of the mapping between the functional elements and the physical components can be seen.

In the example there is a functional structure for the components of the trailers. First difference starts here, about the relationship of these functional elements and the physical components of a product. A functional structure may consist of one or more functional elements, which in this example is a collection of several

[32] cf. Ulrich (1995), p.424

[33] Ibidem

elements. These elements are in relation with the components, since they are actually the functions of the components. This relationship between the components and their functions are different in modular and in integral archıtecture.

As can be seen in Figure 5 the relationship between each component of the trailer and the functional tree is a one-to-one mapping. This one-to-one mapping is an important attribute of a modular product. Every component has one function to apply. For instance the 'Box' has only the function of protecting cargo from the weather and the 'Bed' only supports the cargo loads. In an integral product on the other hand, this mapping is more different.

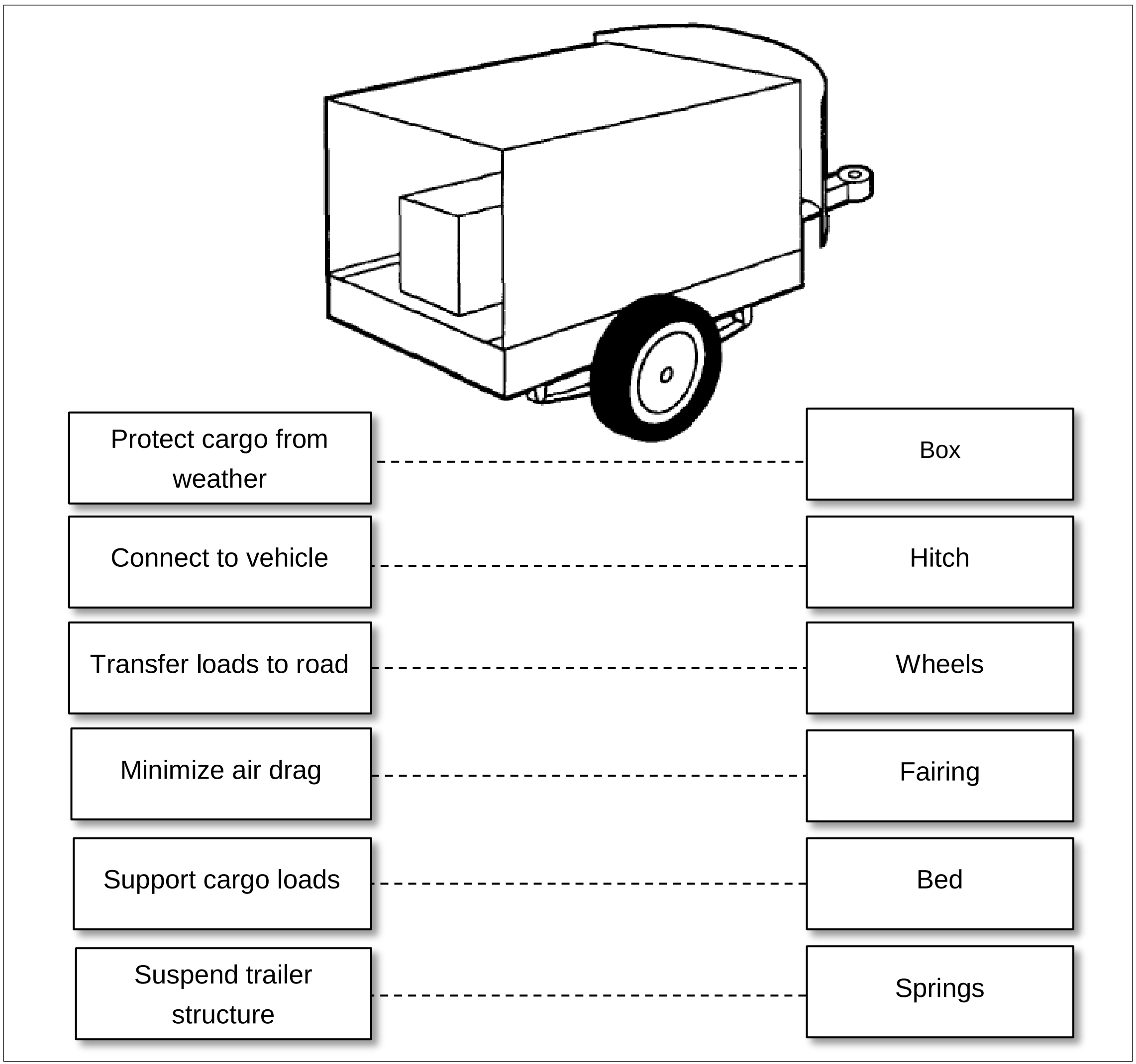

Figure 5: Modular design of a trailer[34]

[34] Ulrich (1995), p.424

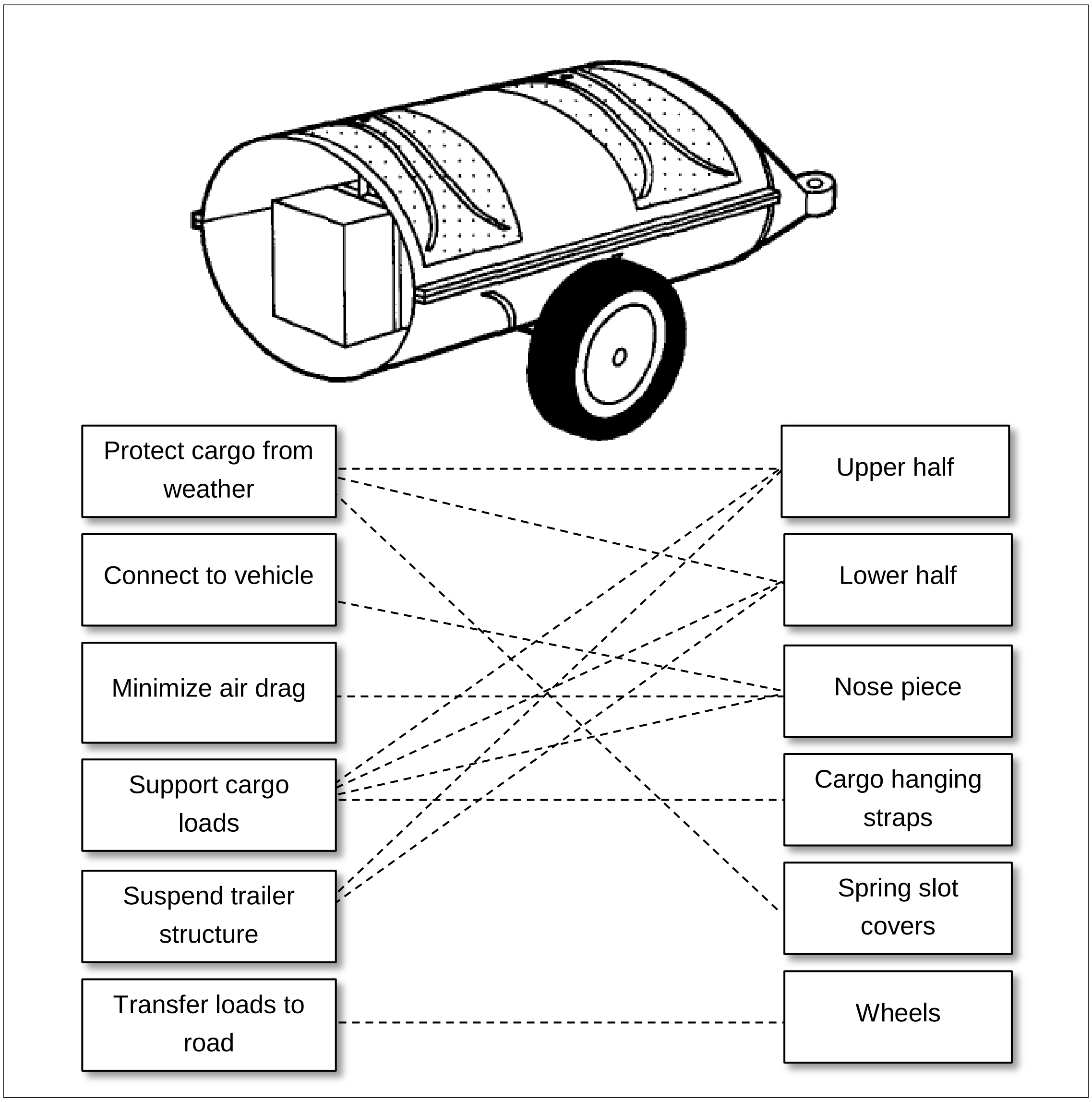

Figure 6: Integral trailer architecture of a trailer[35]

As it is shown in Figure 6, an integral product has a more complex mapping between the components and their functions. The mapping between the components and the functional elements can be many-to-one or one-to-many.
For instance the function of ‘protecting cargo from weather’ is not achieved only with one component as it was in the modular trailer example, but with more than one component. In this case this function is carried by the ‘upper half’, ‘lower half’ and ‘spring slot covers’.
Another attribute modular and integral architectures have differently is ‘interface coupling’. In modular architecture components have de-coupled interfaces

[35] Ulrich (1995), p.422

between each other, which mean that the change of a component doesn't affect the neighbor components. In contrast to that, in the integral architecture components have coupled interfaces; they have dependency on each other. In case a component changes or needs modification, neighbor components would require changes either partially or completely.

Figure 7 shows the interface coupling of the modular and the integral architectures. On the left side the box and the bed has a decoupled interface between each other. If for some reason the bed needs to be changed with a new one or needs to be modified, this would not require the box to be changed. However on the right side, there is a coupled interface between the bed and the box, which is an integral design. If there is a change or a modification that needs to be done on one of these components, the other one gets affected as well. A change on the bed would require a change on the box.

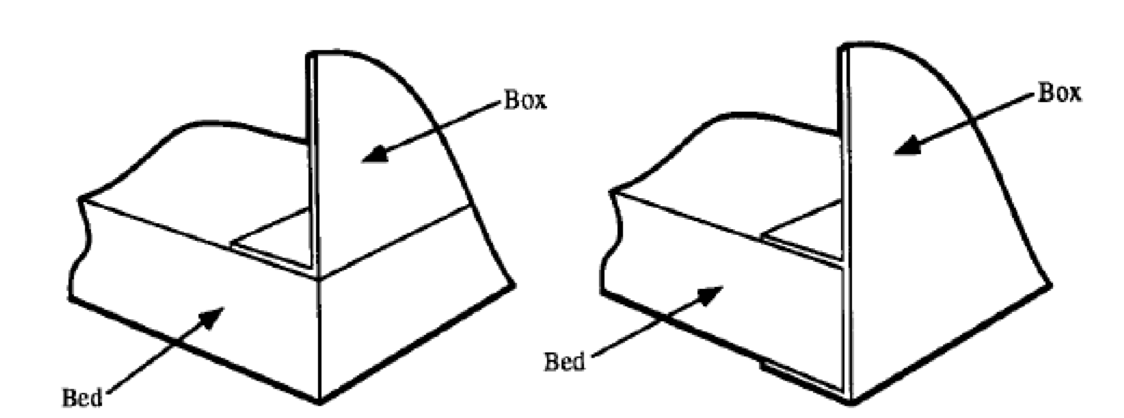

Figure 7: Interfaces between the trailer box and the trailer bed[36]

Modular architecture is divided into three sub-types called slot, bus and sectional; depending on the way components interact with each other. Else, the type of interface coupling and mapping between components and functional elements are the same in all three types.[37]

2.2.3 Types of Modularity

As mentioned before, modular architecture can be divided to three subcategories; slot, bus and sectional.

[36] Ulrich (1995), p.423

[37] cf. Ulrich (1995), p.421

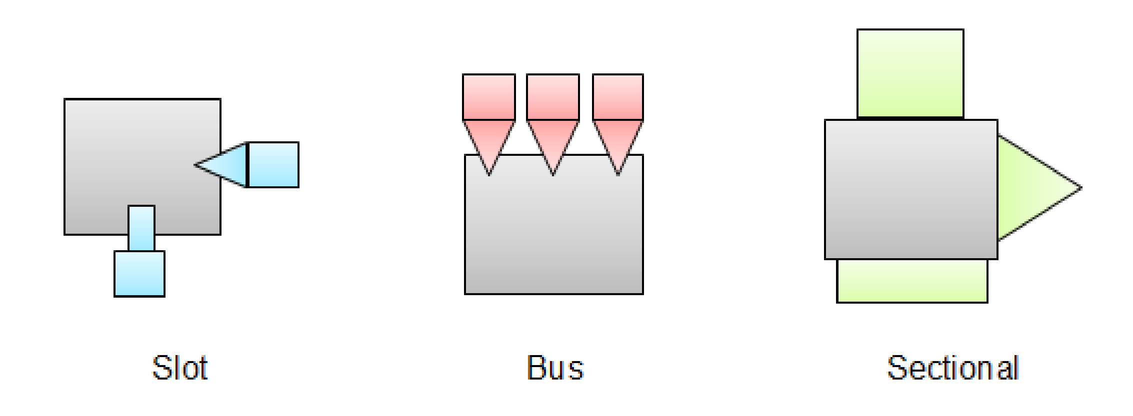

Figure 8: Slot, Bus and Sectional Type Modular Products[38]

In slot type architecture the components are decoupled and also have the one-to-one mapping as required to be modular, however these components have different interfaces than each other. Automobile radios are slot type modular products, as their interfaces are different than the rest of the parts inside an automobile.

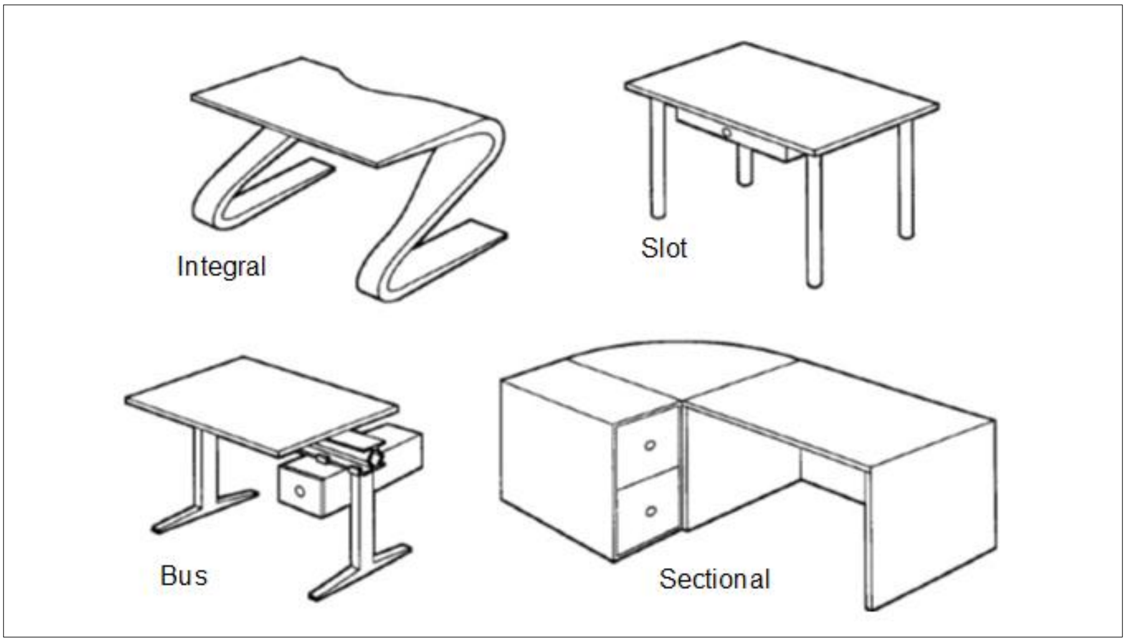

Figure 9: Integral and different types of modular desk design[39]

[38] Own Ilustration

[39] Ulrich (1995), p.425

In bus type architecture there is one component, which the other modular parts are built on. For instance shelving systems with rails and adjustable roof racks for automobiles have bus type modular architecture.
Lastly the sectional type neither has a particular part as a base, as in bus type nor has completely different interfaced parts. An example for this type can be sectional sofas.[40]
A more detailed classification of the modularity is done by Joseph Pine II[41], in which he divided the modular products into six different types as shown in Figure 10.

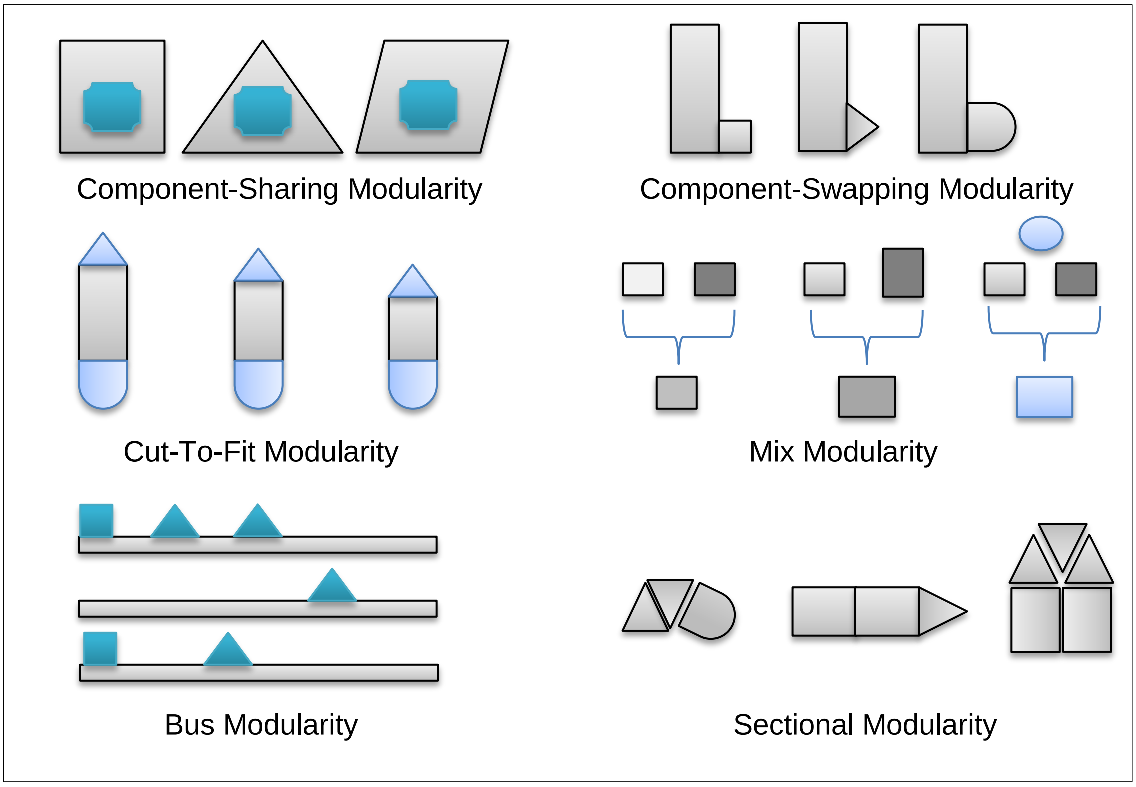

Figure 10: Types of Modular Products[42]

With *Component-Sharing Modularity*, the same component is used among several products, thus creates a variety. Companies can find such key components to make them used by as many products as possible, so that the

[40] cf. Ulrich (1995), p.424
[41] cf. Pine II (1993), p.201
[42] Pine II (1993), p.201

number of different components is reduced as well as the cost while also the variety of the end product is increased.

Component-Swapping Modularity can be defined as the opposite of the component-sharing Modularity, since in this case the same part is used by different component. By increasing the variety of the components that could fit on the base product, increases the product variety. The important step here is to define or create a product which is most suitable to the customization and then separate the product into the components. An example to the component-swapping can be the T-shirts, which are produced and later on can have various patterns or writings by the heat transfer process.

Cut-To-Fit Modularity has a similar meaning with the component-swapping modularity except that in this case the product size is changeable. The base of the type is that product size can be smaller to fit for any usage, any customer needs, such as clothing or wall papers which are suitable for any wall size.

Mix Modularity is basically having different components available to be able to mix and create a variety of products. In these types of modularity as the Figure 10 shows, the components are not the same as before, after getting mixed with the others. They may change their shape, their taste, their taste or etc. mixing the different colors of paintings according to the customer demand and order is an example for the mix modularity.

In *Bus Modularity*, there is a standard product that the other components get attached on. It has many examples from the computer industry like hard disks that can fit on the casings of any desktop, USB sticks that can fit on the desktop computers, notebooks, printers and so on.

Lastly the *Sectional Modularity*, which gives the greatest variety and customizability among these all types of modular products. In sectional modularity, it is possible to use any component with any other existing ones in any desired amount. The best example for this type is the Lego blocks, which have the special interface that enables any of the blocks to attach to each other and to form any shape. The shapes that can be created using these blocks are only limited with the imagination of the Lego owner.[43]

2.2.4 Advantages of Modular Product Architecture

Since the competition in today's market is more aggressive and companies need to compete in several ways like customizing products for the customer,

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[43] cf. Pine II (1993), p.201-209

shortening the response times, increasing the product variety and lowering the costs.

Modularity enables a flexible manufacturing process, and is seen as the solution of mass customization with lower cost, shorter lead time while also increasing the product variety with much less component configurations.

Modular architecture enables the changes of components within the product lifetime with much less cost and with higher ease. Depending on how frequently the components of a product will need to be modified, upgraded, changed or repaired, the necessity of modularity can be defined.

Products may need changes on some components, or just an add-on or an adaptation. With modular architecture, the components can go under these changes without causing any effect/change on the neighbour components.[44]

A good example of modular product platform is Sony's Walkman. Sony used three different platforms for its products and produced 250 different Walkman models only in the US market, derived out of these three platforms.[45]

Another example is from the automotive industry: Volkswagen, which reduced its development and production costs by $1.7 billion annually, while using the right product architecture.

VW, Audi, Skoda and Seat are sharing the components of the same platform.[46]

Modular production gained a wide acceptance in many industries and it still continues its evaluation. Computer and car productions are commonly known examples. Beside these popular examples which give an insight about the profitability of modular products, there are many others from various industries which in daily life are in use, however, might not be realized by many users. One good example is from the jewelry industry: Pandora. Pandora has bracelets with different materials and colors as well as various charms. Customers can design their own bracelets or necklaces either online or in Pandora stores. A charm from a necklace also fits to a bracelet which enables the customers to change the styles of their existing jewelries by replacing the charms about the existing bracelets or necklaces.

Another good example is the cereals for the breakfasts. Cereal companies are benefiting from the modularity by mixing the different products and forming

[44] cf. Ulrich (1995), p.425

[45] Simpson (2003), p.5

[46] Dahmus et al. (2001), p.409

various cereal types according to the consumer needs. This type of modularity is named as mix-modularity.[47]

Chinese Restaurants follow the same type of modularization. They prepare the various vegetables, different kinds of noodles, rice, fried seafood and meat. By mixing these products so to say the noodles with different type of meat and vegetables and by adding the different type of sauce, they are able to create a large menu.

2.3 Modularization as a Solution to Reduce the Activities on a Construction Site

Modularization in construction industry has a different meaning than the modular architecture in the literature which has been explained previously. The term modularization for the construction industry should be evaluated with the terms pre-fabrication, pre-assembly and onsite/offsite construction. In the literature, modularization and pre-fabrication terms exist mostly for housing industry.

In housing industry, modularization is gaining speed over the time. With the ready panels it is much easier and quicker to build the houses, health care centers etc. according to the need.

In the power industry, such as thermal power plants the acceptance of modular products is increasing as well. However, modularization doesn't always have the same meaning with its sense in literature. In some cases the term "module" is only used to describe a pre-fabricated product.

2.3.1 Definitions in Modularization on Construction Site[48]

Pre-fabrication

Prefabrication is a term which refers to the construction process of the sections of the large buildings/structures which is done offsite. Prefabrication is done at a special place that exists for this process, which is away from the construction site. After the pre-fabrication process, these large components are brought to site and the final assembly works are completed on site. Depending on the complexity of the component pre-fabricated, the works that need to be done on site can vary.

[47] cf. Pine II (1995), p.205

[48] cf. Schoenborn (2012), p.3-4

Pre-assembly

Pre-assembly can be either onsite or offsite. Pre-assembly is the process of joining the pre-fabricated components at a place different than the final area of the final structure.

Modular Construction

Modular Construction is the process of manufacturing which uses pre-fabrication and the pre-assembly on a separated area than the final construction site.

Onsite construction

It can also be called as 'stick-built' construction, which means the construction works done on the construction site either at final destination or away from the final location of the final structure.

Offsite construction

Offsite construction is consisted of pre-assembly and the pre-fabrication of the structures at a special place, a workshop which is away from the construction site.

Modularization

Modularization in the construction industry is defined as breaking down a complete big structure into some small sections, which can be constructed offsite and transported to the site as a single module or a few sub-modules depending on the transportation limits. Modularization decreases the construction works on site to only a few steps like assembling the modules and completing the foundation works.

2.3.2 A Brief History of Prefabrication and Modularization

The Crystal Palace is an early example of pre-fabrication in Europe. It was built in 1850s by Joseph Paxton for the Britain's Great Exhibition. Crystal Palace was designed by Joseph Paxton in less than two weeks and constructed in a few months. Manufacturing costs were not high since it is mainly consisted of iron, wood and glass. After the Great Exhibition it was taken apart into pieces and moved to Sydenham.[49]

Modern beginning of the prefabrication and modularization is started in the early 1900s. Aladdin and Sears Roebuck Company prefabricated houses and delivered to their customers as mail-order homes.

During the Second World War the modularization increased, since the military crew needed accommodations. After the Second World War the need of buildings increased as well especially in Europe and in Japan, which triggered the prefabrication and offsite construction. Starting from 1970s on, in the US the modular construction started to be used in the commercial applications as like hotels, offices, hospitals and schools. This demand rose because of the increased demand exceeded the number of existing structures.[50]

Nowadays, the modularization in construction sector is gaining more complex structure. An example of a current application of the modular construction can be the construction of the new cruise liner Queen Mary 2. The ship owners nowadays prefer the modular construction in a workshop than on a construction site in order to make sure that they get the highest possible quality. Every passenger cabins including the VIP suites are being modularized.[51]

Since a few years the ABB Group is modularizing its Gas Insulated Switchgears (GIS). GIS is used in every power plant to control and isolate the electrical equipment. ABB is constructing the GIS different voltages as functional modules, which means they are ready to be plugged-in and work on site.

[49] cf. McGraw (2011), p.9

[50] Ibidem

[51] Ibidem

3 Modularization in Alstom Power

This chapter firstly will give the definition of modularization concept in Alstom Power and the differences between the modular products explained in literature and existing in Alstom Power.
After clarifying the modular approach of Alstom, there will be the historical evolution of the modules in the company. The first project of the company that used modules in Power Island will be evaluated and the lessons Alstom learned at the end of the first initiative will be reflected.
Currently available modules of Alstom power will be introduced and the future of the modules as well as the learning curve will be interpreted.

3.1 Types of Organizational Structures

There are several models for organizational structures. Companies can have different types of structures such as: [52]

- Functional Structure
- Divisional Structure
- Matrix Structure
- Hybrid Structure

3.1.1 Functional Structure

Functional structure divides the organization into different functions such as sales, R&D, finance, human resources etc. Depending on the size and the complexity of the company the number of functions can alter. A simple functional structure may have a few separate functions like the technical ones (R&D, Production) and the rest of the functions (Sales, Purchasing, Human Resources etc.), while a more complex organization can be divided into many more functions as shown in Figure 11. In comparison to the divisional or matrix structure, functional structure is rather simple and more suitable for the companies who don't have diverse products, unlike Alstom Group.[53]

[52] Daft (2008), p.104-124

[53] cf. Daft (2008), p.104-105

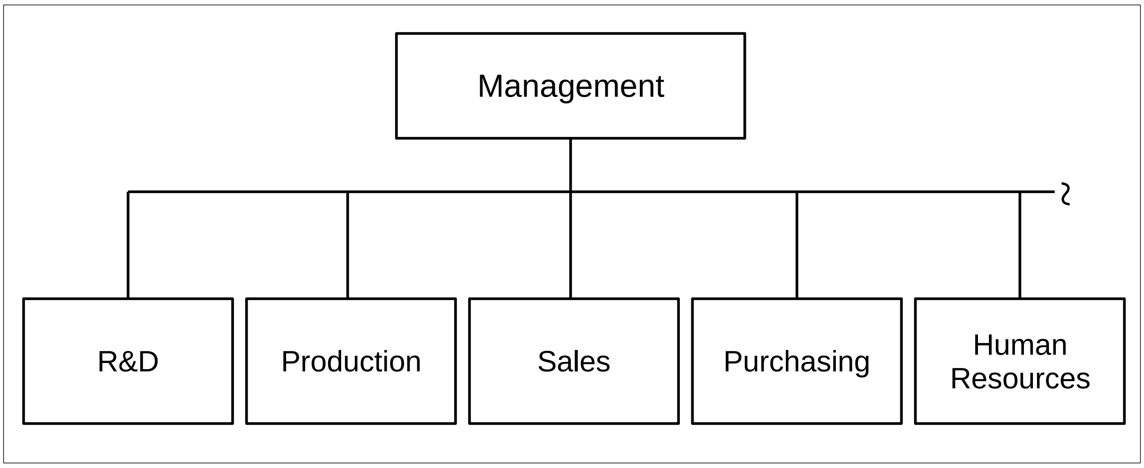

Figure 11: Functional Structure of an Organization[54]

3.1.2 Divisional Structure

Divisional structure is suitable for the multi-product-companies who have diversity of products or who are located in several regions, countries or continents. A division can be considered as almost independent unit of a company.

Divisional structure can be formed according to the product groups, regions of the company or customer segments.

Figure 12 shows a the divisional structure of a company which is formed according to the product groups like Thermal Power, Grid, Renewable Power and Transport.

In some companies the division can be formed according to the regions as stated before. Structuring by the region is beneficial if there are distinctive market requirements, if the local resources are required, if there is high transportation costs between the regions or if there are special legal or economical requirements and so on.[55]

[54] cf. Daft (2008), p.104-105

[55] cf. Daft (2008), p.106-108

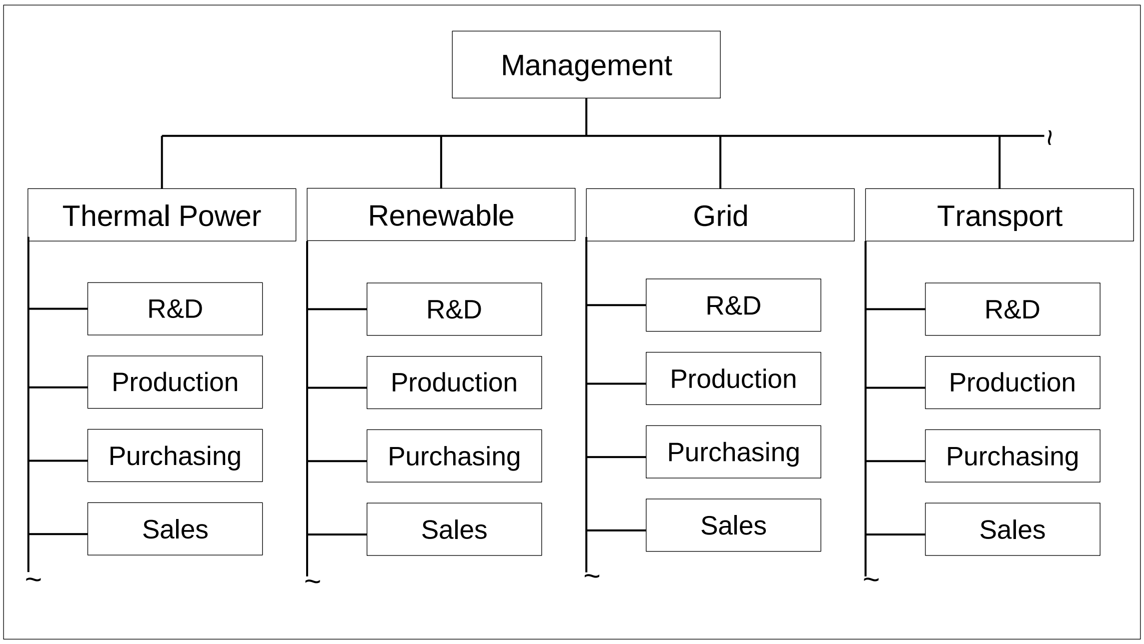

Figure 12: Divisional Structure of an Organization by Product Groups[56]

[56] cf. Daft (2008), p.106-108

3.1.3 Matrix Structure

Matrix structure has several parameters of grouping applied simultaneously.

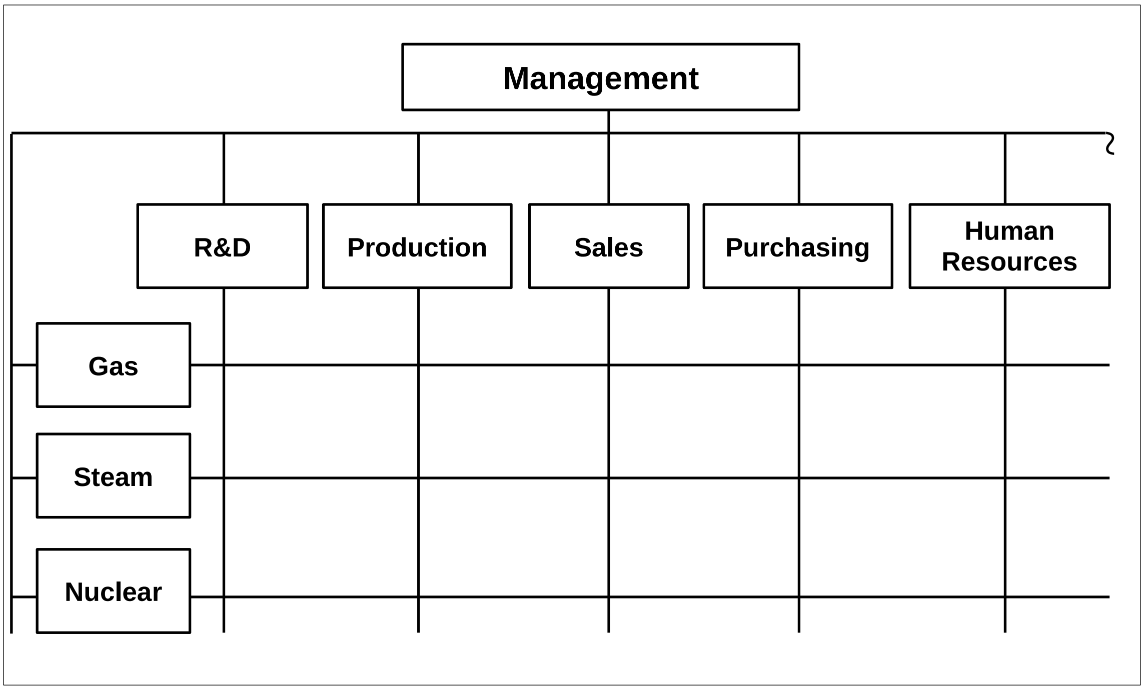

Figure 13: Matrix Structure of an Organization[57]

Similar to the divisional structure, matrix structure is also suitable for the multi-product-companies and also for the companies which have clear differences between the products and the markets. In
Figure 13 there is a two dimensional matrix structure which has the functions as one dimension and the products as the second one.[58]

3.1.4 Hybrid Structure

Hybrid structures combine more than one type of organizational structures such as for instance functional structures at the top level followed by a divisional structure in certain functions according to the product groups. Such an organization is divided to the different functions such as R&D, Purchasing, Sales and so on as illustrated in Figure 11 and the R&D department can be

[57] cf. Daft (2008), p.110-111

[58] cf. Daft (2008), p.110-111

formed as a divisional structure according to the different product groups or regions.
Opposite to the previous example, the organization can have a divisional structure at the top level according to the regions and these regional divisions can be broken down to the functional structures.[59]

3.1.5 Organizational Structure of Alstom Group - Hybrid Structure

Alstom Group has hybrid organizational structure which is a combination of the divisional structure at the top level and a functional structure at the lower level. Figure 14 illustrates the organizational structure of Alstom Group as taking the example of Thermal Power.
At the top level the company has a regional-divisional structure, which is consisted of three regions. Secondly each region has a divisional structure according to the product groups like thermal power, renewable power, grid and transport as can be seen under the ELA region. Each of these product groups then has a functional structure. In Thermal Power there are nine functions and some of these functions have a divisional structure according to the product groups such as gas, steam and nuclear.

[59] cf. Daft (2008), p.122

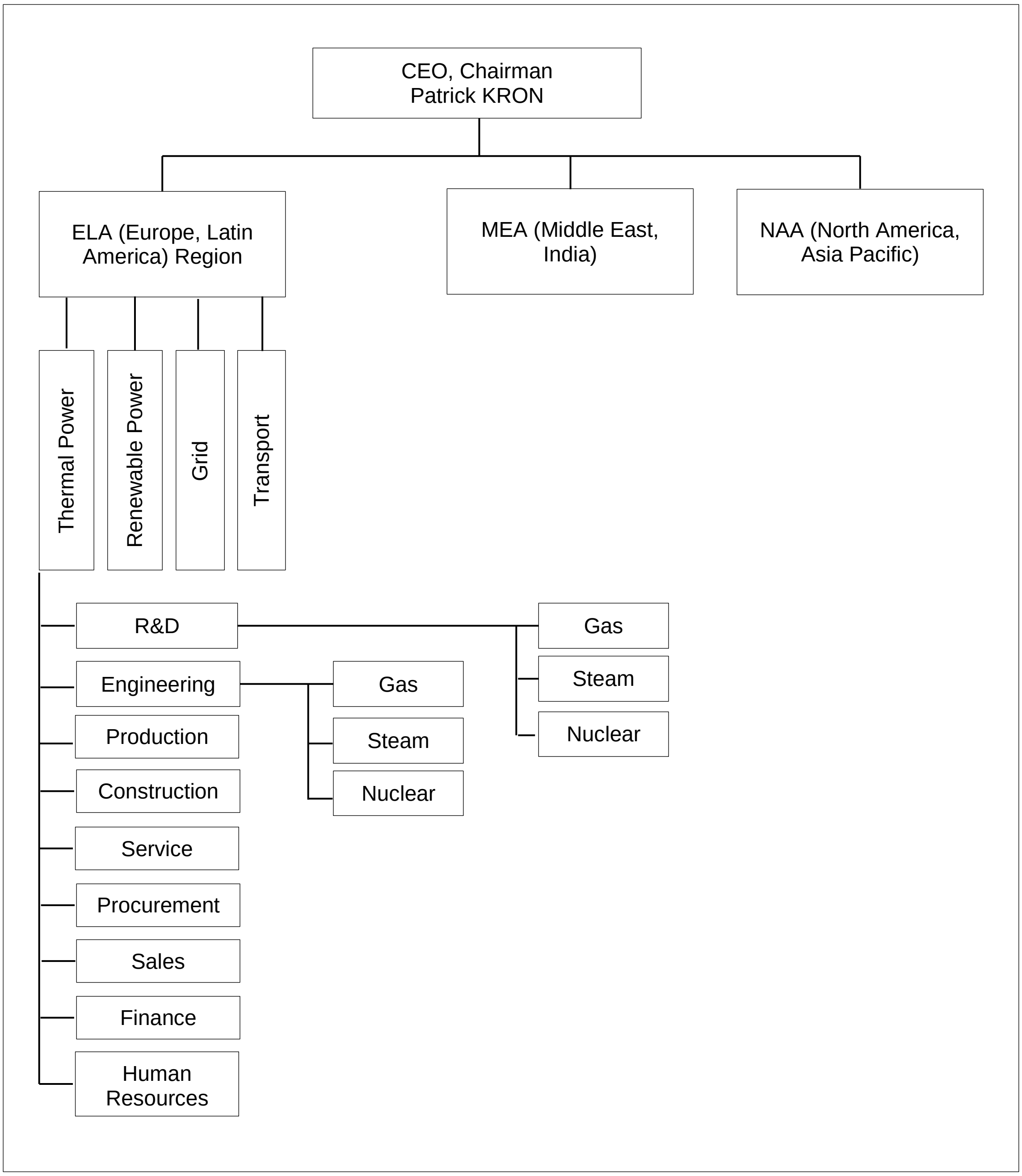

Figure 14: Organizational Structure of Alstom Group[60]

[60]Own Illustration

3.2 Features of Power Projects[61]

Figure 15 shows a general structure of a power project, with the basic agreements between the project owner and the other parties including an EPC (Engineering, Procurement, and Construction) Contract which is described in the next chapter.

In power sector, if the owner of a power project or in another term the customer is a private institution; firstly this institution has to have an agreement with the government which is called *Concession Agreement*. Concession agreement allows the private institution to build a power plant, to generate and sell electricity for certain amount of year. After this defined allowance period, government owns the power plant.

For financial support, the company who undertakes the project of power plant erection, and named as "the Project Company", can make agreements also with lenders. For bankability it is important that the project company can show that the electricity produced in the power station will be sold. To prove that the electricity of the power plant will be sold, mostly there is an agreement between government and the project company. Government assures to purchase a certain amount of electricity produced in the power plant.

Another concern is certainly to have a fuel supply. The Project Company finds the institution for the fuel of the power station and signs a contract for the fuel purchasing as well.

[61] cf. DLA Piper (2001), p.1

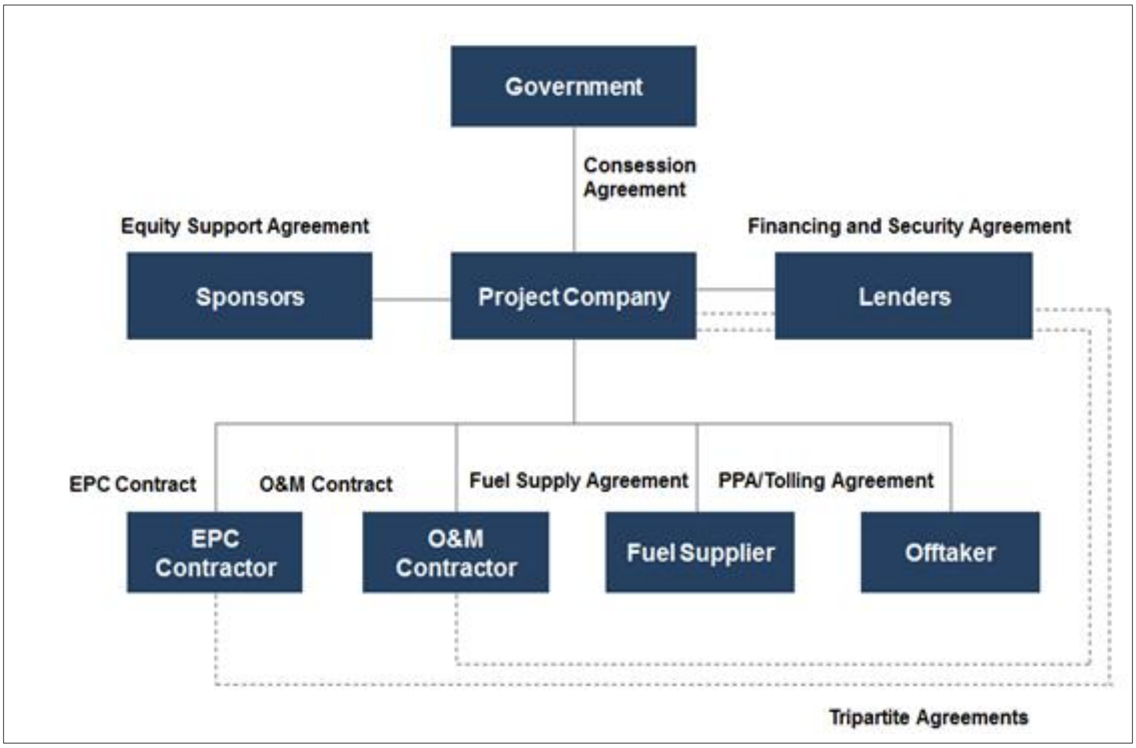

Figure 15: The Basic Contractual Structure of a Power Project[62]

Financing and security agreement is usually signed with the lenders to make sure that the lenders will finance the development of the project.

After the construction of the power plant, there should be an operator to operate the plant and do the maintenance. For this operation and maintenance process there is a long term O&M (Operation and Maintenance) agreement with an operator.

Depending on the project there can be more and more contracts, the Project Company might need, e.g. agreement with the Offtakers or with the sponsors.

Alstom Power as an EPC Contractor

'EPC' stands for Engineering, Procurement and Construction, and EPC contracts are widely used in sectors which has large and complex projects like e.g. power sector, oil & gas, and transport.

To construct the power plant, in most of the cases Project Company cooperates with an EPC contractor. The EPC contractor can either undertake all the engineering, procurement and construction works, or can work with the subcontractors.

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[62] DLA Piper (2001), p. 1

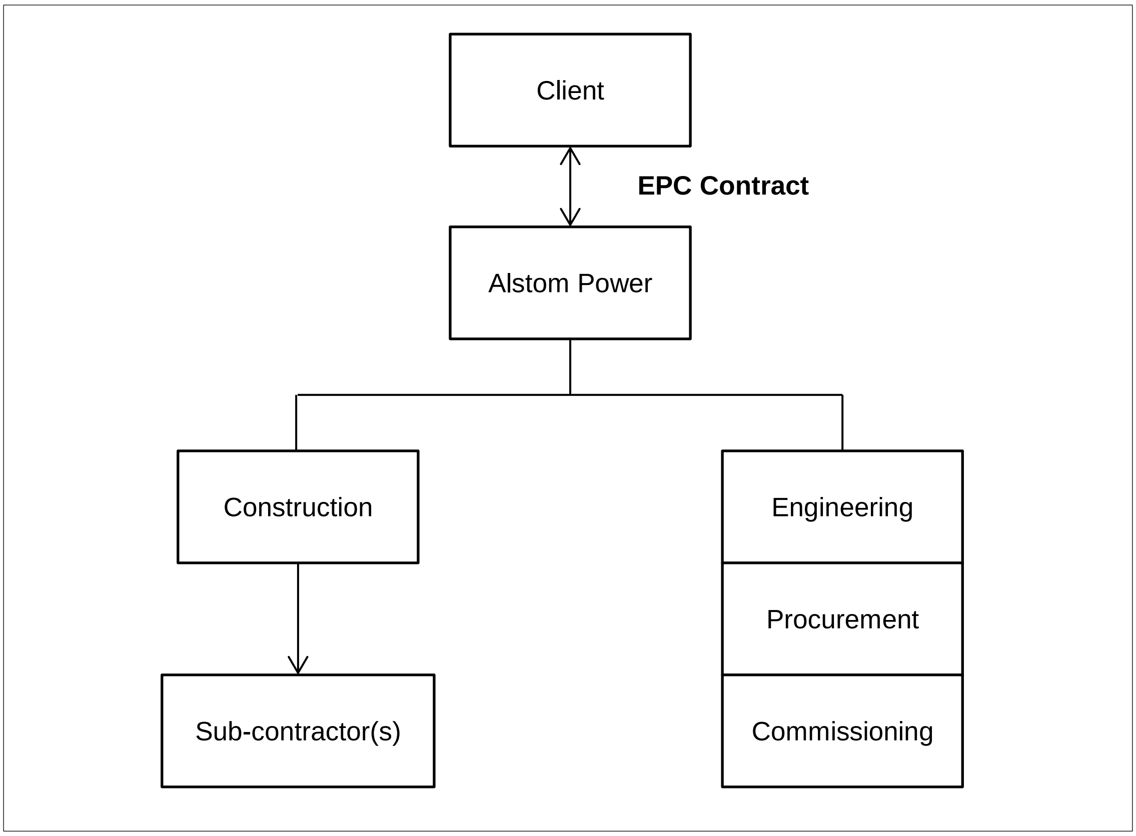


Figure 16: Alstom Power as an EPC Contractor[63]

Under an EPC contract a contractor is obliged to deliver a complete facility to the project owner in such a condition that the project owner can start the facility by only turning a key, so these contracts are also called as turnkey contracts. [64]

Figure 16 illustrates the process of EPC contract in Alstom Power. As can be seen from the figure, as an EPC contractor Alstom Power does the whole engineering, procurement and also commissioning works of a power plant, while leaving the construction works to the subcontractor(s).

The subcontractor can be one or more depending on the project country, available resources, and its expertise.

Alstom Power mostly works with four subcontractors for a full EPC project, to ensure that all the construction works are done by the experienced sub-contractors and also to reduce the risk. Usually the construction works are given to the four subcontractors as following four construction packages: [65]

[63] Expert Interview (2013)

[64] cf. DLA Piper (2001), p.1

[65] Expert Interview (2013)

- Water Steam Cycle erection works
- Heat Recovery Steam Generator (HRSG) erection works,
- Power Train (PT) erection works, and
- Electrical works

These construction packages are named as CP-1, CP-2, CP-3 and CP-4.
Dividing the construction works among several subcontractors reduce the risk on site, however the interference between the subcontractors is an issue to be taken care of. Conflicts among those people who work together on a construction site are unavoidable. The ideal solution is to decrease their workload, to reduce the time spent on site, hence to reduce the site activities.

3.3 Concept of Modularization in Alstom Power

Alstom Power defines modules as the sections of a power plant which are pre-assembled in a workshop and are transported to site either in single or in split parts depending on the transport limitations. These transport limitations might require splitting the modules in several sections, which are called *sub-modules.*
Combination of more than one sub-module is called a *composite module*.[66]
In the literature review the most important attributes of the modular products were given, and starting with this chapter the Alstom way of modularization will be clarified. As can be understood from the Alstom definition of a module, there are major differences between the modules in the literature and the modules in Alstom Power.
Firstly, the products of power sector have quite big dimensions. It is hard to compare a production process of, for instance, a computer with the construction of a power plant. A power plant has much more complex components which are also much bigger than the components of a computer or a car. A company which produces a computer can fully integrate the modular product architecture into its production line, and can benefit from the advantages this architecture brings, like customizing its products with much less costs and with a faster respond time. However, the process of building a power plant is much more complex. Modules of the power plant, which will be described in detail later on in this research, can be up to 300 tons.
A module has well-defined interfaces with its surrounding components and a change or a replacement of a module would not require any change of any

[66] Expert Interview (2013)

neighbor components. On the other hand this flexibility doesn't exist for the modules of the power plant. Any change on a module in the power plant would require a change or a complete replacement of the neighbor components which a module is interacted with.

A module which is designed according to a particular 'Reference Plant' might not be suitable for another one. This means, if a new reference plant is designed for the power plant, modules need to be constructed in a different way; their design has to be changed. This redesign requires long hours of engineering works.

The modules of the Power Island cannot be produced in advance as in the other sectors. They are constructed based on a project, according to the site layout and might require a change for the next project.

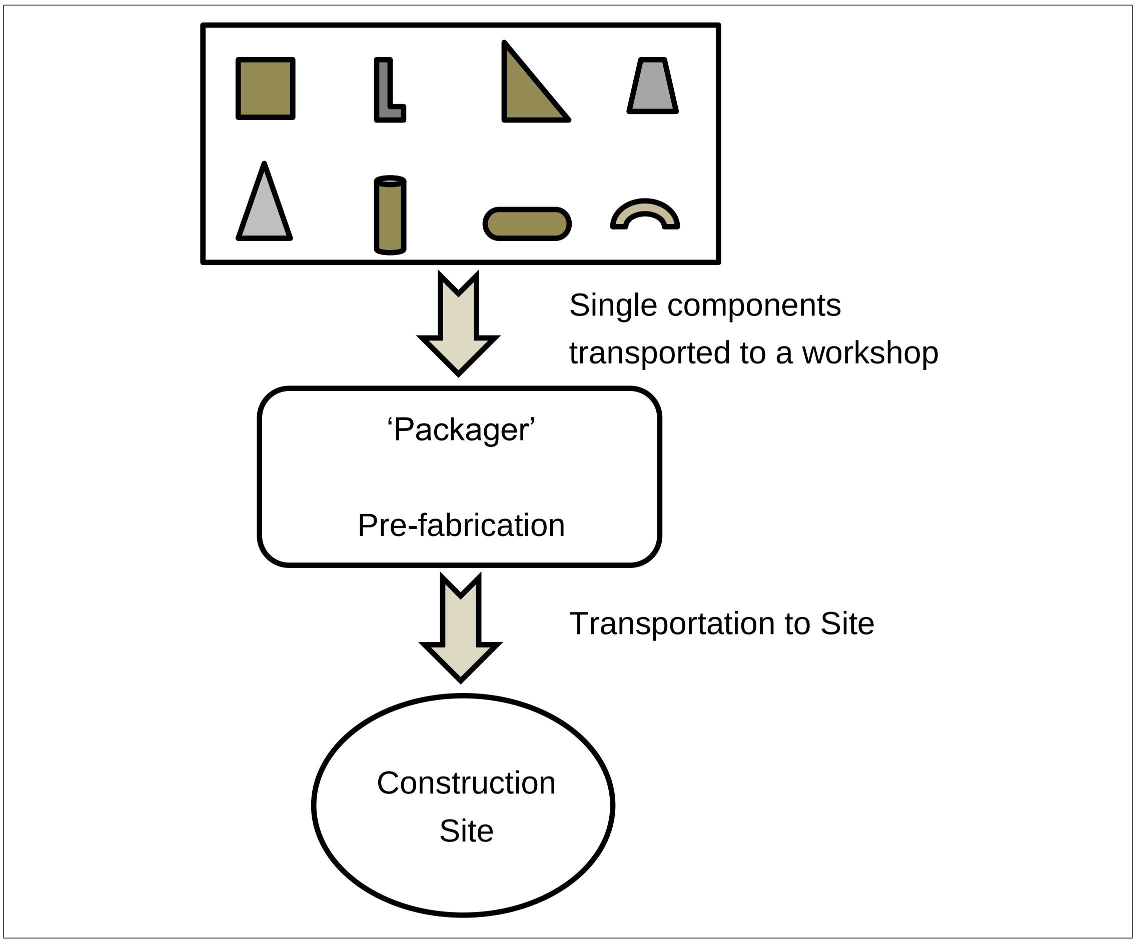


Figure 17: Offsite Fabrication of Modules[67]

[67]Own Illustration

Although the definition of the modules in the literature and in Alstom Power are quite different, the fact that the modules of the power plant has high benefits on a power project in terms of project lead time, quality, risk elimination and cost does not change.

Figure 17 shows the process of the construction and the transportation of the modules. Modules are constructed in a workshop of a seller who will further be called ‘Packager’. Packagers are constructing the modules based on the design requirements of Alstom Power and complete all the necessary preparation for them to be ready for transportation.

Transportation from the packager to the project site is under Alstom’s responsibility. Purchase of the components is either in packager´s scope (mostly) or in Alstom’s scope.[68]

SWOT Analysis

SWOT is the acronym for ‘Strengths, Weaknesses, Opportunities, and Threats’ and it is a strategic tool which helps companies to analyse their internal and external surroundings in many cases. It helps companies to analyse their strong points and weak points as well as the possible opportunities and threats that may occur in their external environments. It is widely used as a competitive intelligence tool.

As Table 8 shows, SWOT is divided firstly to two sections as internal and external. Internal attributes are the strengths and weaknesses of the company, while the external attributes are weaknesses and opportunities the company is confronted with in certain cases. [69]

[68] Expert Interview (2013)

[69] cf. Pelz (2004), p.5

		INTERNAL	
EXTERNAL		STRENGTHS	WEAKNESSES
	OPPORTUNITIES	INTERNAL STRENGTHS & EXTERNAL OPPORTUNITIES	INTERNAL WEAKNESSES & EXTERNAL OPPORTUNITIES
	THREATS	INTERNAL STRENGTHS & EXTERNAL THREATS	INTERNAL WEAKNESSES & EXTERNAL THREATS

Table 4. Structure of SWOT[70]

Strengths

Strengths are simply the strong points of an organization against the competitors can be tangible assets and intangible assets. Strengths can be for instance people, know-how, experience, location, machines, patents, value, quality, innovative aspects and many others.

Weaknesses

Weaknesses are opposite to the strengths, weak points of an organization. It gives an insight to the organization about the points that can be improved. These weak points should be formed also by including the customer´s opinion. Weaknesses of an organization might be insufficient financials, lack of know-how, non-robust supply chain, lack of competitiveness, lack of expertise and many others.

Opportunities

It can be any opportunity that might occur externally and can have benefits on the organization for its future results. There can be a change in the market

[70] cf. Pelz (2004), p.10

which increases the sales of the organizations products. A competitor might have a tough situation which decreases its competitive strength. There can be a possible partnership or acquisition, which can increase the know-how and the expertise of the organization. These are only a few examples of the opportunities.

Threats

Threats are the external obstacles which affect the growth, development and competitiveness of the organization. Some examples for the threats are; a new competitor in the market, political issues, changing demands of the market, sudden increase of the supplier prices and so on.

SWOT analysis can be used with various purposes, for instance during the business planning of an organization, to analyse the competitiveness in a certain market, before entering to a new market, before a new investment opportunity or a product development, etc.

Table 5 shows the SWOT analysis of the modular construction in Alstom Power. Strengths, weaknesses and possible external threats and opportunities are evaluated.

As can be seen from the table, offsite fabrication of the modules, which is an innovative idea to reduce the project duration of the KA26-1 full EPC projects, is thought to have several important strengths. Shifting the construction works from the construction site to the shop will reduce the risk on site and will improve the Environmental Health and Safety (EHS) on site, although much less time will be spent regarding the EHS requirements.

The risk on site is much higher than a factory environment because of several reasons like; the weather conditions of the project country, contractor issues on site, lack of experienced contractors, legal issues and the political inconsistency of the project country. If the construction works are done in a controlled environment such as a workshop or a factory rather than a construction site, there will be less risk and higher quality. This controlled environment, opposite to the construction site, will not get affected by the bad weather conditions, such as rain, extreme cold, extreme hot or dusty wind. The effects of the bad weather condition on the project schedule will reduce, since a big portion of the construction works are carried to the shop. No matter where the project country is, and how hard the weather condition of this country for the construction works is, the probability of the project delay will decrease with the pre-fabrication of the modules.

As explained before, Alstom Power works with more than one contractor for the construction works. These different groups of people, who belong to the different contractors, often have issues between each other. These contractors might have lack of expertise as well. In order to eliminate these kind of contractor issues, Alstom Power as an EPC contractor has to have a high level of supervision and control on site. Constructing modules in a workshop decreases these contractor issues as well.

For the external opportunities, schedule acceleration is a good point to be considered. Offsite fabrication has a high potential to decrease the overall project duration and to get a more robust schedule.

Beside the benefits of the modules there are also internal weaknesses and external threats that might occur. One of the weaknesses is that the modules require high level of monitoring. In order to benefit from the modules in terms of time reduction of a project, their engineering, procurement and transportation have to be done on time and they have to be delivered to site on time, otherwise the project schedule might have a delay. The suppliers and the packagers have to be monitored carefully.

Another weakness point is that they have a tight execution time on the schedule. Project schedule requires the modules to arrive at a certain time and to be installed in a defined sequence. They should be on site on time and should be installed in the required sequence and required time, in order not to affect the sequence and the completion time of the following activities.

One of the possible external threats is any failure that can occur from the packager side. To eliminate that, the Alstom Power should monitor the works of the packager in the packager’s workshop if possible and prevent any failure or supervise when necessary. Another threat can be the delay of the components to the packager. Suppliers should be steered closely to make sure that the packager will get the components on time. Transport is a substantial point, which can have delays or problems that arise from the weather conditions, insufficient protection of the modules, and the failure or the delay of the packager.

In order to benefit from the modules and decrease the time needed for this new process to get mature, weaknesses and opportunities have to be handled carefully.

Strength	Weakness
Less risk on site • Contractor issues • Weather condition • Exposure to strike / unions issue Environmental Health and Safety (EHS) improvement at site	Tight execution time schedule Additional monitoring required on all areas of the sub-project
Threats	**Opportunities**
Failure of the packager Supplier Delays Transport Potential cost increase	Schedule Acceleration

Table 5. SWOT Analysis for the Modules in Pembroke[71]

FMEA

For the risk assessment of the modules like all the other products within Alstom Power, Failure Mode and Effects Analysis (FMEA) is often used. FMEA tool is used to identify the possible failures that might occur on a product, project or process and to assess the severity of their consequences. [72]

According to the severity of the consequences of the possible failures (S-Severity), the frequency of these failures coming into being (L-Likelihood) and lastly the ease of detection (C-Controllability), a Risk Priority Number (RPN) is calculated. Likelihood, Controllability and Severity is ranked between 1 and 10, so the RPN has a range from 1 to 1000.[73] Equation 1 shows the formula of Risk Priority Number.

[71] Own Illustration

[72] cf. Teng et al. (1995), p. 10-11

[73] cf. Teng et al. (1995), p. 10-11

$$\text{RPN= Severity x Likelihood x Controllability}$$
$$\text{RPN= [S] x [L] x [C]}$$

Equation 1: Calculation of Risk Priority Number[74]

The quantification of S, L and C can be done internally with a particular evaluation critera, and the can be named differently in different literature sources. S, L and C is the Alstom indication.

FMEA is used when there is a;

- New product, process, design
- Change, upgrade or modification on a product or a component
- Change of the region of usage for an existing product

There are two different FMEA:[75]

Design FMEA

It is done by the design team at the design stage of a product or a process.

Process and Product FMEA

It is done by the product development team during the development phase of a product.

	RİSK/FAILURE MODE	**EFFECTS**	**LIKELIHOOD OF OCCURRENCE**	**SEVERITY OF EFFECT**	**CONTROLLABILITY/DETECTION**	**RPN**
Close Cooling Water – **CCW**	Modules being large has enhanced risk of damage in transport & handling	Impact on Project Schedule & Cost	3	5	4	**60**
Atmospheric Drain Vessel – **ADV**	Late Delivery on Site	Impact on Project Schedule & Cost	2	6	6	**72**

Table 6. FMEA Example for ADV and CCW

[74] Alstom (2012), p.1

[75] cf. Teng et al. (1995), p. 12

Table 6 illustrates a simplified example of RPN estimation for a possible late delivery of ADV module on site and a possible damage that can occur on CCW module during the transportation to site. According to the rating of severity, occurrence and detection, the RPN rate for each case is calculated.
After the RPN estimation, the actions to avoid these failures are decided. For instance the risk of transportation damage can be reduced by;

- Special packing and handling instruction for the transportation,
- Study of proper lifting concepts,
- Supervision to ensure the instructions is followed.

For the case of ADV, to reduce the risk of late delivery to site some actions to be taken;

- Purchase orders should be given on time,
- Supervision in the packager’s workshop to ensure the works are done according to the schedule.

After the improvement actions are decided, the RPN rate can be estimated again and the new RPN indicates the risk rate by considering these actions, so to say precautions.

3.4 Quality in Alstom

Quality of a project, product and the satisfaction of a customer is a key asset in Alstom Power. Both the field employees and the office employees are trained about quality processes by the experts of the company. EHS and Quality are two key factors that are considered at the initial phase of every project. The way of working in Alstom is defined through precise work instructions and processes. This control is not just a paper work, but a strictly followed way of measuring the quality to see if the work is done in a safe way, without the reworks and according to the customer requirements.

3.4.1 Quality Policy

The five Alstom commitments to have better products, a profitable and competitive company, satisfied customers and safer working conditions are: [76]

1. Prevent all poor quality situations
2. Focus on the customer
3. Be responsible

[76] Alstom (2012), p.9-11

4. Be open and transparent
5. Measure and act

The Quality Policy in Alstom Power must be applied to every site and describe how the work shall be led in order to:[77]

- Provide safe working conditions for the workers
- Deliver a product meets completely with the client's needs
- React in a proactive manner in case of quality alerts
- Continuously improve the processes
- Not hide the problems

To control the processes and measure the improvements, PDCA (Plan-Do-Check-Act) is used continuously.

PDCA (Plan-Do-Check-Act) [78]

PDCA is an important quality management tool, which is used to plan and improve the quality processes. It is also called Deming cycle, since W. Edwards Deming is a pioneer and a developer of the tool. It has four steps which are named as Plan, Do, Check and Act.

Plan

Firstly the problem is identified. It is crucial to understand the problem clearly and describe it with all the necessary aspects. To identify the problem, several tools such as 5Whys or Cause and Effect Diagram (Fishbone) can be used.

Do

For the problem identified in the previous step, possible solutions are generated. Generated solutions are then evaluated and the most suitable one is defined as a test solution.

Check

The so called test solution is at this stage implemented to see if the problem can be handled, and the process can be improved. The results are evaluated to

[77] Alstom (2012), p. 9-11

[78] cf. Alstom (2012,) p. 14

see what can be improved, what went wrong, or if there is any weak point which the test solution couldn't eliminate.

Act

According to the results gathered from the "Check" step, necessary actions are taken.

PDCA cycle is quite often used within Alstom Power with the other quality management tools.

Figure 18 illustrates the PDCA process of the company.

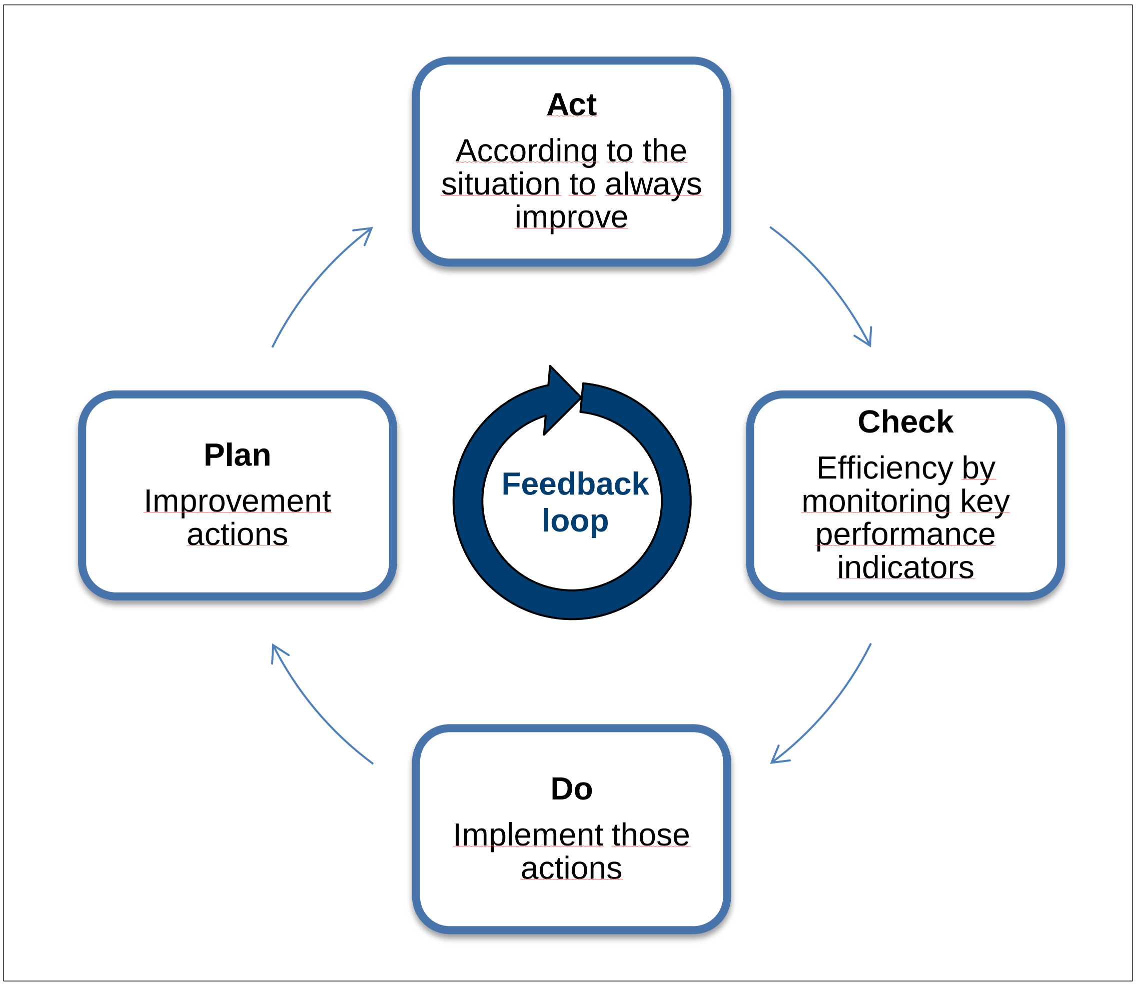


Figure 18: PDCA to Monitor the Quality on Every Site of the Company[79]

[79] Alstom (2012), p.15

To control the quality of the works and the processes, there are basic quality control tools used like Ishikawa Diagram (Cause and Effect Diagram), and Pareto charts as well as the advanced control tools like 8D and Statistical Process Control Methods.

Cause and Effect Diagram[80]

Cause and Effect diagram is also known as Ishikawa Diagram or Fishbone, which is a useful tool for identifieng a problem. Usually after the realization and the detection of the problem, people start thinking about the possible solutions to eliminate it. however searching for a solution without a clear understanding of the causes of this problem might lead people to miss some important points and thus can cause a repetitive problem. Cause and Effect forces people to think about the causes of the problem, hence make a brainstorming. For an effective solution, clear understanding of the problem and the elements which cause the problem is an asset.

As figure shows, the head of the fishbone is the problem itself, which is identified by a "why" question. "Why did the KA26-1 projects delay in the UK?". This "why" questions leads to the brainstorming. The bones are the causes of this problem, which can be group in several structures. One suggested structure is the "6 M+E", which is suitable for the manufacturing industries.

The 6 M+E

- Machines
- Methods
- Materials
- Measurements
- Environment
- Manpower (People, Operator)

[80] cf. Gwiazda (2006), p.439-440

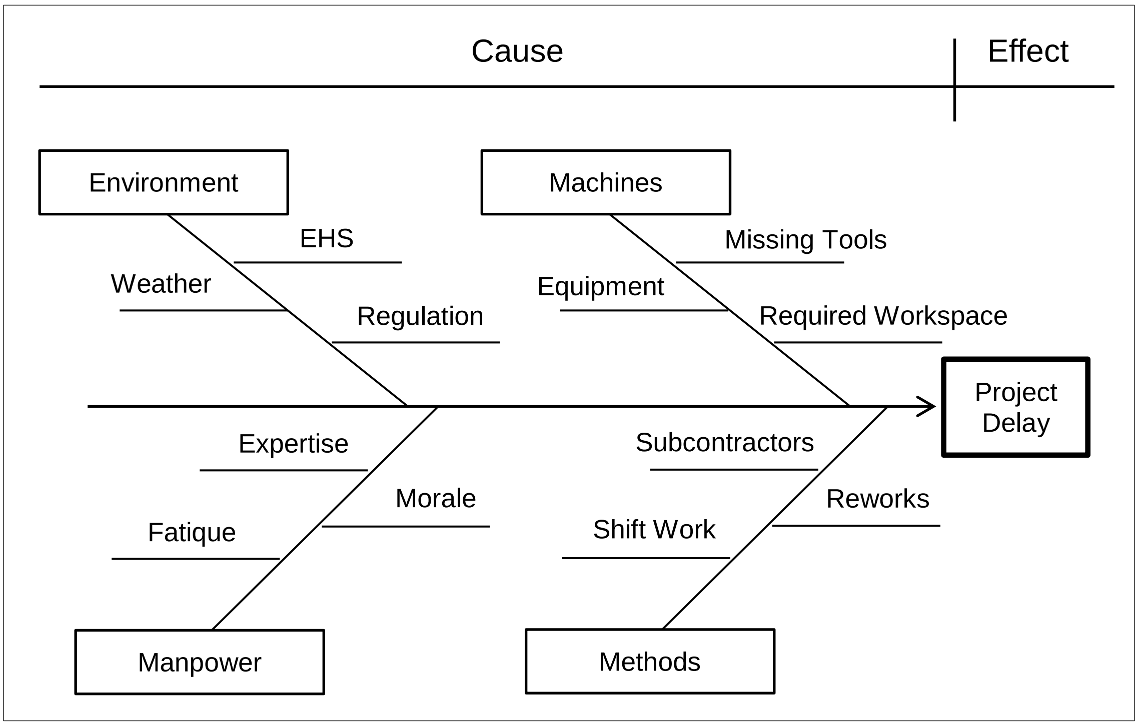


Figure 19: Cause and Effect Diagram for "Project Delay"

Figure 19 shows the causes which are structured as a result of a brainstorming session, which is done according to the 6 Ms.

3.4.2 Quality on Site

Quality process on site is much more difficult to control in comparison with the office works and the works in production plants. Measure of the quality of the site works are done by the number of Non-Conformance Reports (NCR) on site.

Non Conformance[81]

Non fulfilment of specified requirements, including a deficiency characteristic, documentation or process implementation, which causes delay to the program and/or causes significant unplanned expenditure.

Thus the "Non Conformance Report (NCR)" is the document which records the non-conformance.

The aim is to reduce the number of NCR received from a construction site, since the corrections of NCRs result with very high costs and also loss of time.

[81] cf. Alstom (2012), p.4

The less work on site means the less process to control, less number of NCRs, less reworks, less cost spent to avoid poor quality and so on. Craft on site and in the office are also trained to be able to define the NCRs.

NCRs can grow out of the deviations from the technical drawings, faulty or missing materials and damages to the materials, assembly problems, etc. Solving an NCR can cost thousands of Euros, while also lasting a few weeks long. NCRs lead to the work delays which sometimes can cause to incremental costs. While waiting for an NCR to be fixed, the manpower stays stand-by, it is possible that an expensive crane rented for the construction work will wait without any work, and also the delay of this particular work will affect the sequence of the other upcoming works.

Most of the NCRs occur from the assembly of small parts such as missing bolts, welding of pipes or wrong sizes of pipes etc. which can be easily eliminated if most of the construction works are done in a workshop and the site activities are reduced to the level of assembling these parts transported from the workshop.

The less the construction works on site, the less NCR will occur. Shifting the works from site to shop will bring a better quality, less works on site and less NCRs.

Figure 20 shows some examples for NCRs and also some issues which are not NCRs and might create confusion.

NCR	NOT NCR
• Control cabinet installation different from electrical drawings (elements missing) • Missing insulation and cladding • Cables damage • Air dryer is not working well • Clash between a GT pipe and the steel structure • Joint left without termination for a few days (only first pass weld carried on) • Missing elements compared to the packing lists	• Insufficient budget allocated for a defined scope • Query for technical support or advice from Engineering Department • BOQ variations • Missing scope from the main contract • Cost variations due to productivity • Subcontractors claims (but the source of the claim can be the result of a NCR)

Figure 20: Examples for NCRs[82]

Every construction site is exposed to high number of NCRs. While some of them are completely new issues, the big portion is consisting of the repetitive NCRs. In order to avoid the repetition of an NCR, there is Experience Response System (ERS).

ERS aims to avoid repetitions of non-conformities and/or create additional benefits. In other words ERS: [83]

- collects all deficiencies, non-conformities and risks systematically,
- identifies potential non-conformities,
- defines necessary preventive actions.

Module pre-fabrication saves hugh amount of NCR costs on site. It is important to pay attention to transport the modules with the necessary steel frames and the ensclosure to site also not too early from the agreed schedule. A carefull

[82] Alstom (2012), p.5

[83] cf. Alstom (2012), p.9

transport, and assembly on site would save the company from paying high NCR costs which occurs during the stick built solution.

3.5 Currently Available Modules

Alstom categorises its modules under the name *"Wave"* and currently there are Wave 1 and Wave 2 modules available.
Wave 1 modules are fully completed; some of them were used in Pembroke and since then they were further developed. Currently there are six modules available in Wave 1 whose designs were completed and being used currently in several projects.

Wave 1 modules:

- Atmospheric Drain Vessel (ADV)
- Blow Down Tank (BDT)
- Closed Cooling Water (CCW)
- Feed Water Tower (FWT)
- Natural Gas Module (NG)
- Once Through Cooler –Control Valve (OTC-CV)

Table 7 shows the Wave 1 Modules with their dimensions, small sketches and the information regarding their availability as a single or a split module.

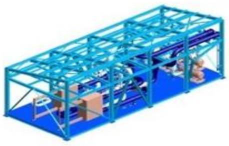
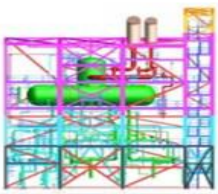
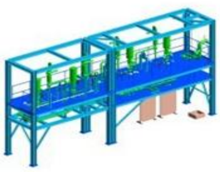
WAVE 1 MODULES			WEIGHT (MT)	DIM (M) L X W X H
ADV		Split	S1(6.4) S2(7.0) S3(8.2) S4(6.1)	S1 (5.63 x 2.99 x 3.02) S2 (5.63 x 4.29 x 3.02) S3 (7.30 x 3.88 x 3.24) S4 (7.30 x 3.88 x 2.39)
		Single	24.3	7.28 x 6.90 x 5.6
BDT			23	15.5 x 7.3 x 6.0
CCW			66	15.5 x 7.3 x 6.0
FWT		Split	283	Z11 (20.1 x 6.55 x 12.7) Z12 (20.1 x 6.55 x 14.2) Z13 (23.0 x 6.55 x 4.3)
NG			18.9	8.5 x 4.6 x 2.66
OTC-CV		Split	15	S1 (6.58 x 2.26 x 4.0) S2 (5.52 x 2.26 x 4.0)
		Single	8.5	6.58 x 2.26 x 4.0

Table 7. Wave 1 Modules[84]

Figure 21 and Figure 22 are showing the prefabricated modules ADV, CCW and FWT. After the prefabrication process modules will be prepared by the packager for the transportation which is in Alstom Power’s scope.

[84] Alstom (2013), p.8

Figure 21: Pre-fabricated ADV Module[85]

Figure 22: Pre-fabricated FWT Module[86]

[85] Expert Interview, (2013)

[86] Expert Interview, (2013)

Wave 2 modules are the modules which were designed after the completion of Wave1; therefore they are called Wave 2.

Wave 2 consists of five modules:

- Ejector Skid Area (Ej)
- Main Cooling Water (MCW)
- Main Cable Tray (MCT)
- Main Pipe Rack (MPR)
- Small Pipe Rack (SPR)

Technical specifications of Wave 2 modules are done, and some of them are being used in the current projects in Singapore and Israel.
Due to the transportation restrictions, they are either available as a single modules or as split sub modules. In case they are delivered as sub modules to the site, they need to be assembled on site.
Wave 2 modules are shown in Table 8 with their dimensions, small sketches and the information regarding their availability as a single or a split module.

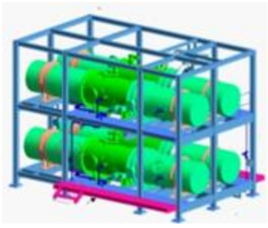
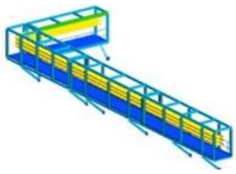
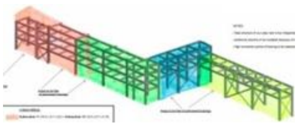
WAVE 2 MODULES			WEIGHT (MT)	DIM (M) L X W X H
EJ		Single	39	11.8 x 5 x 4.2
MCW		Split		Z31 (6.1 x 5 x 4) Z32 (11.7 x 5 x 4)
MCT		Split		Z91 (14.9 x 2.3 x 2.8) Z92 (21.6 x 2.3 x 2.8) Z93 (11 x 2.3 x 2.8) Z94 (12.7 x 2.3 x 3.2) Z95 (18.2 x 2.3 x 2.8)
MPR		Split	Z81(97.3) Z82(11.3) Z83(108.4)	Z81 (20.3 x 6.2 x 6.3) Z82 (23.5 x 6.3 x 6.3) Z83 (23.5 x 6.3 x 6.3)
SPR		Split	Y21(33.7) Y22(33.7) Y23(18.75) Y24(21.8)	Y21 (14.3 x 2.7 x 2.2) Y22 (14.3 x 2.7 x 3.5) Y23 (10.5 x 2.7 x 4.05) Y24 (1.8 x 2.7 x 2.75)

Table 8. Wave 2 Modules[87]

3.6 First Project with Modules – Pembroke

Alstom Power used the modules for the first time on a large scale in 2009 in the UK project named "Pembroke", located in Pembroke, Wales. Pembroke was a big project consisted of five unit of combined cycle gas turbine single shaft arrangement (5 X KA26-1). Plant has in total over 2000 MW gross electrical

[87] Alstom (2013), p.8

output. Figure 23 the Pembroke power plant, which consists of five unit of KA26-1 configuration.

Since a similar UK project was experiencing difficulties in the construction activities for several reasons, to avoid any project delay the company decided to use modules to shift the man-hours from site to a workshop. The difficulties experienced in the UK were mainly;

- Claim oriented attitudes of the Mechanical & Electrical sub-contractors
- Strict union regulations of UK, which decreases the progress speed of construction works
- high labor costs of the sub-contractors, despite low productivity and insufficient experience
- bad weather conditions of the country; often rainy and windy.

Figure 23: Overview of the Complete Pembroke Plant (All Five Units)[88]

Alstom aimed to eliminate these difficulties by modularizing some sections of the power plant.

[88] Alstom (2010), p.5

Since modularization was a totally new solution for the company, and was being applied for the first time; besides its advantages there were also some challenges, some downsides of this new concept. They were mainly the possible cost increase and the risks that could occur from lack of experience.
In Table 9 the upsides and the downsides of these new initiative is listed.

UPSIDE	DOWNSIDE
Shifting risk from site to workshop – earlier in the project schedule	Increased cost of steel – more steels are used during module transportation
Less expensive labor costs than on site	Increased cost of transportation
Reduced indirect costs	Earlier start of engineering
Better productivity	First time working with the packagers – no previous experience
Better quality	

Table 9. Upside & Downside of Modularization

There were three modules used in Pembroke;

- Feed Water Tower (FWT)
- Atmospheric Drain Vessel (ADV)
- Close Cooling Water (CCW)

Each of these modules were prefabricated to the maximum extent, i.e.:

- Steel work supply and erection
- Piping, valves and instrumentation erection
- Painting and insulation
- Equipments installation
- Electrical supply and erection
- Testing (hydrotest, looptests)

Modular concept in Pembroke was successful in general, however there were some points which needed further development. Since it was totally a new concept and a new experience for the company, some problems occured about the modules during the transportation and the erection. After confronting with these problems, management made the necessary changes and modifications and took action for the next projects.

3.6.1 Overall Feedback from Pembroke

Modularization for Pembroke was a big success. Modules were delivered to site on time and their quality was satisfying. This successful module prefabrication was contributed to overall success of the project. The modules have produced an advantage on schedule and reduced the costs for acceleration.
The modularisation was overall very much appreciated at site and recognized as part of the success of the project. The main benefits of the modules for Pembroke are:

- Reduce risk of delay: less exposure to strike, union issues, to weather conditions (wind, rain), to interference between contractors
- Reduce risk of claim: less interference and disruption between contractors, better access to the areas
- Minimize Site coordination and interface
- Reduce the site direct manpower: flattening of the manpower curve. Contractors and Alstom supervision can be focused on other activities
- Improve productivity: erection activities made in a workshop rather than at site –simultaneous Civil and pre-assembly activities
- Improve quality of works – QA/QC activities in factory under a more controlled environment
- Improve EHS on site: less work at height, in confined space

Quality and Legal Management
Construction engineering was in charge of Quality Control of the module prefabrication. One person was based full time in the packager's facility to ensure compliance with the specification and follow-up the technical problems that could occur during the prefabrication phase.

Risk Management
At the beginning of the project, the execution of the module was identified as carrying some specific risks. Those risks had to be managed with special care, and a strategy has been put in place to make sure they are under control.
The major risk was the late delivery of the modules to the construction site. This could have several reasons:

- No experience of modular design - design delivered late or not compatible with the modular execution.

To eliminate this risk a specific engineering team has been to put in place, supported by experts during design reviews.

- Late delivery of free issued items to the packagers due to the specific & complex supply chain for modules.

To avoid the late delivery of free issued items a dedicated PPLM has been nominated to manage specifically the free issued items delivery.

- No readily available knowledge/experience of shop prefabrication contractor (packager).

To manage the selection of the packagers, possible candidates were audited and qualified to ensure that their experience is adequate and brings confidence in their ability to deliver on time. A project float duration was generated in the time schedule to have some provisions of time in case of delay of the module execution. A full time dedicated supervisor has been appointed to monitor and report the progress of the construction of the modules

- The transport of the such big elements was never done before, and the risk to subject the bad weather conditions was high.

There was a good collaboration of the engineering and the transport departments to make sure the design of the modules was in line with transport constraints. A project float was generated in the time schedule to have some provisions of time in case of bad weather restrictions

3.6.2 Lessons Learned from Pembroke and Necessary Future Improvements

As stated previously, modularization in general was a success for Pembroke project. However, as it was a highly new experience for all the departments of the company, some unsatisfying points occured in the area of contruction. These points have been taken care of for the next projects by the engineering and the construction team. Below, there are some points that has to be eliminated for the next projects:

Feedwater Tower (FWT)[89]

Feedwater Tower was delivered in four sub-modules to the construction site. It was installed in a short time, however it had to be re-scaffolded to be able to install the missing components such as:

- HVAC ducts and cables
- PA system
- Side cladding, roof cladding
- Touch up painting of the bolts of the staircase bracings
- FW pump crane rails

Future modules have to be delivered with all the necessary components, so that there will be no further site works required. The ideal case is, just to place the module on its foundation and assemble the sub-modules.

Besides the addings of the missing components, there were some other modifications done on the construction site after the installation of the Feedwater Tower. These modifications were:

- Installation of a second way of escape from the 18m level. This was a requirement in the UK laws, was not foreseen before.
- Modifications done for the handrails of the staircase to meet the local regulations (Elevation, gap between posts and missing ones).
- Completion of the toeboards at all levels to meet local regulations

These above three items were sourced of the country regulations. For the future projects, the design and the prefabrication of the modules should be done by considering all the regulations in the law.

[89] cf. Alstom (2012), p.4-6

Figure 24: On the Left Side FWT, On the Right Side a Cladding[90]

Another issue was that the module was exposed to the bad weather like rain for a few months. In the future, modules should be delivered without any open items, preferably with a good cladding especially for a country like UK, where it rains quite often. Figure 24 shows on the left side a picture of the Feedwater Tower used in Pembroke and on the right side a possible cladding that can be used for the modules in the future to protect them from the bad weather conditions.

Atmospheric Drain Vessel (ADV)[91]

ADV was delivered to Pembroke site as a single module and was installed in the final location upon arrival. Some issues occured about the ADV module on site:

- the thermal insulation of the module was not done properly, so it had to be done on the construction site.
- Access ladder of the module didn't meet with the local safety regulations. Modifications of this acess ladder had to be done on site.

[90] Alstom (2012), p.7

[91] cf. Alstom (2012), p.15

- The Junction Boxes were relocated to allow a safe mean of exiting from the lower floor.

Closed Cooling Water (CCW)[92]

CCW Module was delivered as a single module to the construction site. Some issues occured about the CCW module on site:

- Handrails all around the module were modified to meet the safety regulations of the country
- Access stairs were installed again from the ground floor to the module floor, as the step was too high.
- The floor gratings were reinforced, as the deflection was too much.
- Installation of a lifting beam to allow removal of the pumps (Delivered from factory, but modified and tested on site)
- Pump enclosure was supplied loose and had to be modified on site to fit.

Future modules should arrive to construction site without any missing components, and no need of any modifitaction. Modularization can be done to the maximum level with the insulation, painting, and testing included.

[92] Alstom (2012), p.18

3.7 Future Modules

The next generation of modules will be named as “Wave 3” which already has been started to develop, however their feasibilities are not yet completed. For that reason, in this research only the Wave 1 and Wave 2 modules are evaluated and the Wave 3 modules are excluded.

Although it requires a high effort of especially engineering and the construction departments, the next step should be not only the new modules but also some modifications on the modules so that they would be suitable for the new reference plants. This is a difficult process, since each reference plant requires different technical features. However, the closer the modules get to its sense in the modular architecture, the less work will occur in the beginning of each turnkey project. Modules then can be used again and again in every project with some additional modifications.

This might take a long time and might also have some obstacles that would require special care. For instance as can be seen from Pembroke case; depending on the safety regulations of the project country the height of the access stairs, position of the handrails etc. might have differences. When standardizing the modules, these constraints should be considered as well. An option could be that the modules are designed according to the most strict safety regulations, so that they would get the acceptance of each possible project country.

4 Practical Approach

In the practical part of this thesis, firstly Alstom's approach to the modular concept is analyzed. Then with the case studies, current modules of the company are evaluated in terms of time (man-hour shifted from site to shop), cost, and quality.
Firstly, there will be an overview about the current schedule of Alstom for the full EPC project of CCPP, and the situation of the last project durations. Secondly, the key factors affecting the productivity on site will be reviewed. Afterwards, the modules will be evaluated in terms of their contribution to the time reduction of a KA26-1 project. With the case studies modules will be compared with the stick built solution in terms of cost in six different project countries.
In the evaluation, there is a combined cycle reference plant used, which is called "CAB Reference Plant."

CAB Reference Plant[93]

CAB Reference Plant is a reference plant, which has been developed to provide a standardization of the overall Power Island and includes the developed modules Wave 1 and Wave 2 integrated in its arrangement. Reference plants differ from each other by some technical features. One may have a steam turbine with lateral exhaust and the other with axial. A module is designed according to a reference plant, is usually not suitable for another reference plant. This is the most significant difference of a module in a power plant and a module with its sense in the literature. A change in a reference plant, results with a high degree of change in the modules.

Notice to Proceed (NTP)[94]

NTP is a letter from a client or a project owner to a contractor which states the date that the contractor can start the works of the project which are subjected to the contract conditions. The performance time of the contract starts from the NTP date.

[93] Expert Interview (2013)

[94] Expert Interview (2013)

Provisional Acceptance Certificate (PAC)[95]

This letter is upon the completion of the full project. After the power plant completely finished, and all the tests are done, if there is no mismatching between the agreed performance, plant is delivered to the customer. Provisional Acceptance Certificate simply means the customer acceptance of the power plant.

4.1 Scope

Scope of the practical part of this thesis is consisting of the mechanical & electrical installation, cold commissioning and hot commissioning works of the Power Island (PI) in Alstom Power's combined cycle gas fired power plants. Civil construction works are excluded as well as some parts of the Balance of Plant (BoP). BoP and PI equipment are listed below. Although the costs and man-hours of the BoP works are deducted from the overall cost and man-hours spent during the power plant erection, while assessing the modules in terms of time and cost, some sections of the BoP are included (Main Cooling Water Area- MCW and Fuel Gas Compressor Area), since some of the modules belong to the BoP.

Below list is aimed to give a better idea for the sections and equipment of the scope.

Power Island:

- Common GT & ST Building
- Gas Turbine & Generator Block
- Steam Turbine & Foundation Block
- Heat Recovery Steam Generator (HRSG)
- HRSG Stack
- Feed water Tower
- Pipe rack
- Closed Cooling Water Equipment
- Closed Cooling Water Pipe rack
- Transformer Area
- Electrical Modules
- Emergency Diesel Generator

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[95] Expert Interview (2013)

Balance of Plant (BoP)

Cooling Tower Area:

- Cooling Tower
- MCW Pumps
- MCW Water Treatment
- MCW Electrical Module
- MCW Sampling Station

Water Treatment Plant:

- Demineralized Water Production
- Demineralized Water Storage

Fuel Gas Compressor Area:

- Fuel Gas Compressor
- Fuel Gas Treatment
- Fuel Gas Electrical Room

Waste Water Treatment:

- Lifting station
- Oil Water Separator

As mentioned before, research is following the scope of *CAB KA26-1 (U3/U4) Reference Plant* of Alstom Power.

4.2 Project Duration of a Combined Cycle Power Plant installation in Alstom Power

Market requirement for combined cycle power plant project duration is approximately 28 months.

Alstom schedule for full EPC KA26-1 SS projects was used to be 2+22+2 Months; first 2 months is a period for pre-engineering and last 2 months is for the project float. However, 22 months schedule of Alstom has never been achieved.

Best lead time has been achieved in a project named ‘Cartagena’, in Spain, with 24 months duration. Average lead time of the past 11 full EPC, CCPP projects is over 30 months from NTP to PAC, which will further be called “Mean Time” of the project, since it has been generated by calculating the average value of the past 11 projects. Project countries of these past EPC projects are Australia, France, Italy, Netherlands, Spain, and United Kingdom.

As illustrated in the Figure 25, the mean time of the last projects is far above the 20 months as well as the 22 months schedule. This result of mean time of the last projects is also exceeding the market requirement.

On the figure, different phases of the project are shown in different colors and they are located on the bars in the same sequence as they carried out in the project. The bars start with the transport duration of the Gas Turbine Thermal Block (GT), which is named as 'GT Ex-Works' within the company.

After the arrival of the GT on site, there is the phase called 'Ex-Works-on foundation', which is the GT installation on its foundation. GT thermal block is installed on its foundation and the necessary valves, piping, insulations and casings are installed during this phase. The foundation of the GT is set previously, during the civil works. GT installation lasted two times more than the target schedules (both in 22 and 20 months schedules) even in the best achieved unit.

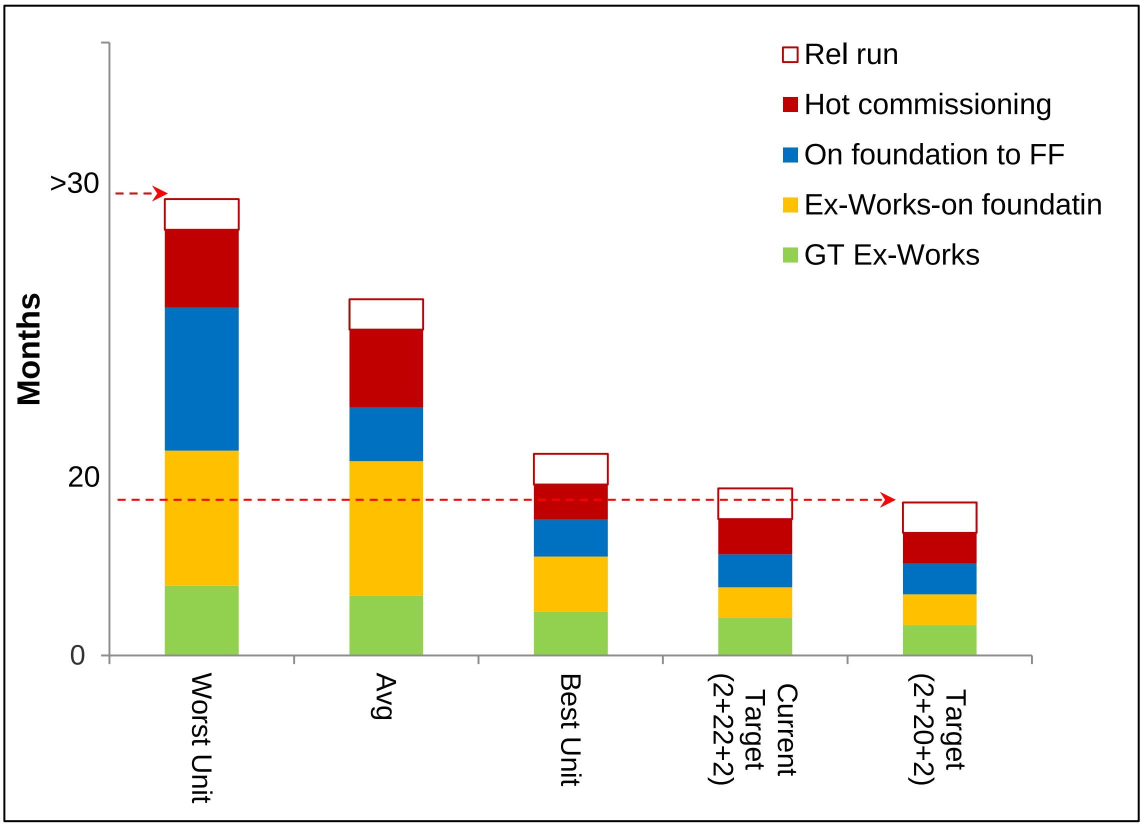

Figure 25. Best Lead Time for KA26 achieved in Cartagena: 24 Months

Third section on the bars with blue color is the duration between the GT installation and the First Fire (FF). During this phase basically all the other

sections of the power plant is erected. For instance Steam Turbine (ST), Condenser, Generator, Heat Recovery Steam Generator (HRSG), Air Intake Manifold, Cooling Water Area, Fuel Gas Area, and so on. Till the FF, all the connections, piping installations, welding, insulations etc. are completed. This phase is a critical phase and with the pre-fabricated modules, the number of parallel activities can be increased and a high volume of man-hours on site can be reduced.
FF is done when all the construction works are completed. The power plant is ready to be fired and the commissioning of the plant can be done. After the FF, starts the 'Hot Commissioning' phase. During this phase, the power plant equipment is being commissioned and the values are observed to see if everything is working as it is supposed to, if there is a need to fix any equipment connection and so on. When the Hot Commissioning phase is completed with all the necessary refinements, changes and fixations the plant is operated for a short time to ensure that it runs without an issue and gives the contractually agreed performance. This last phase is named as 'Reliability Run (RR)'.

Long duration of an EPC project can cause huge extra costs, and in some cases the company might even be obliged to pay high penalties, which will be further called as 'Liquidated Damages (LDs)'. To avoid the unexpected costs and LDs, mean project duration has to be shortened and has to be more robust. With this purpose, Alstom Power has a project called "Lead Time Reduction". This project is focused on reducing the project duration (Lead Time) of the full EPC projects by generating innovative ideas with the cooperation of different disciplines within the company.

Lead Time Reduction Project

Lead Time of a Project: lead time is the amount of time that elapses between when a process starts and when it is completed. Lead time is examined closely in manufacturing, supply chain management and project management, since the companies aim to shorten the time duration of the product delivery to the market.
Main objectives of LTR Project in Alstom Power are:

- to achieve the 2+20+2 schedule with a high productivity
- to consistently achieve project lead times in less than 30 months[96]

[96] Scheurer (2013), p.4

Key solution is to shift the man-hours from site to shop. This means 2 months reduction of the lead time and substantial reduction of the mean time of a CCPP project. Although the likelihood to achieve the 20 months schedule is difficult, improvements will help to get more robust.
The main actions Alstom decided to take in order to reduce the mean time are to reduce the time during: [97]

- Equipment Procurement, Equipment & Civil Engineering, and Civil Construction phase,
- WSC, Power Train, and HRSG erection phase,
- Hot Commissioning, Reliability Run phase.

There are several actions to take in each phase in order to meet with the time reduction objectives. One of the crucial actions is to modularize and standardize the Power Island; to shift M&E erection man-hours from site to shop and increase the parallel activities of the project on site.
Modularization of the power island is one of the innovative solutions in terms of shifting man-hours from site to a workshop. With shifting the man-hours from site to shop, the risk of unexpected issues on site is omitted. Those issues can have various sources according to the project, country (different country regulations, weather conditions etc.), contractors, and/or customer. Also modularization will bring much higher quality with less effort since modules are built in a workshop which is a controlled environment.

4.3 Reasons for Project Delays

Project delay is an important and often occurred issue on power projects, which is derived from several reasons. Conditions on site are much tougher than a workshop, so the construction works are confronted with variable driving factors of which would not be seen in a case of factory production.
EPC contractors like Alstom Power are experiencing difficulties on every construction site depending on the project country regulations, environmental factors, customers and contractors. It is a key requirement to eliminate the loss of efficiency and low productivity on a construction site to make sure the project

[97] Scheurer (2013), p.5

meets with the customer requirements on an agreed date, so that there is no time overruns and highly increased extra costs arise from that.
The driving factors of the low productivity of the construction works on site are given under the following headlines. These factors will be analysed as they are in the literature, while also keeping the common issues Alstom Power has been experiencing in several project countries.

4.3.1 Country Specific Issues

First of all, it is important to give a description of ‘productivity’. Productivity simply means a measurement of the rate at which work is performed[98]. Productivity can be estimated in different ways depending on the sector and even on the company. Each company may have a different way of evaluating their productivity, so has the Alstom Power.
Productivity is usually a ratio between the production output and the required resources to get this output. The resources in the case of a construction site can be labor costs, energy costs, raw materials, etc.
Alstom Power defines the productivity factors of its projects by doing benchmarking. Firstly, the man-hours necessary to complete every task during the construction is estimated by the related department. In this case, as the scope of the thesis comprises the M&E erection works and the commissioning works of the Power Island; man-hours needed to complete the erection and commissioning tasks are estimated by the Erection Technology Group (ETG) and simply called ‘the ETG Man-hours’. This estimation of the ETG is considered as a base and the actual man-hours gathered from a project are compared with the ETG man-hours to measure the productivity of this project. The more projects are evaluated from the same country; the better defined the country specific productivity. For instance if there are already a few projects completed in Country A, and the productivity factors of these projects do not show huge gaps between each other, a general statement can be derived about the productivity factor of this country as well. This estimation of the country productivity is beneficial to estimate the project duration of a possible future project in this country.
On the other hand if the productivity of the different projects of a country have huge gaps between each other; there might be several other issues occurred during execution which are independent from the country itself.

[98] Intergraph, (2012) p.1

Country specific factors which affect the productivity on a construction site can be:

- Weather conditions
- Location
- Political & union regulations
- Lack/Presence of experienced contractors
- Culture

Weather Conditions

Weather has a significant role on the productivity of the construction works. If the project country has extreme weather conditions, like extreme cold or hot, the productivity on site decreases.

Alstom Power experienced bad weather conditions during its projects in several countries like the countries in Middle East, in northern Europe and in Asia.

In the UK the weather is quite often windy and rainy interrupts or slows down the construction works. In Middle East or in some Asian countries like Singapore on the other hand, the temperature is quite often above 50 Celsius degrees which also make the work on site more difficult. Especially the workers who are not used to that climate can get demotivated quite easily. This demotivation leads to inefficiency in labor works and results with low productivity, longer working hours and schedule delays.

Beside the extreme high temperatures of Middle East countries, there is also the sand factor. Even though the location of a project is far from the desserts, the air carries a high number of sand particles with the wind to the construction site, which are dangerous for the equipment of the power plant. During the construction, the equipment can get damaged because of this sand concentration in the air.

Location

Location of a project country is important for several reasons. It is important to have reliable suppliers close to the project country or at least easily reachable. It is not always easy to find a supplier that a company can trust on, and that has the sufficient experience and knowledge about the products. There are some suppliers that Alstom Power has already built trust with and worked together on several projects. That is why; it is quite a relief to have the current suppliers reachable from the project country in case of any recent, instant changes required from the customer. If a change or a modification is required by the customer, some new components might need to be purchased. If the country has a good location, close to the harbor or has a good location of road transportation, waiting time of the new components delivery will not take long and the schedule will not be missed.

Political & Union Regulations

Strict union regulations of a project country are a factor which slows the works on site. UK and Netherlands are examples of the countries with strict union regulations, which results with the relatively low productivity of the projects executed in these countries. This is one of the reasons that these countries are chosen for the case studies in Chapter 5. Environmental Health and Safety (EHS) requirements in the UK and Netherlands are extremely high, and at the end these requirements cause intensive care of every work and worker, slows the works on site.

Alstom Power is quite experienced about EHS regulations and had no conflict with any customers from these countries of strict regulations. EHS is one of the priorities of the Alstom Power and the EHS team of the company is always quite well organized for any project, and monitors the health and safety of the field personnel as well as the ergonomics of the workplace. However, it is a fact that the higher the EHS requirements are, the slower the works on site are.

Strikes are another point of concerns. A strike during the erection of the power plant can lead to high time overruns of the project and can cost a lot to the company.

Lack of experienced sub-contractors

This is one of the problems Alstom Power is experiencing in its projects in Singapore. Labor costs in Singapore are quite low compared to Europe, and it is not that difficult to find workers for the construction works. However, it is difficult to find well-qualified and experienced sub-contractors for the works on site. In comparison to Europe, it takes much more time to monitor the sub-contractors´ works, and to do the reworks.

Culture

Different cultures mean the different habits, way of works, holiday schedules. In some countries in Middle East for instance, the weekend starts on Thursday instead of Friday. That means the people in the office in Europe are not able to contact with the field employees on a Friday, and need to wait till Monday. Field

employees on the other hand might feel a bit uncomfortable to this unusual working time and this can affect the labor productivity.
Even the food, life style of the new country might affect the workers who are gathered from different countries. The less it takes to complete the project, the less is the risk of the field employees getting demotivated because of the site life in a foreign country.

4.3.2 Sub-contractor Issues

As an EPC contractor, Alstom Power executes the engineering, procurement and commissioning works in-house, and works with several sub-contractors for the construction works on site. Sub-contractors can be one or more according to their experiences and the available work slots.
Managing the works of the sub-contractors is quite a big challenge for the company. Having more than one sub-contractor company on site means hundreds of people who have never worked together before, gathering on site for the completion of a huge task. It is quite often that these individuals have problems between each other, with the stress of workload, shift works, long hours of work without a proper holiday, thus physical and mental tiredness. Their way of scheduling works can decrease the speed of the others and can lead to the delay of the overall schedule.
Problems don't only occur between the sub-contractors but also between the sub-contractors and Alstom power. Depending on the location of the project, it is not always easy to find the well qualified workers, with sufficient experience. Sometimes the subcontractors build their workforce from a group of people who have never done such a construction work before. This situation requires Alstom to check and to monitor almost every work the sub-contractors execute and make the necessary corrections as early as possible. In order to be able to keep the track of the works sub-contractors do, Alstom has to provide sufficient number of its supervisors to the construction site. These supervisors monitor the sequence and the quality of the works, and take action when needed.
Changes, modifications, corrections and the reworks needed because of the poor working quality of the sub-contractors, lead to increased man-hours, high labour costs and the risk to delay on the schedule.

4.4 Importance of Labour Productivity

Labour productivity is the key factor on the construction works on site. All the issues mentioned above like; country specific issues, customer claims, sub-contractor issues have effects on labour productivity. They directly or indirectly affect the labour productivity, so the productivity of the project. In power plant construction, the productivity on site is mainly the labor productivity.

The definition of productivity by American Association of Cost Engineers is mainly related on labor productivity: '*relative measure of labor efficiency, either good or bad, when compared to an established base or norm*.' [99]

Because of its high importance and effect on construction works on site, labour productivity deserves its own headline.

There are many factors which affect the labor productivity. According to the Mechanical Contractors Association of America (MCAA) some of the factors are listed below. The list is called Impacting Factors on Construction Crew Productivity, which includes around 35 factors affecting the labor productivity on a construction site. These factors are summarized as following:

One of the biggest and common factors is *overtime* on site. Usually the working hours on site are much higher than in the office. Depending on the regulations about the site employees of the project country, daily working hours go up to ten and per week the working hours can be up to sixty hours, and this causes physical *fatigue* and poor mental attitude which results to low efficiency.

Due to overtime, over-inspection, excessive hazards and increased conflicts on site, workers might lose the willingness, confidence, and desire to perform their tasks. In case of extreme physical exertion and long working hours, physical and mental fatigue can occur.

Construction projects in such areas which have extreme weather conditions (extreme hot or cold) as explained before will cause *absenteeism* and *turnover*. In case of any turnover, the new workers who replace with the previous ones are usually not familiar with the work and the working areas, and they will need the supervision from the more experienced ones. This will cause the time loss and delay of works.

It is quite usual to *work on holidays* on a construction site. However, in this case, the hourly rates of the workers are much higher and their efficiency is lower than the usual working days. Being away from home and besides working

[99] cf. Intergraph ,2012 p.2

on a holiday is often a demotivation for the workers and they don't perform their work with their usual productivity.

Another common issue is being obliged to *work in a limited space* with other contractors, which results into the inability to use or locate the tools conveniently, increased loss of tool, delay of work or even additional safety hazards.

If the construction site is in a *rainy location*, this might cause some craft to stop their works. Work will either stop or continue with less efficiency. Moreover, some tools and equipment can get damaged because of interacting with the rain.

Besides the long working hours, there will be also *shift work* during the erection of a plant. Unfortunately the second and the third shifts always have less efficiency than the first shift.

There can be some *access problem* from one point to another one on site, which would then decrease the work speed of the craft. Besides the access to the different points of the site, there can also be a problem about accessing to the certain tools, or waiting for some other craft to hand over the necessary tools to perform the work. The higher the number of employees on site is, the more often these restrictions are experienced. Also the fact of working with a high number of people every day in a restricted area can disturb the employees and the risk of the possible conflicts between them increases.

All those factors and many others cause unproductive and long working hours on site which increases the cost and project lead time. Shifting man-hours from site to a workshop will result with less and more productive man-hours. Since shop is a controllable environment, there will be less quality and safety issues as well as no worker issues such as dissatisfaction, complains, physical fatigue and so on. [100]

4.5 Productivity Factors in Different Countries

As explained before, productivity factor of a country or a project is calculated by making a benchmark by using the man-hours calculated by the Engineering and Technology Group (ETG) within Alstom Power.

Productivity factor of the erection works of a project is a ratio of the total erection man-hours recorded on the field to the ETG man-hours.

[100] cf. Intergraph, (2012) p.6-9

Productivity factor of the erection works of a country on the other hand, as can be seen from the formula below, is the ratio of the erection man-hours recorded on site to the product of ETG man-hours and the number of projects taken into consideration in that country.

$$Productivity\ Factor\ of\ the\ Country = \frac{Total\ Mhrs\ Recorded\ from\ the\ Projects\ in\ the\ Country}{ETG\ Mhrs\ X\ Number\ of\ Projects\ in\ the\ Country}$$

Equation 2: Productivity Factor of a Project Country[101]

Usually productivity is shown as a factor which is equal or less than 1. If the productivity factor equals to 1, the system has the highest productivity and it cannot have a higher value than that. The more the gap between a productivity factor and 1 is, the less productive a system or a process is. However, as it can also be seen from Equation 2 above, Alstom indication of productivity is vice versa.

First of all, productivity factor can be more than 1. If the result is equal or less than 1, project is aligned with the schedule or beyond the schedule. The higher it is from 1, the less productive is the country/project. To make it more clear; if the man-hours recorded on a project site are higher than the ETG man-hours, the result is more than one, which also means more man-hours spent on erection works than they actually require, hence the productivity is lower although the value is higher than 1.

Figure 26 shows the productivity factors of Power Island, Heat Recovery Steam Generator (HRSG), Water Steam Cycle (WSC) and Electrical works in some of the past project countries.

'Baseline' in this graph shows the theoretical calculation of the man-hours by the Erection Technology Group (ETG) and considered as having a productivity factor of 1. The other man-hours on the legend are:

- SG: average productivity value of the projects in Singapore
- UK: average productivity value of the projects in the UK
- AUS, I: average productivity value of the projects in Australia and in Italy

[101] Own Calculation Based on Expert Interview in Alstom Power

- ES & FR: average productivity value of the projects in Spain and in France
- 20 KA26-1: average productivity value of the past eleven KA26-1 projects, which have 20 units in total. These twenty units include the projects in the UK, Australia, Italy, Spain, France and a few more, but do not include the projects in Singapore.

Productivity factors for Singapore, UK, Australia, Italy, Spain, France and the 20 KA26-1, are estimated in comparison to the productivity of the 'Baseline' value. The productivity factors are estimated by ratio of the man-hours spent on a project to the man-hours estimated by the ETG group. If the man-hours recorded on a project, is higher than the theoretical value (ETG man-hours), the ratio has a value more than one. Although the result is more than one, the productivity is less than the theoretical estimations. Hence, the higher the result of the ratio from '1' is, the less the productivity is. In this case the least productive projects are the projects in Singapore, which have the highest number on the graph.

As can be seen with the colorful bars, the productivity is calculated for the different sections of the Power Island and also for the complete Power Island.

Firstly, a productivity factor is estimated by considering the man-hours of the whole Power Island, and then for the whole Power Island by excluding the electrical works.

Secondly, the productivity factors are estimated by dividing the Power Island in a way that it is usually divided for the different contractors for the construction works. As explained before, as an EPC contractor, Alstom Power does the Engineering, Procurement and also the Commissioning of a power project and gives the Construction works to some construction companies. These companies, or so called the contractors undertake the construction works. Alstom Power usually divides the construction works into four categories and each category is undertaken by a different contractor. This separation of the Power Island for four different construction companies, as shown in
Figure 26, is:

- Power Train (PT) – Gas Turbine & Steam Turbine mechanical and piping works
- Water Steam Cycle (WSC) mechanical and piping works
- Heat Recovery Steam Generator (HRSG) mechanical and Piping works
- Electrical works

There is a huge difference between Singapore and Europe in terms of productivity on site. Productivity in Singapore is much less than the productivity in Europe, which either delays the schedule or achieves the aimed completion date but has much higher man-hours recorded than projects in the other countries. Some of the reasons of the low productivity could be, working with less experienced contractors and labor that are not capable of performing the work on their own and need recruitment, and insufficient regulations of the working hour in those countries which have much less productivity like Singapore. There could be also project specific reasons such as client issues, last moment changes in the project, late equipment delivery etc.

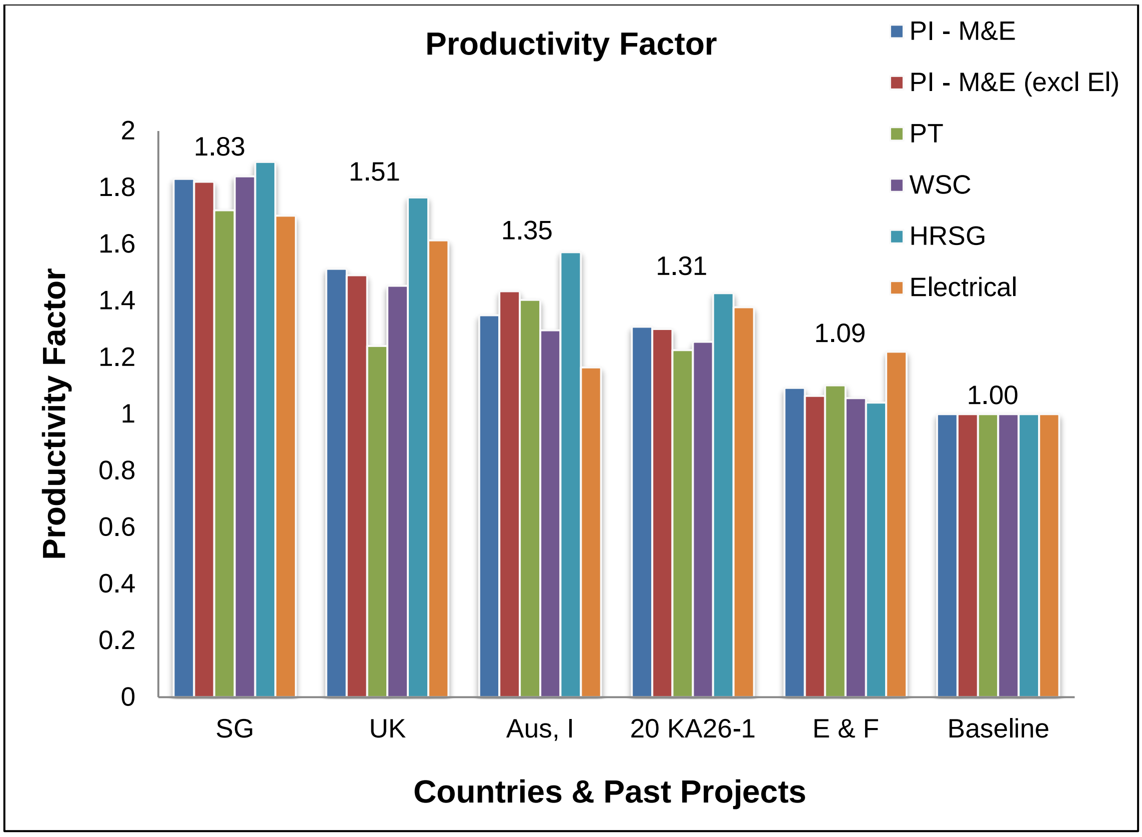

Figure 26: Productivity Factors for Power Island – Mechanical & Piping Erection

On the other hand labor costs in Singapore are less expensive than Europe. Despite the much higher inefficiency, overall construction costs might be lower than the ones in Europe. For that reason it is essential to assess the impact of the modularization in terms of cost, time and quality in different countries. In the practical part of this thesis, module costs are assessed according to nine different countries to make a conclusion where the modularization is essential to reduce the project lead time and where it is too costly, or where the modules should be constructed to avoid the high transportation costs.

4.6 Impact of Modules on Time Reduction

Modules in Alstom are being developed in multiple waves, targeting at optimizing repeatability through assembly in a protected environment and reduction of uncertainty regarding quality and lead time. There are currently 2 Waves of modules. *Wave 1 Modules* and partly *Wave 2 Modules* designs are completed and have already been used in some projects.
Modules have one of the biggest portions of man-hours reduction (shifting man-hours from site to shop) on site.
Table 10 shows that by only building currently available Wave 1 and Wave 2 modules, man-hours of Power Island can be reduced by approximately 17%, and Water Steam Cycle Erection works on site can be reduced by 66%.

	MAN-HOUR REDUCTION ON SITE
Wave 1	8,5% of all Power Island
Wave 2	8% of all Power Island
TOTAL	**16,5 % of all Power Island**

Table 10. Man-hour Reduction of Each Wave

Modules reduce the man-hours spent on time and increase the probability to achieve the target project lead time. Pre-fabricating the modules helps also to increase the parallel activities on site.
One of the aims of the Lead Time Reduction Project is to increase the parallel activities on site, so that the different disciplines and subcontractors will not wait for other works to be done in order to perform their activities. The more sections of the power plant are modularized, the more parallel activities can be created and the less time will be needed on site. With the same logic, the more parallel activities are created on site, the higher will be the probability to achieve the target lead time of a project and the more robust the project duration of KA26-1 power plants will get. Figure 27 shows the probability to complete a KA26-1 project in 20 and 30 months in the UK, Spain, France as well as the average of

the last twenty units installed. This graph is valid for all the Power Island erection works except the electrical works.

The two solid lines (blue and green) are based on the estimations of the past twenty KA26-1 units. These projects in average lasted more than 30 months, and the probability curves show that without any man-hour reduction, the probability to complete the erection works of the power island of a unit is around 50%; however this probability for the 20 months schedule is less than 10%. If the man-hours are shifted from site to shop, pre-fabricating the complete Wave 1 and Wave 2 modules, the probability will follow the red arrow and will increase for 30 months to more than 85% and for 20 months to almost 40 %.

In Spain and in France the probability factor is much higher in comparison to the United Kingdom.

As the Figure 27 shows that a project in France (FR) or in Spain (ES) already achieves a 30 months schedule with more than 90% probability while in the UK this probability is only around 10%. This means for a project country like UK which has low productivity, modular installation is crucial in order to increase the probability. Modules increase the probability to achieve 30 months schedule in the UK, from 10% to 70%. However, in order to achieve this enormous change of probability, all the modules have to be included to the pre-fabrication. Wave 1 and Wave 2 modules should be seen as a big unique package and have to be applied together in order to benefit from the increase of the parallel activities on site and reduction of the man-hours.

Lastly, in Spain and in France the probability to achieve 20 months schedule is around 10%, which is not good at all; however more dramatically, the probability for 20 months in the UK is 0%. With the modular installation this probabilities are increasing for Spain and France to more than 90% and for the UK to almost 10%.

Without any other improvement package, only with the pre-fabrication of the modules, the probabilities are increasing enormously.

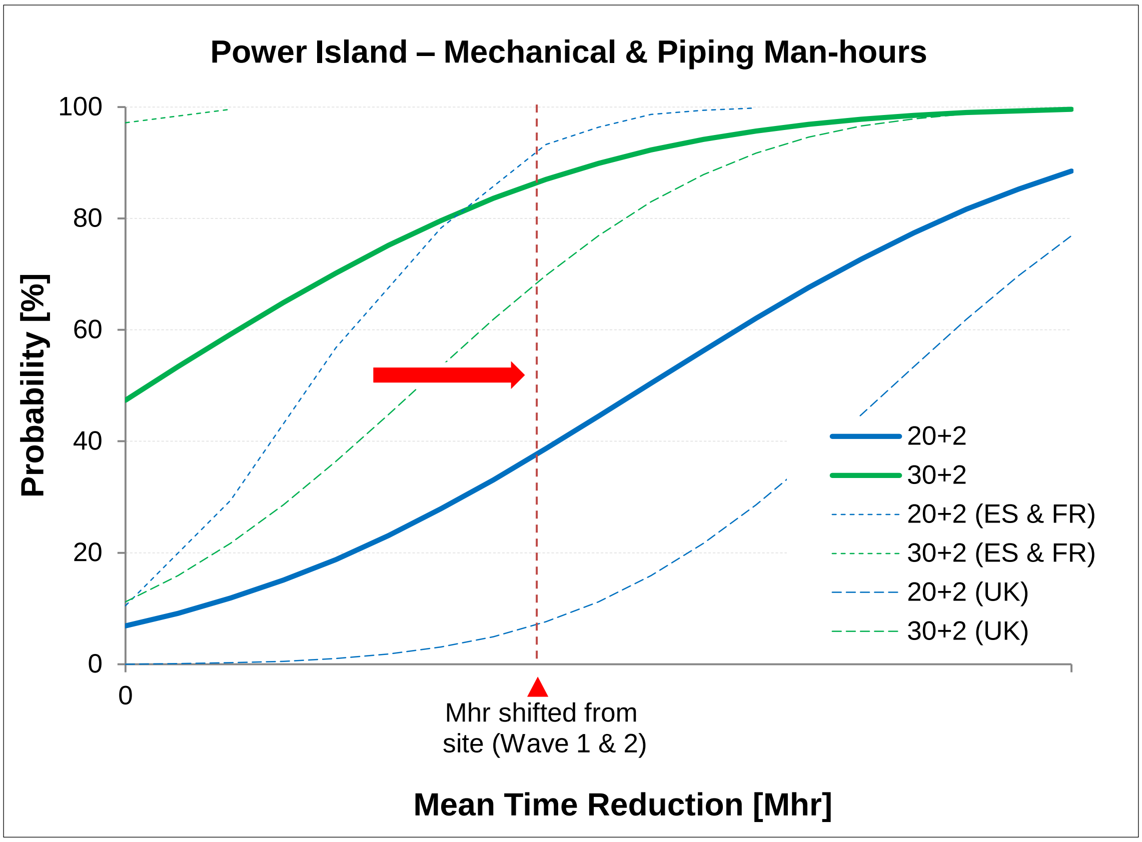

Figure 27: Contribution of Man-hours Reduction on Probability

4.7 Cost Impact of the Modules

Cost impact of modules highly depends on the project country, since the shop hourly rates and transportation costs are the key factors. Ideally modules should be built in the project country to avoid the high transportation costs; however it is not always the case. In case there is no packager suitable for Alstom criteria, modules have to be constructed in another country and transported to site.

To assess the cost for different scenarios, in addition to hourly rate of the packagers in different countries, transportation costs should be taken into consideration as well.

Below there are some case studies for a possible project site in Italy, UK, Netherlands, Australia, Singapore and Saudi Arabia. Module prices, transportation costs and additional import costs are estimated considering the packager in one of those countries. There are several reasons for selecting these countries for the case studies, and all those reasons will be mentioned under the headline of each case study.

Depending on the labor costs of the project country, country of the packager and the transportation costs; in some cases modular installation might cost more than the stick built solution. However, there are more to consider then only the module costs, for instance better quality in shop, liquidity damage in case of late delivery of the project or opposite; possible bonus in case of early completion.

Figure 28 shows Liquidated Damages according to different project countries in case of 10 days late delivery of a CCPP project with 500 MW output. LDs are estimated for Australia (AU), Netherlands (NL), Italy (IT), Singapore (SG), the United Kingdom (UK) and Saudi Arabia (SA).

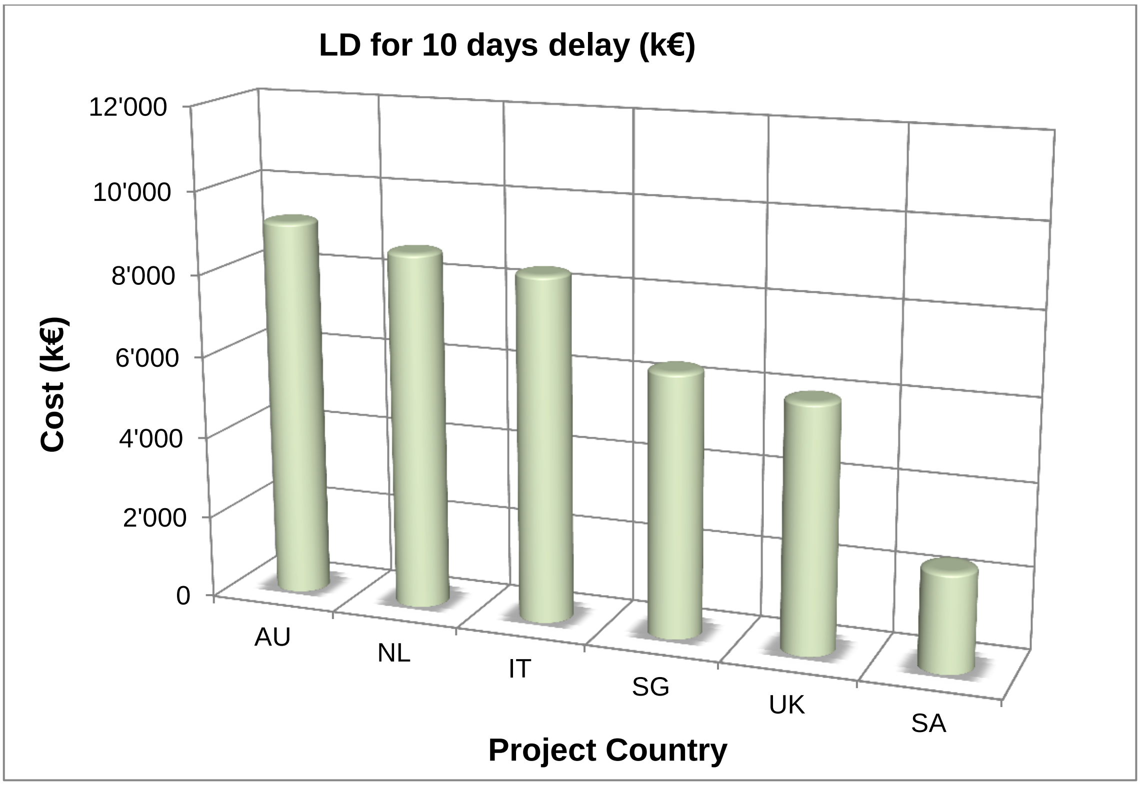

Figure 28. Liquidated Damage (k€) for 10 days delay of 500 MW Power Plant[102]

Module costs in case studies are estimated while considering man-hours of Wave 1 and Wave 2 modules in total. Firstly for each project country the cost of stick-built solution is calculated as product of composite rate and man-hours

[102] Own Calculation Based on Expert Interview in Alstom Power

spent on site to build the modules. Equation 3 shows the cost calculation formula of a stick-built solution.

$$\boldsymbol{Cost\ of\ Stick\ Built\ Solution} = \\ \boldsymbol{Country\ Composite\ Rate\ x}\ \{\boldsymbol{M\&E\ Mhrs} + \boldsymbol{Civil\ Mhrs}\}$$

Equation 3: Estimation for the Stick Built Solution According to the Project Country[103]

In case of building the modules in a packager's shop, there will be much less man-hours on site. Shifting man-hours form site to shop will increase the quality and probability to achieve the target project duration, and also reduce the reworks, contractor issues and EHS issues on site.
Costs of modules are estimated according to the shop hourly rates of the packager country and man-hours spent in shop to construct the modules. Also transport of modules from packager to site as well as the remaining works on site should be added. So overall module cost can be calculated with the formula shown in Equation 4.

$$\boldsymbol{Cost\ of\ Modular\ Installation} = \\ \boldsymbol{Project\ Country\ Composite\ Rate\ x\ Remaining\ Mhrs\ on\ site}\ + \\ \boldsymbol{Module\ Price}\ +\ \boldsymbol{Transportation\ Costs}$$

Equation 4: Estimation of the Modular Installation Cost[104]

Although module price depends on the packager, to have a general figure for the different countries, it can be assumed as the product of required man-hours to build the modules and the shop composite rate, which is shown below, in Equation 5.

[103] Own Calculation Based on Expert Interview in Alstom Power

[104] Own Calculation Based on Expert Interview in Alstom Power

$$Module\ Price \cong \{Shop\ Composite\ Rate\}\ x\ \{Total\ Mhrs\ for\ Module\ Construction\}$$

Equation 5: Module Price for the Different Packager Countries[105]

Transportation costs from packager to site have a big portion on module costs depending on the distance between packager and the project country.

4.8 Case Studies

Case Study countries are Italy, United Kingdom, Netherlands, Singapore, Australia and Saudi Arabia. Italy is chosen to represent the countries in central Europe which would have the similar labor costs.

Netherlands and the UK on the other hand are chosen, since they have much higher labor costs in comparison to the central European countries while also having more strict union regulations. The projects executed in these countries have lower productivity then the ones in for instance Italy, Spain and France. Also the weather conditions and customer attitudes in Netherlands and the UK are tougher than the central and eastern European Countries.

Singapore and Saudi Arabia have the lowest labor costs among the case study countries. They are chosen to represent the low cost Arabic and Asian countries with low productivity on site. The low productivity, often occurring delays on site works, difficulties to find skilled and well qualified site craft makes the modularization an asset.

The last case study country Australia is chosen since it was an extreme example of a packager country for all the other countries. As it can be seen on the following graphs, prefabrication of the modules in Australia has always much higher costs than the stick built solution. However, as mentioned before, this is just an extreme example and Australia; this far and high labor cost country will probably not be chosen as a packager country.

Graphs in all the cases, have the same scale; however, there are no numbers shown as cost values in order not to expose any confidential information. On every graph, the total cost of the construction on site (stick built solution) is

[105] Own Calculation Based on Expert Interview in Alstom Power

shown and the cost value on the y-axis is marked with “SB”. Moreover, the total cost of modular installation in the remaining five countries are calculated as a sum of module construction in a packager´s workshop, transport to the project site, and finally the remaining works done on site. The most expensive modular solution is marked on the y-axis as “Max”.

The gap between the “Max” and the “SB” are in every case much lower than a liquidated damage that needs to be paid in case of a project delay.

4.8.1 Case 1: Project Country – ITALY

Packagers are located in UK, Netherlands, Australia, Singapore, and Saudi Arabia.

Italy, Spain and France have approximately the same composite rates on site; however productivity of Italy is less than those two countries. Italy has a productivity factor of 1.35, while France and Spain have a productivity factor of almost 1. Since it has lower productivity, instead of Spain or France, Italy has been chosen as a case study country. Lower productivity means higher need of modularization. For the evaluation of transport costs, it is safer to estimate far distances like intercontinental distances like Singapore or Australia, although in real life the first choice as a packager country would be a country in Europe or closer to Europe to avoid the high transportation costs and risks.

As it can be seen from

Figure 29, modular solution in Singapore and in Saudi Arabia are less expensive than stick built solution in Italy, although they have high transportation costs. Netherlands and United Kingdom on the other hand are more expensive; however it would still be beneficial to build the modules in those countries, when the aspects of quality, safety, risk and time constraint are considered. Australia seems like an extreme example. As this country has the highest labor costs in shop of all the others, and also it is very far from Europe, overall modules costs are much higher than the other countries. Although the first option for the packager country should be the countries with the lowest costs like Singapore, Saudi Arabia or the UK, the cost gap between the stick built solution and the module construction in a packager in Australia is less than possible delay liquidated damage of a project in Italy.

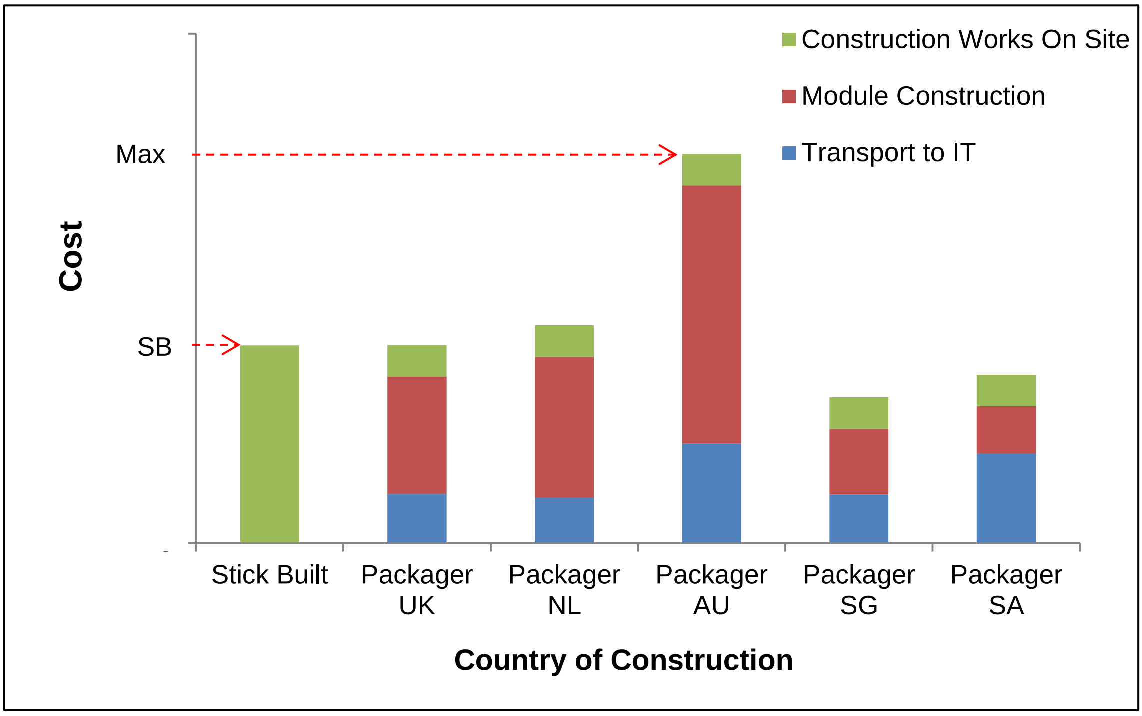

Figure 29. For a project in IT, cost comparison of modular and stick built solutions of Wave 1 & 2 Modules

4.8.2 Case 2: Project Country – UNITED KINGDOM

Packagers are located in Italy, Netherlands, Australia, Singapore, and Saudi Arabia

United Kingdom is a labor expensive country and also has very strict union regulations, which decreases the construction speed on site. Shop pre-fabrication eliminates the time consuming and sometimes hard to follow EHS regulations.

Another issue about a construction site in UK is the weather conditions. Since it is quite often raining, it affects the labor productivity, slows down the works on site and causes project delays.

The results of the case study for United Kingdom can be seen on Figure 30. This figure shows that the only case which is even higher than the expensive stick built solution of the UK is Australia, as in all the other cases. However the other countries like Italy, Singapore, Saudi Arabia and Netherlands will have better costs then the stick built solution in the UK.

Productivity factor of the UK is 1.51 which means man-hours spent on construction works during a project in the UK lasts around one and a half times more than the ETG estimations. This low productivity factor of the UK makes modularization an essential way in order to avoid any delay of a project.
When considering the cost benefit and the other benefits of modules, it is clear that a power project in UK should definitely have modular installation.

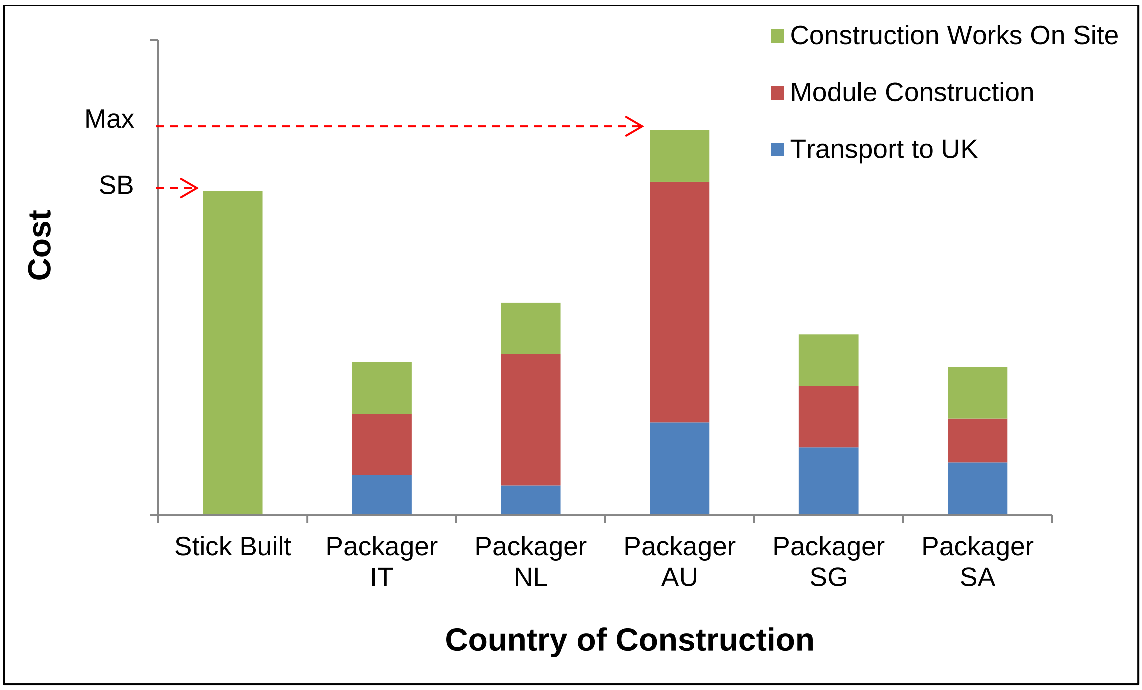

Figure 30. For a project in UK, cost comparison of modular and stick built solutions of Wave 1 & 2 Modules

4.8.3 Case 3: Project Country – NETHERLANDS

Packagers are located in Italy, UK, Singapore, Australia and Saudi Arabia.
Netherlands is another European country with strict EHS regulations and high composite rates like the UK. In terms of productivity the results of the Netherlands projects show that the productivity factor of this country is also similar with the UK, which is 1.51.
Figure 31 shows the cost calculation of module construction in Italy, UK, Australia, Singapore, and Saudi Arabia. Module construction in Italy (or another central European country), Singapore, Middle East and even in United Kingdom costs less than a stick built solution in Netherlands and reduces the risk of a project delay.

Although the UK has higher labor costs on site than Netherlands, module cost in the UK is less than stick built solution in Netherlands since the shop hourly rates are much less expensive than site composite rates.
Transportation costs from the UK to Netherlands are less expensive than the transportation costs from Italy, Singapore, and Saudi Arabia to Netherlands.

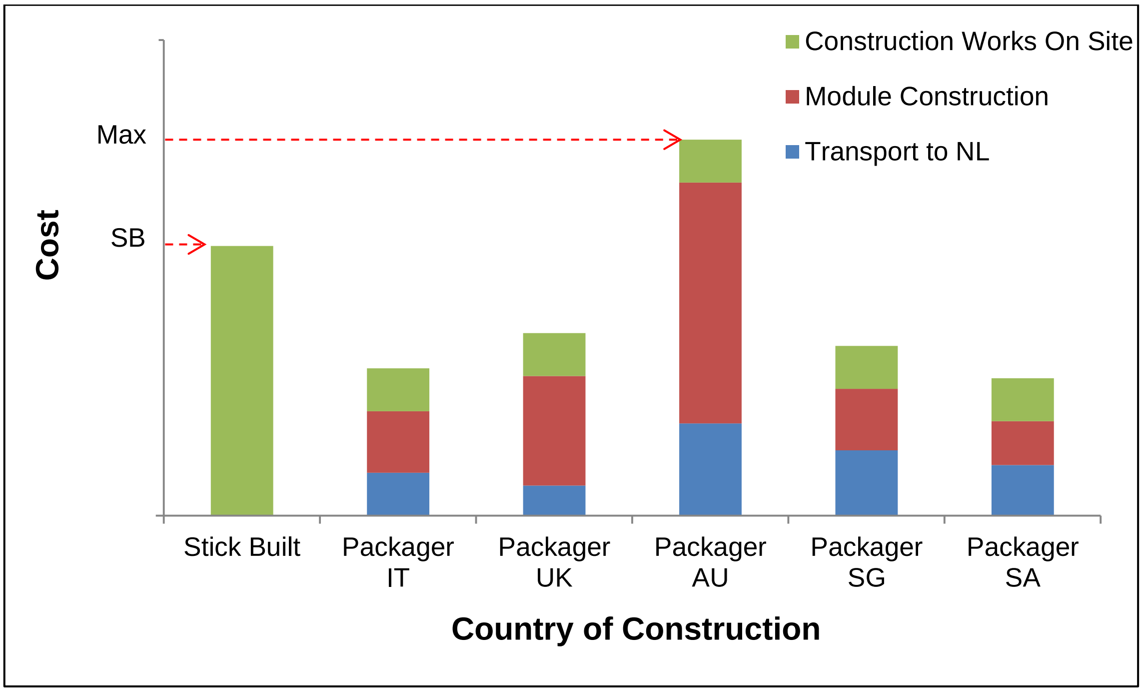

Figure 31. For a project in NL, cost comparison of modular and stick built solutions of Wave 1 & 2 Modules

4.8.4 Case 4: Project Country – SINGAPORE

Packagers are located in Italy, UK, Netherlands, Australia and Saudi Arabia.
Singapore has the least expensive labor costs among these countries of the case studies, as can be seen on Figure 32. Even though a project lasts much longer than expected, labor costs would not cause enormous extra costs. However, having the least expensive labor costs doesn’t change the fact that a project delay would oblige the company to pay very high Liquidated Damages.
Singapore has the lowest productivity factor with 1.83 among the countries of the case studies, which means that the probability of a project to delay in Singapore is much higher than the others.
In Singapore one of the biggest issues is to find well-qualified and experienced craft for the construction works. The contractors need high level of supervision

and their works have to be monitored carefully. Thus the risk on site in Singapore is higher than it is in a European country.
For a project in Singapore, the ideal packager countries would be Singapore, or a close country which also has low shop hourly rates like Thailand.

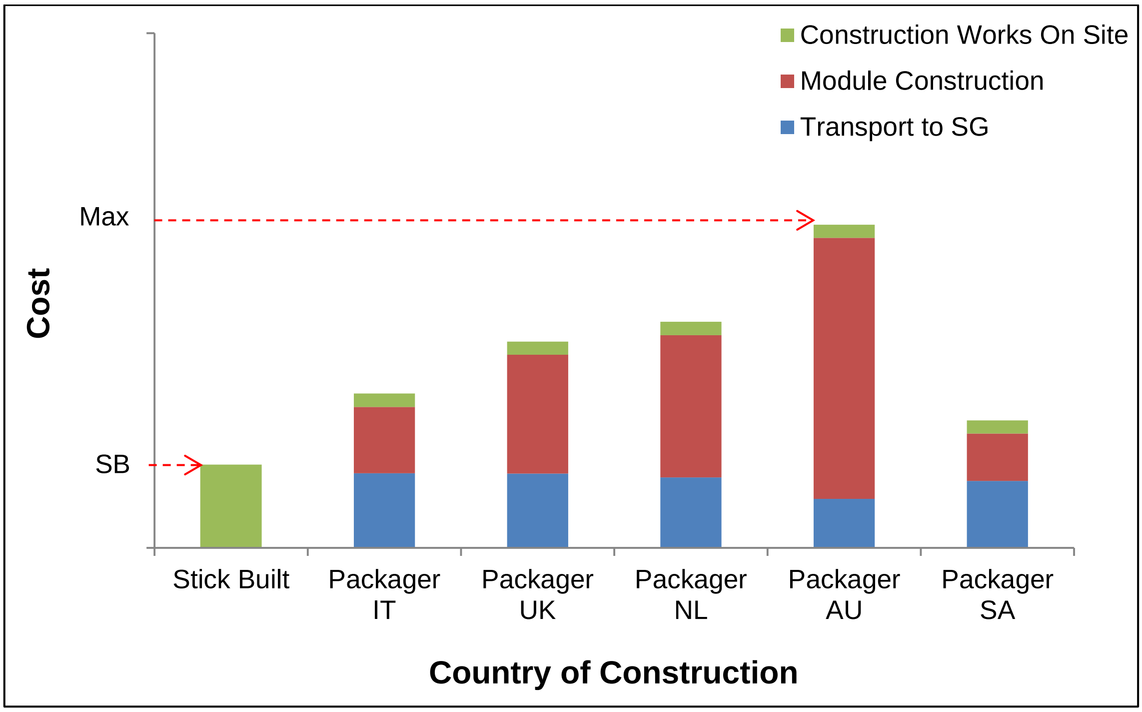

Figure 32. For a project in SG, cost comparison of modular and stick built solutions of Wave 1 & 2 Modules

Saudi Arabia or another Middle East country is good packager countries as well.
An interesting fact about Singapore is that it is the only country among the case study countries, which has higher hourly rates in shop than on site. However, module construction in shop would still be a less risky, more robust solution with higher quality even though it would cost around 20% more to build the modules in shop.
The contribution of the modules to the time reduction of a KA26-1 Power Island erection covers extra cost in shop and much more.

4.8.5 Case 5: Project Country – AUSTRALIA

Packagers are located in Italy, UK, Netherlands, Singapore and Saudi Arabia. Australia in contrast to the previous case (Singapore) has the most expensive labor costs among these six countries both on site and in shop. This means, building modules in a packager's workshop even from a far country like Netherlands and United Kingdom which also have high hourly rates in shop, would cost less than a stick built solution. Although the productivity in Australia (1.35) is not as low as it is in Singapore or in the UK, the probability to have a project delay is still high. In case of a project delay, there will high amount of LDs to be paid. On the other hand, Australia already has much higher labor costs than European, Middle East or Asian countries, and the modular construction is always less expensive than the stick built solution.

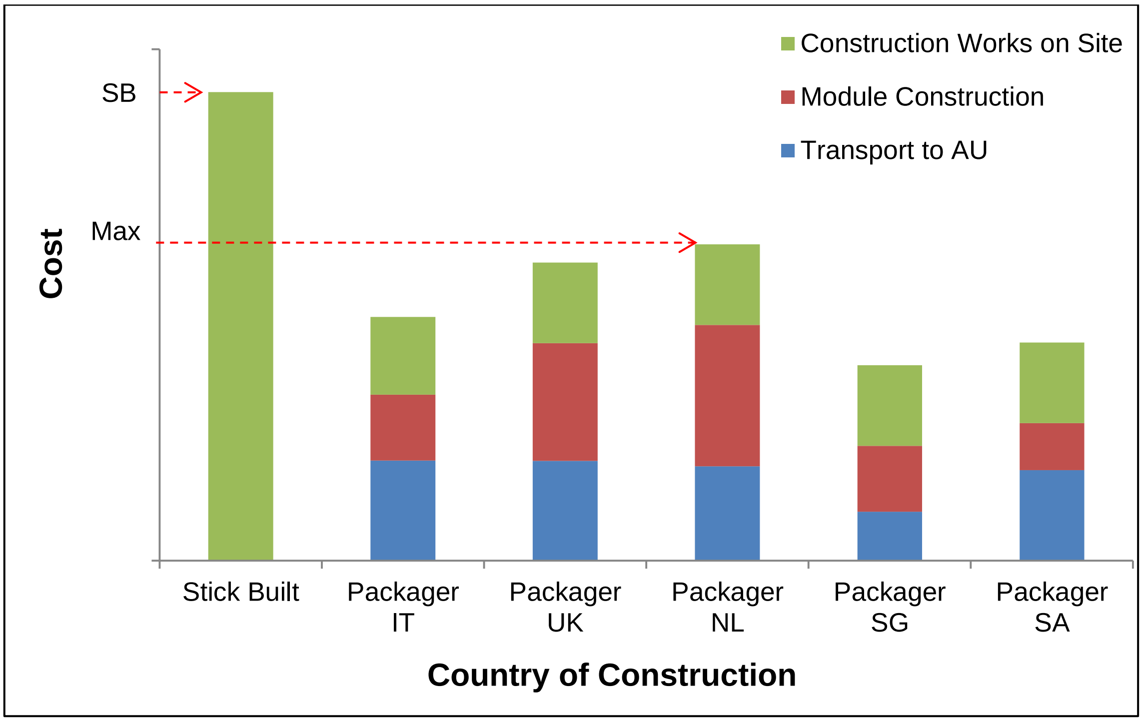

Figure 33. For a project in AU, cost comparison of modular and stick built solutions of Wave 1 & 2 Modules

Figure 33 shows the results for modules in Italy, United Kingdom, Netherlands, Singapore and Saudi Arabia, which are less expensive solutions than doing all the construction works on a site in Australia. For Australia in terms of cost, modules are crucial. As the other countries, modules are also crucial because of time constraints, as well as productivity and quality improvement.

4.8.6 Case 6: Project Country – SAUDI ARABIA

Packagers are located in Italy, UK, Netherlands, Singapore and Australia.
Saudi Arabia, like the other neighbor countries in Middle East, has low labor costs on site as well as in shop. Cost of the stick built solution doesn't have much difference with Singapore. Thus this case of Saudi Arabia is similar with Singapore case as can be seen from the Figure 34. One difference between Singapore and Saudi Arabia is that Singapore unlike the other countries has higher labor costs in shop than on site. Saudi Arabia has a better productivity than Singapore; however, it still has a low productivity factor, which is around 1.5 like in the UK.

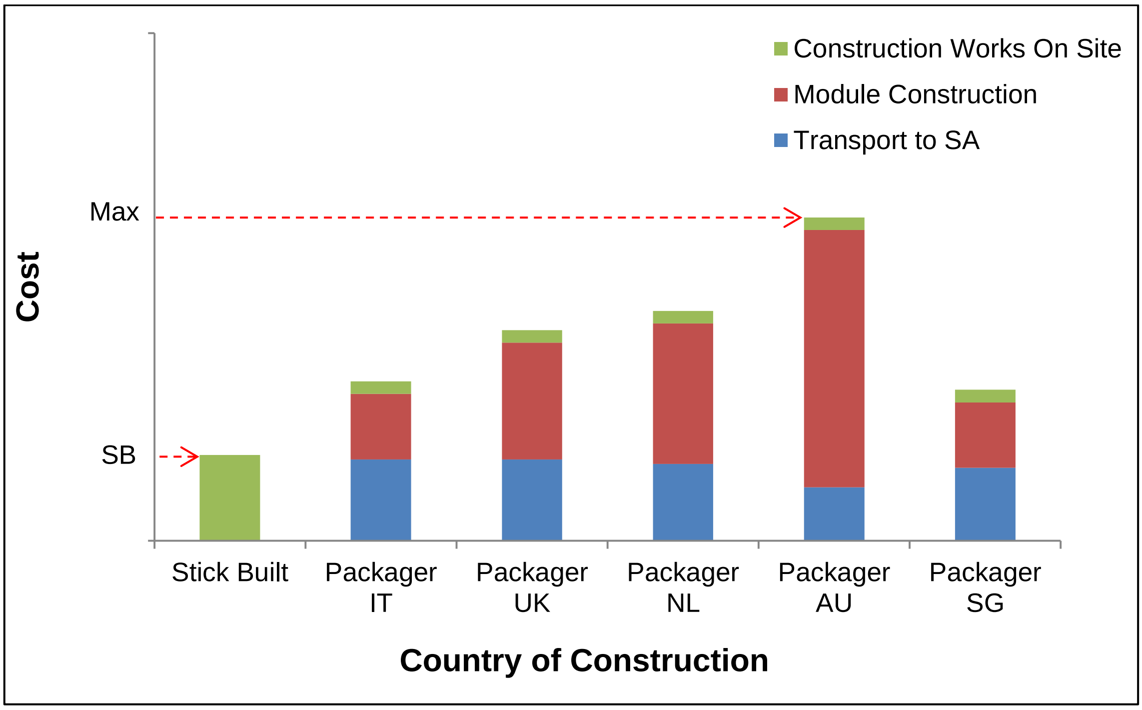

Figure 34. For a project in SA, cost comparison of modular and stick built solutions of Wave 1 & 2 Modules

In case of having Saudi Arabia as the project country the optimum packager country would be again a Middle East country which also has low labor costs. Since the distance is not too long between the countries, transportation cost would be low as well. A packager in a low cost Asian country like Singapore compensates the high transportation costs by low labor costs and reduced risks and better quality than on site.

4.9 Pre-fabrication and Transportation

Selection of the packagers for the prefabrication and the arrangement of the transportation are the most critical points about the modularization. There is only a limited work that has to be done on site, which is mainly the assembly of the sub-modules, setting the foundation and the connection of the modules with the other sections of the power plant. Therefore the focus should be shifted to the timely completion of the engineering works, the pre-fabrication works in the workshop on time with the required quality and finally a safe transportation to site.

4.9.1 Packager Selection[106]

Selection of the packager is highly important in terms of experience, available work slot, quality and the location. Since the road transport is most of the time not possible for such big parts, packager ideally should be close to the harbor or at a location easily reachable from the harbor.
In Alstom Power there are two different working models applied, when cooperating with the packager:

- One Stop Shop Model
- Free Issue Material Model

In ‘One Stop Shop Model’, the packager is responsible for management of the supply chain based on commercial terms with components suppliers pre-negotiated by Alstom.
In ‘Free Issue Material Model’, the packager is responsible for production of the modules. Alstom is managing the components supply chain and is free-issuing the components.
When selecting packagers, one of the factors to be considered is the location. As stated before, the workshop should ideally be close to the harbor.
Packager should be investigated in terms of technical capability, expertise and reliability. But on the other hand, it should be small enough to appreciate the work from Alstom, since sometimes there might be just one module to be

[106] Expert Interview (2013)

constructed per project and Alstom might decide using another packager for another project which might be more advantageous in terms of location, experience and so on.

4.9.2 Transportation of Modules[107]

Transportation costs have a big portion on the overall module costs. Especially in some cases when the transportation is intercontinental for instance between Europe and Middle East as can be seen on the graphs of the case studies, the cost of transportation is more than the one third of the overall modules cost. Transportation therefore, is an important point and there are not many possibilities to reduce the transportation cost. It is also not easy to manage in case the modules are pre-fabricated in more than one packager. If the packagers are in different countries, it is not possible to make a unique transportation thus the transportation costs would increase even more.

Transportation of the modules also depends on the two working models explained above; one stop shop and free issue material model. In case of having the free issue material model, Alstom is responsible for both the transportation of the components from the supplier to the packager and the transportation of the modules from the packager to the site.

If the working model is one stop shop model, Alstom is only responsible for the transportation of modules from the packager to the site. **Error! Reference source not found.**

Modules are most commonly transported by sea, since they are quite big parts and sea is the most convenient way of transport.

There are two types of shipping in the international area:

- Liner: goods follow the vessels
- Charter (or Tramp): vessels follow the goods

In liner shipping there are specific dates that the carrier is operating. Also the ports are defined and the carrier doesn’t go out of the defined ports. Charter shipping on the other hand is much more flexible than the liner shipping.

In charter shipping there is neither pre-defined port schedule nor fixed operating dates. The tariffs are defined according between the ship owner and the charterer who rents the ship for the carriage. Tariffs depend on the negotiation, market situation, etc.

[107] Expert Interview (2013)

For the liner shipping on the other hand, there is a fixed price. Liner shipping is less expensive than the charter shipping; however, it is less flexible since it has fixed departures to fixed regions. One key asset is that modules should be preserved well while transporting. Ideally they should be fully enclosed which would also help in case a late assembly occurs on site and they might be exposed to bad weather conditions.

5 Recommendations

It is clear that the modular construction helps to reduce the complexity of a power project by reducing the site activities. By reducing the site works, it is possible to reduce the risks and the problems that can occur in the construction site. With less risk, less reworks and issues between the contractors, the probability to achieve the target duration of the project is increased.

Shorter lead time of a project and shorter time spent on site also reduce the construction costs, hence a lower price of a power project by preserving the quality. Lower price will increase the competitiveness and will bring a better market share. These benefits will bring a wide acceptance of the modular construction of a power plant, hence further developments of the modules.

With currently available Wave 1 and Wave 2 modules, man-hours of Power Island can be reduced by approximately 17%, and Water Steam Cycle Erection works on site can be reduced by 66%. This reduction of man-hours increases the probability to achieve the 20 months and 22 months project schedule incrementally. In central Europe the probability to complete a KA26-1 full EPC project is almost 90%; however the probability is only 10% for the 20 months schedule. By using the Wave 1 and Wave 2 modules, it is increased to 90%. In the UK, which has a much less productivity on site, the probability of completing the KA26-1 project in 30 months is increased by 60% with the module pre-fabrication. 20 months schedule is also increased by 10%.

Every module that has constructed for the first time may have some issues, and thus requires modifications and reworks on site. These modifications or reworks are occurred because of lack of expertise. However, in every project the process will get more mature and the site craft will get more experienced about the modular installation concept as well as the packagers about the module pre-fabrication. Like every new product or process, this new concept of construction also needs some time to get mature and to be built with almost no reworks. Reworks on site can be tolerated to a certain point unless they cause incremental consequences and they are repeated in more than one project.

Engineering phase of the modules starts earlier than the stick built solution. Engineering should be completed on time with all the necessary drawings so that the packager can start to construct the modules and deliver them on time. If something is designed wrong or for some reason some change is required on the design of a module, this wrong design or change better be considered as soon as possible.

A change on a product in engineering phase or in development phase or the worst case in phase of usage has a big difference in terms of cost.
As shown in Figure 35 if a change on design is made at an early stage like the planning period, it would cost much less then a change at a later stage like manufacturing or usage. Necessary changes should be detectd and done on the earliest stage of product life cycle to avoid the tremendous costs.
Awareness of the stuff is a key success factor for the new process in a company. To be able to implement this new construction method, there should be a high commitment from both the management side and the technical personnel. The more people get committed to the modular construction; the faster the process will get mature.

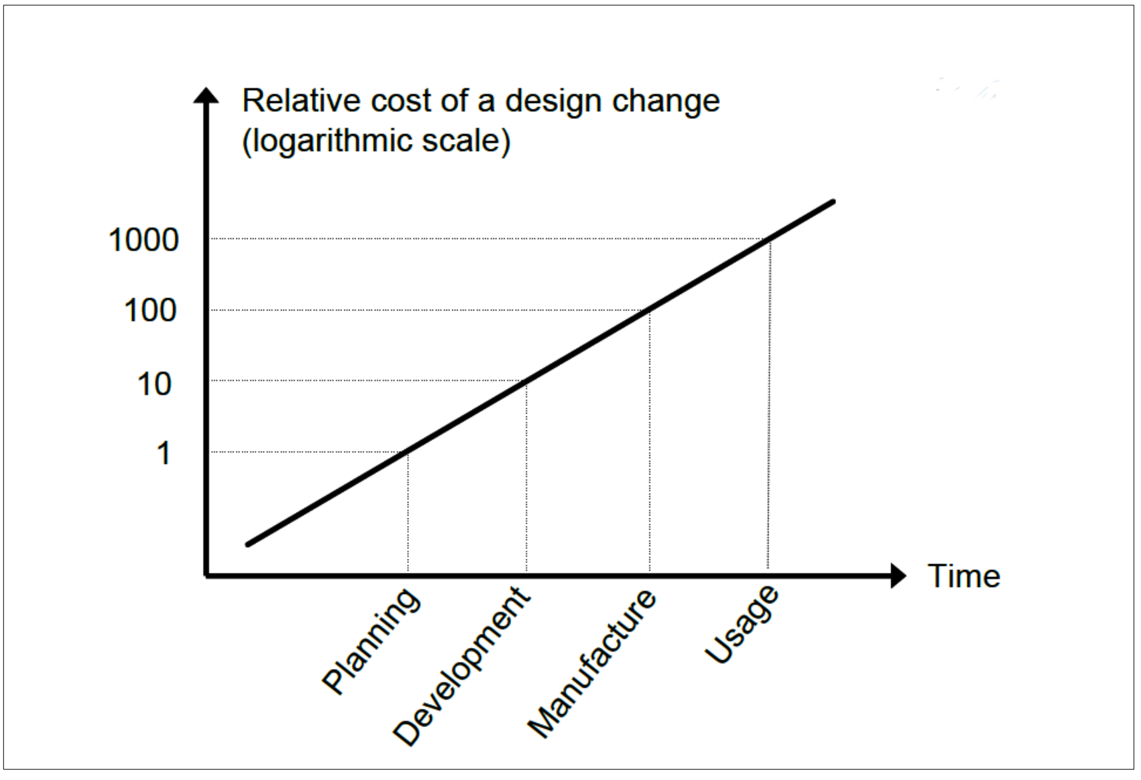

Figure 35. The Costs for Design Changes as a Function of Time during the Planning and Production Process[108]

The cross-functional involvement to the process is highly crucial. Which means, from the purchasing to the engineering; construction to the quality, all the departments should be informed well about the changing process. Every department/function has its own responsibility in the process, and everyone should feel committed.

[108] Bergmann et.al (1994), p.25

Another point to be considered carefully is the selection of the packagers. Since a high portion of Power Island man-hours is shifted from site to the packager's workshop via modularization; the company should arrange the packager network well.

Firstly the packagers should be evaluated according to their experiences, locations and the capacities, although the selection criterion depends also on the project location. Secondly there can be a price evaluation among the ones who are selected. The work capacity of the packager is an important criterion in selection, since as stated a high portion of man-hours are shifted to the packager, there will be a high workload in case more than one module is given to the same packager. There can be large scale packagers in some key locations like near to a big harbour in Europe, the US and Asia and these large scale packagers can take over the construction of all the modules and the modules can be transported together from the same harbour. If they are transported together, the transportation costs will be lower in total than transporting separately.

On the other hand if the packager is a smaller scale company, its commitment to Alstom Power might be stronger despite a period without any work.

Current improvements in the construction sector show that modular concept will continue to be developed further. A power plant in the future can be built with a higher degree of modularization. Future construction processes of Alstom combined cycle power plant should have more modules in order to reduce the site works to a minimum.

It might also be possible that Alstom pre-fabricates the modules itself, by shifting not only the man-hours but also some of the site employees from site to a shop. A "make or buy analysis" should be done to assess the profitability and reliability in case Alstom Power undertakes the pre-fabrication of the modules. Assessing the in-house capacity is a more complicated process than assessing the packagers. There has to be a broad assessment of for instance the skills of available personnel, a facility for prefabrication, required tools and machines and a sustainable supply chain for the shop location.

Although it might take more effort in the beginning to evaluate upsides and downsides of the in-house production and might also require huge effort to implement, the more the power plant modularised, the more it might worth to have the capacity to build them in-house.

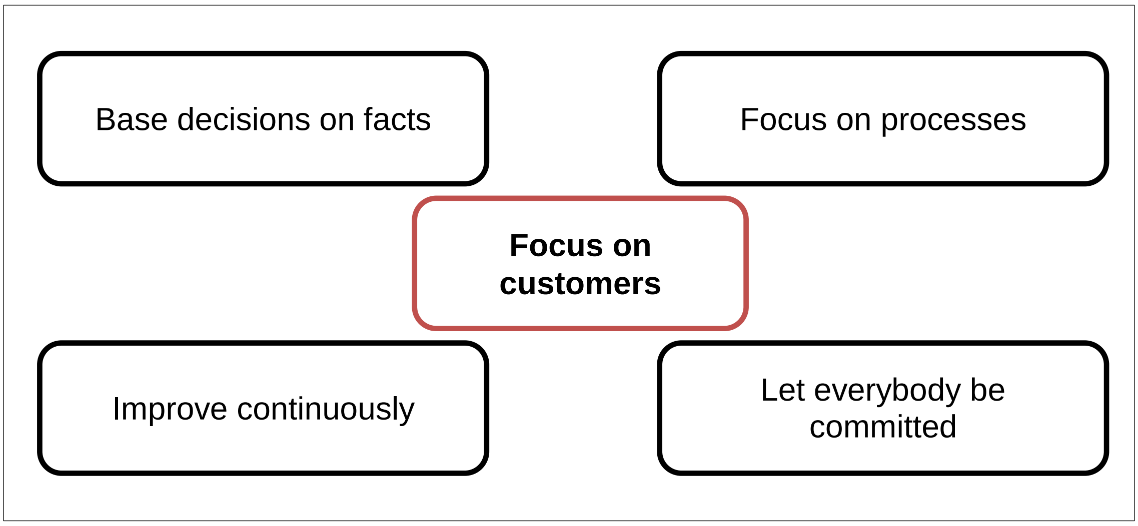

Figure 36. Important Elements to maintain the high quality[109]

Figure 36 shows an illustration of the key points to be considered for a successful quality strategy. As stated above, commitment of the staff reduces the time needed for the new process to get mature while also being a key asset to maintain the high quality.

For a sustainable quality a continuous improvement of the process is required. Beside the studies for the new modules, the existing modules should be investigated regularly to eliminate any weak points, insufficient design to continue focusing on lowering the cost, because it is always possible to improve a product or a process while also reducing the costs. The modules should also be improved to reduce the reworks and modifications on site.

[109] Bergmann et.al (1994), p.25

6 Conclusion

Working conditions on a construction site is much more complicated than a shop environment. There are many factors affecting the productivity on a construction site. One of those factors is the project country. Depending on the project country and its regulations, Alstom Power has to make modifications on the site processes and deal with the difficulty of finding qualified sub-contractors for the construction works in or near the project country.

To divide the risk, Alstom Power works with more than one sub-contractor mostly. More than one contractor means, more complex management required on site. Also thousands of people who have never worked together before meet to work on the same construction site. It is quite often that these people have conflicts between each other and lose their efficiency.

As explained previously, labour productivity is the most important factor on a construction site and there are many factors which cause the drops the labour productivity like overtime, weather conditions, difficulty of working in a foreign country etc. Modularization reduces the time spent on site, so that the probability to achieve the project on an agreed date or even before is increasing enormously.

Modules are crucial when a company like Alstom tries to reduce the complexity of the works, and reduce the time spent on site. Modules help for the erection process of the power plant to get more robust. The higher the number of modules pre-fabricated offsite, the less the risk on site is. Although there might be some issues occurred because of the lack of experience of both Alstom employees and the packagers, in the future the process will get more robust and the more robust it gets the more modules can come into being. Finally and ideally the site works of a power plant construction is reduced to the level of only building the connections between the big sections (modules) which are fabricated offsite.

Depending on the country of the packager, module costs can be different than each other. For the high labour countries like the UK, Netherlands, Australia and many others, it would be beneficial to pre-fabricate the modules in either a low cost country or a high cost country which is not very far in order not to have high transportation costs. For the projects in the low cost countries like Singapore, Malaysia, Saudi Arabia, and so on, the packager country should again be in a low cost country or the best case in the project country itself.

Overall, modules are crucial to reduce the lead time a project. They increase the probability to complete the project on time as well as reducing the costs. By increasing the number of modules, hence the offsite fabrication, it is possible to build the power plant with less risk, lower costs and better quality. This will lower the prices of the turnkey projects and will bring a higher market share. Without lowering the prices, it is almost possible to stay competitive in the long run, which makes it crucial to lower the costs. Current modules should be further developed in order to ensure their quality and their installation without any further rework on site; moreover, more modules should be developed to reduce the time and cost spent on site and to get more robust with the project schedule of the Alstom Power.

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8 Weblinks

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