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Model for installation cost management

Engineering process of a power plant project

Master´s Thesis

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Thesis abstract

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Budgeting tools based on parametric estimation together with modularized power plant solutions enable detailed budget calculation for the installation works of power plant projects. To meet the budget in a systematic way, management of installation costs is required in every stage of the project.

This thesis studied installation cost management during the engineering process of power plant projects. The study was started by defining the main theories behind cost management. The theory of engineering control, engineering monitoring and value engineering were used as key theories. Creation of the installation cost management model was started with the definition of the current engineering process and the inputs and outputs of its each phase. The new installation cost management model was built by integrating the studied theories to the current engineering process. The proper functionality of the new installation cost management model was validated with a virtual test in two executed projects.

In order to keep the effort allocated to installation cost management on effective level, model leans strongly on the theory of Pareto which assumes that a majority of costs is caused only by a few cost originators. In a new model of operation cost originators were implemented by defining the installation cost drivers for the design work. Cost consciousness of project and design engineers as a key element of value engineering was one of the main findings of this study and it was considered worth developing.

The thesis utilizes a constructive research method where empirical and theoretical information is used to build a new model of operation. The new model of operation is tested and evaluated against the studied theories.

Keywords: budgeting, cost calculation, offer calculation, project management, unit prices, value engineering

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Parametreihin perustuva budjetointi yhdessä modularisoitujen voimalaitosratkaisujen kanssa, mahdollistaa tarkan ja yksityiskohtaisen asennuskustannusten budjetoinnin voimalaitosprojekteissa. Asennuskustannusten pysyminen budjetissa edellyttää asennuskustannusten hallintaa projektin jokaisessa vaiheessa.

Opinnäytetyössä käsitellään asennuskustannusten hallintaa suunnitteluprosessin yhteydessa ja sen aikana. Työ aloitettiin määrittelemällä kustannushallinan teoreettinen viitekehys, joka koostuu suunnittelun ohjauksesta, monitoroinnista ja value engineeringistä. Asennuskustannusten hallintamallin rakentaminen aloitettiin määrittelemällä nykyinen suunnitteluprosessi ja sen eri vaiheet. Lopullinen malli syntyi yhdistämällä suunnittelunohjausteoria nykyiseen suunnitteluprosessiin. Luodun mallin toimivuus varmennettiin soveltamalla mallia virtuaalisesti kahteen toteutettuun voimalaitosprojektiin.

Kustannustehokkaan resurssien käytön takaamiseksi luodun mallin yhtenä kulmakivenä toimii Pareton teoria, jonka mukaan suurin osa kustannuksista aiheutuvat pienestä osasta kustanusten aiheuttajista. Luodussa toimintamallissa suurimpien asennuskustannusten aiheuttajat määriteltiin valitsemalla suunnittelutyölle kustannusajurit. Value engineering ja siihen liittyvä suunnittelijoiden ja projekti-insinöörien kustannustietoisuus ja sen kehittäminen olivat myös eräs työn aikana esiintulleista pääkohdista.

Asennuskustannusten hallintamalli on rakennettu käyttäen konstruktiivistä tutkimusmenetelmää, jossa empiiristä ja teoreettista tietoa käyttäen rakennetaan uusi toimintamalli. Uusi toimintamalli testataan ja testituloksia verrataan mallin rakentamisessa käytettyyn teoriaan.

Avainsanat: budjetointi, kustannuslaskenta, projektijohtaminen, tarjouslaskenta, value engineering, yksikköhinnat

SEINÄJOKI YRKESHÖGSKOLA

Abstrakt

Avdelning: Teknisk avdelning

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Ett budget verktyg baserat på parametrisk utvärdering och modulariserade kraftverkslösningar möjliggör noggrann och detaljerad budget beräkning för installationskostnad i kraftverksprojekt. För att hålla budgeten på ett systematiskt sätt krävs projektledning för installationskostnaden för varje fas av projektet.

Detta slutarbete omfattar installationskostnadens projektledning i samband med och under planerings processen. Arbetet började med att bestämmä huvudteorierna bakom cost management som bestod av planeringens styrning och uppföljning samt value engineering. Modellen för att kontrollera installationskostnaden började byggas genom att bestämma den nuvarande planeringsprocessen samt in och ut data för varje fas. Den slutgiltig modellen skapades genom att integrera de studerad teorierna med den befintliga planeringsprocessen. Modellen verifierades genom virtuellt test i två redan utförda kraftverksprojekt.

För att säkerställa att använda resurser allokeras kostnadseffektivt använder modellen sig av paretoprincipen enligt vilken en liten del av kostnadsorsakerna står för den största delen av kostnadsverkan. I praktiken gjordes detta genom att bestämma de kostnadsorsaker som står för den största delen av installationskostnaden. Kostnads medvetenhet för projekt- och planerings ingenjörer som ett nyckel element i value engineering samt dess utvecklande var ett av de viktigaste resultaten i detta arbete.

Modellen för att kontrollera installationskostnaden utarbetades genom att använda en konstruktiv forskningsmetod där teoretisk kunskap nyttjades för att skapa och testa en ny modell.

Nyckelord: anbudskalkyl, budgetering, jämförpriset, kostnadsberäkning, projektledning, value engineering

TABLE OF CONTENTS

List of figures and tables

Abbreviations and definitions

ABC	Activity based costing
AC	Alternating current
BoQ	Bill of Quantities, list of equipments and installation materials to be installed
CDE	Chief design engineer
CPE	Chief project engineer
DC	Direct current
EPC	Engineering, Procurement and construction
HFO	Heavy fuel oil
HSE	Health, safety and environment
HV	High voltage
HVAC	Heating, Ventilation, Air conditioning
LFO	Light fuel oil
LO	Lube oil
LV	Low voltage
MV	Medium voltage
Parametric estimation	Calculation model which are built using material and direct work as a cost element
PE	Project engineer
SLD	Single line diagram

SoS	Scope of Supply defines the items in power plant project that which are to be delivered by Wärtsilä and which are on customers responsibility
Target costing	Calculation method where the requirements of project are converted to costs to define acceptable cost for the product or project
Value engineering	Method which are aiming to achieve required (or higher) value with lower cost

1 INTRODUCTION

1.1 Target organization

The target organization of this thesis is a department called Project services under Wärtsilä power plants – Project management. Project services consist of the following support functions for Project management: Civil project engineering, Electrical project engineering, Mechanical project engineering, Project control and Project documentation. (Wärtsilä 2014).

Figure 1. Power plants management team (Wärtsilä 2014)

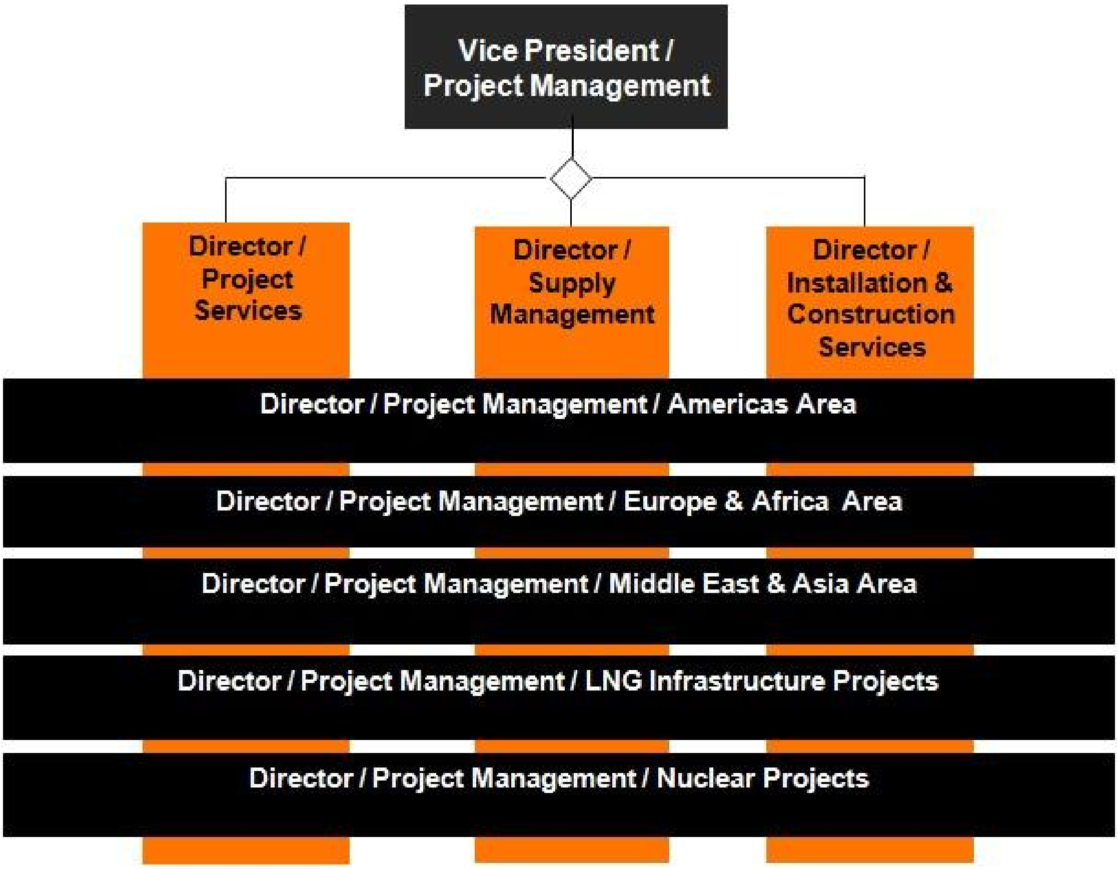


Figure 2. Power plants, Project management (Wärtsilä 2014).

1.2 Purpose of the thesis

As described in the following chapters, in current engineering process, there is no link to installation cost budget. Instead, engineering is a solute process based on same initial data as installation cost budget calculations in the sales phase of the power plant project. The purpose of this thesis is to define and test a model to manage installation costs during the engineering process in order to meet the installation cost budget in a systematic way.

> “To effectively control project costs, the project manager and the team should have a method in place to prevent unauthorized change to the project budget and to manage changes that are determined to be necessary.” (International institute for learning, Inc. 2011, 6-27.)

This basic truth of project management is in place with a majority of Wärtsilä project management processes, but needs to be extended to consider the installation cost management during the engineering process as well. It should also be noticed that the model to be created will manage only the installation costs, not the costs of engineering.

1.3 Objective

The objective of this thesis is to introduce a model for installation cost management during the engineering process. The model should include the installation cost management of Civil, Mechanical and Electrical engineering processes. Questions that this research should find answers are:

- What is the structure of suitable installation cost management model an engineering process?
- What is reasonable effort to manage installation costs during the engineering process?
- Which are the variables to be used as drivers and indicators?
- In which level of details installation costs of each discipline should be managed?

In power plant projects the detailed engineering is outsourced for external partners, which means that these partner companies are in key position in terms of influencing the installation costs. One of the objectives is to define the role of engineering partners in installations cost management.

1.4 Research method

The thesis is employing a constructive research method, aiming to understand the causal connection in different processes. By employing constructive research, a researcher will use theoretical data to build up theoretical framework which will be used for the preparation and testing of new model of operation. (Suuronen 2012, 15.)

When fundamental research is looking for answers to explain the environment and its phenomena, constructive research exploits the results of fundamental researches to build up a new construction. One of the decisions that a researcher needs to make is what this new construction will look like. Typically, in practice, this new construction means some new way of working which controls the organization to a new direction to reach a new goal. In other words, constructive research is looking for a change or improvement to the existing process and typically the research questions are asking if something is possible or how it would be possible. (Järvinen & Järvinen 2000, 102.)

Constructive research starts with a definition of the present state and by defining the problems or needs for improvement in the current state. With the definition of the current state and the needed improvements, a researcher defines the goal of research and what the new construction will look like. The new construction will be built by researching theoretical and empirical information. The created construction will be tested with the current process and by linking to theory. In Figure 3 constructive research is divided to six steps. (Rohweder 2008, 11.)

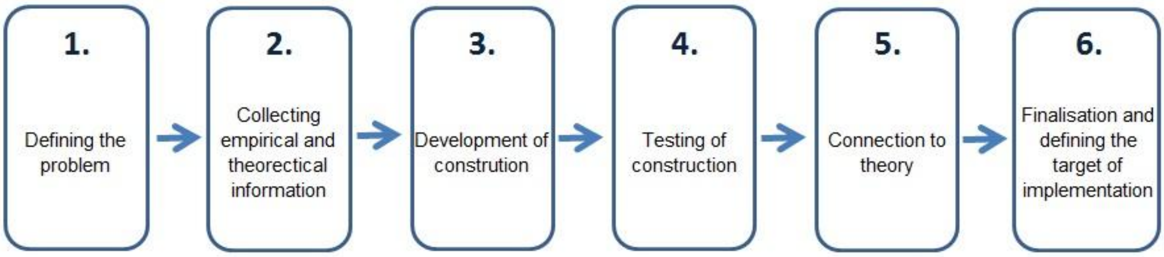


Figure 3. Six phases of constructive research (Rohweder 2008, 11.)

1.5 Previous researches

This subject has been studied earlier on different levels and in different types of industries. A majority of earlier researches has concentrated on manufacturing and constructions industry. Also the level of results varies from very general to very case specific. In the latter group the results are bounded to product specific models as well. The main principles or the theory of cost management of these studies where similar and will be exploited in this research.

Jaana Sandström's doctoral thesis deals with utilizing the activity based costing to engineering design. In her study, Sandström points out several issues related to the cost consciousness of design engineers and searches ways to convert the attributes of activity based costing into cost drivers for design engineers. Also the methods used to satisfy the cost consciousness related needs of design engineers are studied.

Sandströms doctoral thesis deals with the cost information of engineering design from the activity based costing point of view. Target costing among other costing methods is introduced briefly and especially the cost informative substance of target costing is pointed out, but its utilization is not dealt with at all.

1.6 Limitations

This thesis is limited to define and test the model for the installation cost management in power plant engineering process. Possible implementation is limited to be outside of this thesis.

This thesis will also be dealing with the current sales process and the tools included in it. The sales tools and the outputs of the sales tools are assumed to be accurate, meaning that in this thesis the tools are not either questioned or proved to be accurate.

Also the new construction for managing the installation costs aims to find a model for the installation cost management in engineering process, not to look for possibilities to change or improve current power plant products.

2 INSTALLATION COST BUDGETING OF POWER PLANT PROJECT

2.1 Development of sales project

Power plant project opportunities are priced and configured to activities with a separate tool developed for that purpose. Based on the main requirements, such as output power, fuel and scope of power distribution, the sales configurator prepares a Scope of Supply consisting of the equipments, buildings and processes to be offered to a customer.

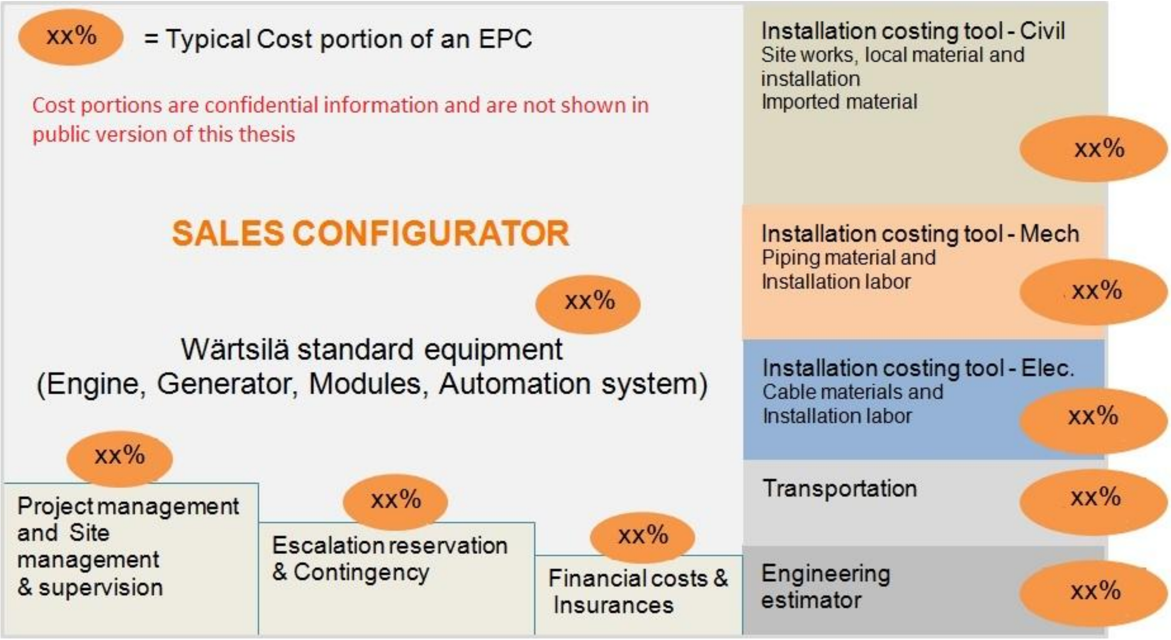


Figure 4. Sales configurator

The costing method of the sales configurator is activity based costing. Utilization of different type of resources is the key element of the ABC system. ABC is aiming to provide more accurate information of the costs of products, services, business processes and activities that the project requires. By exploiting this described method, ABC provides a good estimation of the total cost of a product or a project. (Kaplan & Cooper, 1997, 107.)

Installation costs, as one of the activities offered for the customer, are calculated with Civil, Mechanical and Electrical installation costing tools.

2.2 Installation cost budgeting

2.2.1 Installation costs

Installation costs consist of direct installation material costs, direct installation work costs and indirect installation costs. Indirect installation costs are comprised of mobilization, supervisors, site facilities, transportation & storing, equipments & machines, health & safety, documentation and profit. Installation material costs include the costs of the bulk materials, such as piping, cabling, concrete, sand, gravel and steel structures which are, depending on the discipline and material in question, purchased locally or delivered offshore. Equipments, such as engine, cooling radiators, transformers, switchgears, auxiliary equipments and smaller tanks are not considered as installation material and are not included in the installation material costs. Installation work costs include the installation work of the materials and equipments. Installation work costs are mainly labor costs, but include also the work done with machines, e.g. excavation work or lifting.

2.2.2 Initial data

Installation cost calculations prepared at the sales phase of the power plant project are based on the preliminary data of the project. The main requirements (as described in chapter 2.1) are converted to a scope of supply specifying the equipments and buildings to be offered and fitted to a power layout drawing prepared by a layout team. Typically there is also some more discipline specific information available e.g. soil investigation data, single line diagrams and, in some cases, preliminary flow diagram.

2.2.3 Cost calculation tool

Wärtsilä power plants are based on modularized solutions. Buildings, supporting steel structures and foundations have a standardized design to be used as a base for the project specific design. Different engine types, generators, cooling radiators and auxiliary equipments are modularized, shop fabricated equipments where process piping and electrification between units follows the standard solutions. Electrical control panels, distribution switchgears and auxiliary panels are modularized as well and the power supply and control cabling are standardized between units.

In order to minimize the installation work at site, these standardized process modules, control panel, power distribution switchgears and building structures are prefabricated as far as possible, before delivering to the construction site.

The installation material and installation work required by these standardized solutions and modules are programmed into installation cost estimations tools. Although the process units are modularized, due to different requirements set for the power plant, the process is never standard. Environment, fuel quality and power network are always unique and cannot be standardized, which causes project specific process design. With scope of supply, with the distances between buildings and equipments and with the requirements set for the plant, Cost engineers of each discipline models the power plant process and defines the installation material needed to build up the power plant. Besides the process units, installation costing tool models are built from basic installation material such as concrete, steel materials, soil, wall panels, cabling, cable raceways, panels, switchgear, piping, flanges, tank steels etc. and as a result of process model, installation costing tool calculates the quantity of each installation material and installation work.

From description above we can make conclusion that installation costing utilizes parametric cost estimation. When analogue estimating technique uses the historical data of complete project (e.g. scaling the costs similar, but different size of building), parametric estimation is based to calculation models which are built from material and direct work. Accuracy of parametric estimation is depending on the level of details in calculation models. (Project management institute 2008, 172.)

Buildings, equipments and structures are the main activities defined according the main requirements of the power plant, but besides the fuel, output power and other main requirements there are number of other requirements set for the buildings, equipments, for the process and for the whole installation. It´s not relevant to go through them all, but just to give an idea, here is the example of some of them: Environment has its own limitations e.g. for the power plant cooling system, building materials, foundations etc. Soil type affects to earth works, foundations, earthing etc. Installation standards vary from country to country, which could have massive costs consequences.

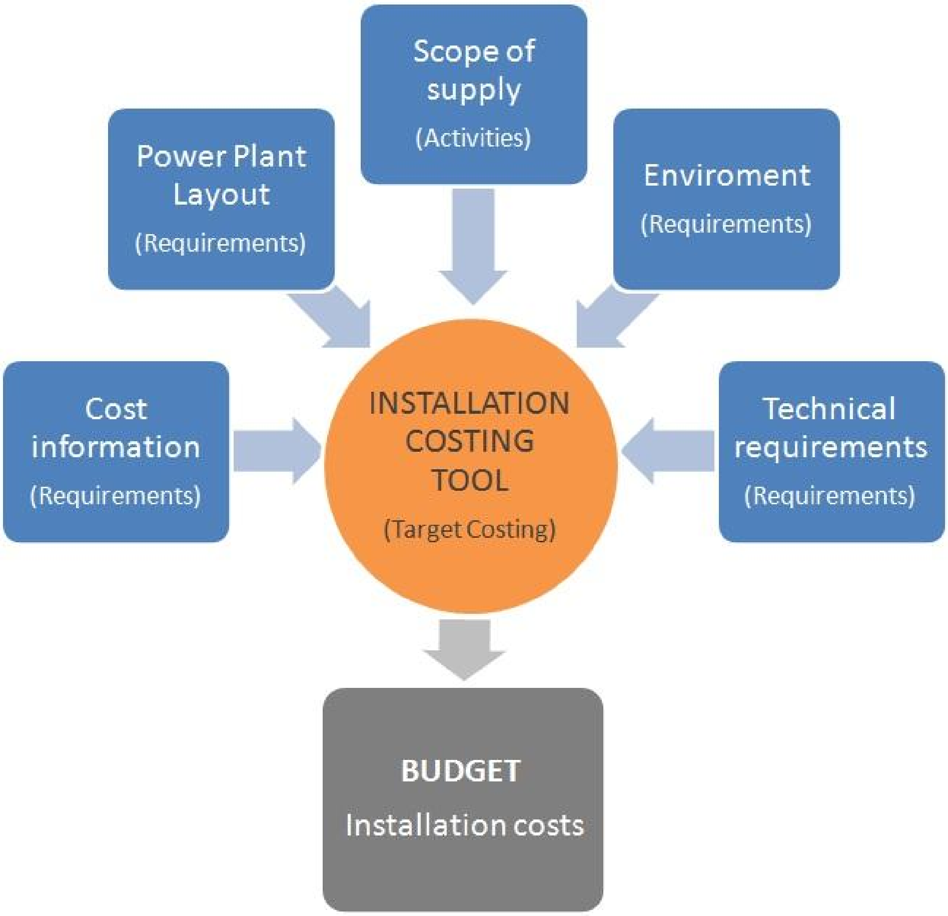


Figure 5. Process of Installation costing

By employing target costing, these requirements are converted into costs. In other words, each requirement has its cost and costs are consequence of each requirement (Haahtela & Kiiras 2013, 22).

2.2.4 Global unit cost database

Installation cost units handled in tool has a unit cost for the installation work and for the installation material. Unit cost of the installation work and installation material varies between countries and is dependable of global cost levels and market situation. Unit cost database is maintained and extended with contractor inquiries during the sales phase of the power plant project and by collecting cost data from executed projects.

With quantity and unit cost of installation material and installation work, Installation costing tool is calculating the budget for installation costs of power plant project.

2.2.5 Installation cost and quantity reports

Based on a budgetary calculation, there are several output reports for different purposes available from installation costing tool:

- Cost calculation report
- Estimated man hour report
- Estimated material list (BoQ)

In cost calculation report, installation cost budget is divided under different systems in order to transfer the cost to sales tool and to define the costs for the different parts of power plant project. Estimated man hours are typically used for define the magnitude of the local purchased installation work and to support estimated material list which is used for the subcontractor inquiries in order to receive local installation unit prices.

2.3 Cost follow-up

Current installation cost follow-up relies to process monitoring, where the installation material list of completed design is compared to estimated material list made in the sales phase of project. For this purpose, electrical, civil and mechanical disciplines has developed follow-up sheets which can be generated project wise with installation costing tool. In follow-up sheet the most cost effective items of installation is to be monitored between estimated and design.

The weakness of this follow-up is that the follow-up is done when design package is completed and there are not many possibilities to control the design when the design is already completed. Hence the follow-up has mainly the role of monitoring, project management organization has never really adopt the usage of these follow-up sheets. Role of the follow-up has been more like feedback connection for the installation costing tool development.

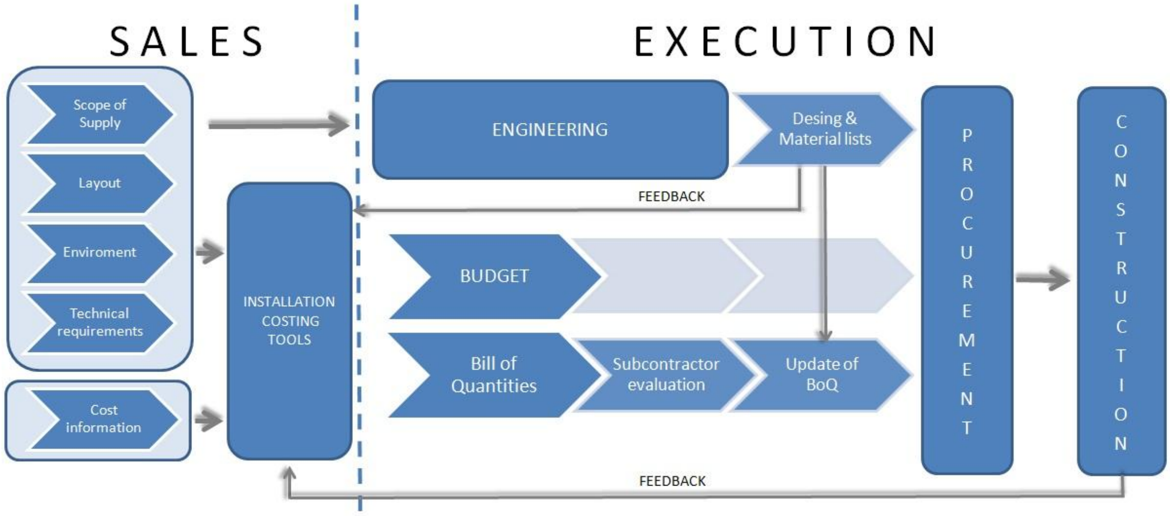


Figure 6. Process of Installation costs

3 INSTALLATION COST MANAGEMENT

3.1 Framework

In order to manage installation costs during the engineering process, this study leans to a three main operation models; control of engineering work, monitoring of engineering work and value engineering. Already in pre-study phase of the thesis and during preparation of research questions, there where references showing that weight of engineering management will be on engineering control, but in order to build a feedback connection from the controller, process requires monitoring. Since the budget for the installation costs are prepared using target costing, achieving the budget within requirements set for the project, some sort of optimizing is one of the key tools of the design engineer. In order to provide tools and techniques for optimizing, value engineering is in key position.

To ensure the compatibility of current budgeting model with the new installation cost management model, also the theory behind current budgeting model was decided to be studied and defined.

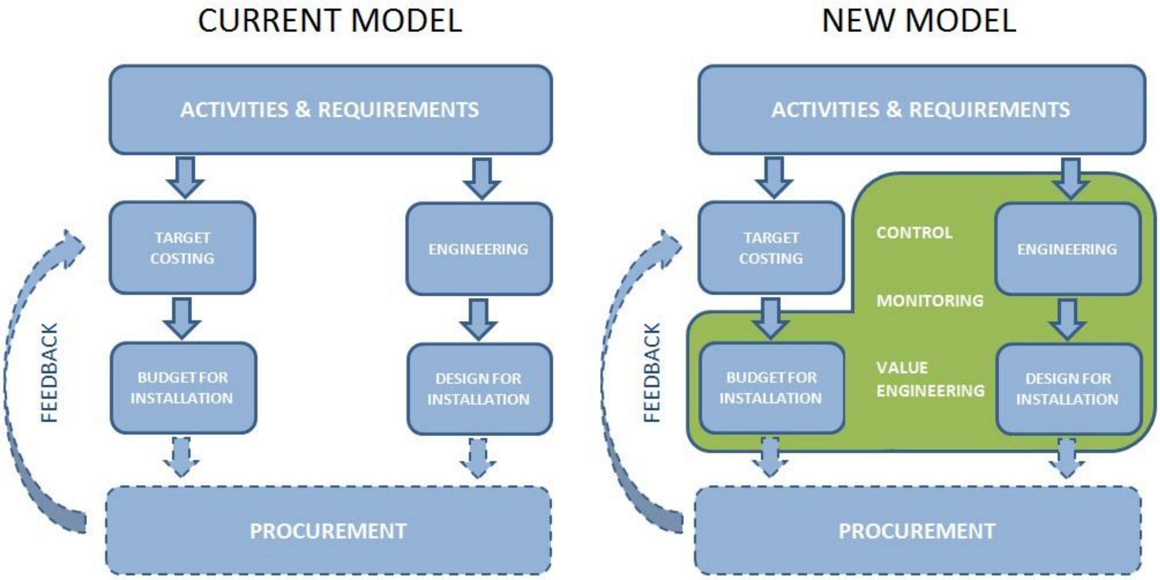


Figure 7. Theoretical framework

Kaizen method refers to cost management and it came up several times when searching material for this study, but it was left out of the studied cost management methods, hence it’s representing the continuous cost reduction, which is not the purpose of the cost management when the aim is to meet the budget defined with existing solutions.

3.2 Budgeting with target cost calculation

Target costing is a method where the requirements of project are converted to costs. By employing principles of goal oriented management and value analyses, target costing aims for the so called acceptable cost for the product, project or for the part of the project. (Karjalainen 1991, 19.)

With target cost budgeting, budget is calculated through the requirements set for the building, earthwork or process in question. Instead of concrete, steel structures, piping and cabling, customer in question is looking the product through its features. (Haahtela & Kiiras 2013, 28.)

Cost data used as a base for the budget calculation must be set slightly over the average cost level in order to ensure project team motivation and leave some room to seek for the most optimized solution (Haahtela & Kiiras 2013, 29). In other words budget must be considered so, that average project team with average resources will meet the budget, good team will fall below and with weak project team the budget will be exceeded (Kharbanda, Stallworthy & Williams 1980, 136).

Traditional budgeting methods are based to costs that most likely will be caused by the project. Difference with target costing is that target costing is aiming for the most optimized solution within the limits of requirements set for the project. (Karjalainen 1991, 19-21.)

Principle of target costing should not be mixed with Kaizen method, where the intension is the continuous cost reduction (Fogelholm & Karjalainen 2001, 105).

3.3 Budget as a target

When project is sold, there is number of targets already been set. One of these targets is the budget for the project. Main reason behind cost management is to meet the budget or stay below it. This being, budget will be the target of the cost and when possible, costs should fall below the budget. (Kharbanda, Stallworthy & Williams 1980, 120.)

Hence the budget is our target, as a main principle with cost management, budget should never be questioned. By questioning the budget, the project team accepts the fact that budget is not reachable and there is no reason for cost management anymore. (Kharbanda, Stallworthy & Williams 1980, 121.)

Two paragraphs above is in line and can be consider as a causal connection of budgeting with systematic approach as described in chapter 3.2 Budgeting with target costing. When budgeting is done in systematic way, it´s transparent and traceable, it will be trusted and also accepted as a realistic target.

3.4 Process control and monitoring

3.4.1 Indicators used for monitoring

When monitoring a process, the process typically has a target. Target could be e.g. to achieve certain quality or cost. Often in spoken language, target is mixed with indicators and sometimes even understood as a same thing. In order to achieve targets set for the process, there should be indicators set to support achieving the target. Sometimes target itself can be used as an indicator, but there are processes that target as such cannot be used directly as an indicator for process and it needs several indicators during the process to gather information which is processed to a value that can be compared to the target. E.g. Lower number of rejected products could be a target and can measure directly. Or improvement of reliability of deliveries could be a good target, but in order to measure it, several indicators should be set to measure the process. Latter example is called indirect measurement and former is an example of direct measurement. (Fogelholm & Karjalainen 2001, 36.)

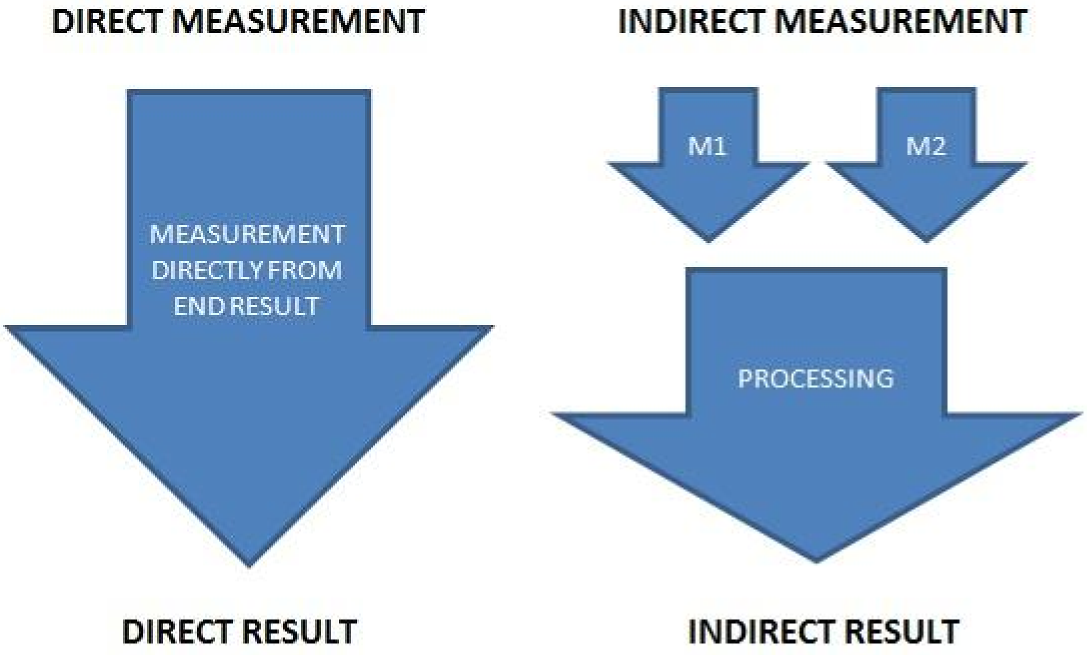


Figure 8. Direct and indirect measurement (Fogelholm & Karjalainen 2001, 37).

About validity and reliability of indicators Fogelholm & Karjalainen (2001, 37-38) writes that indicators can be considered to be valid when there is a rational connection between the measurement and the end result. This evaluation should be emphasized especially in case of indirect measurement. Selection of indicators Fogelholm etc. (2001, 40-41) explained with Figure 9.

When indicators are used for evaluating the performance, indicators should be accepted by the target of measurement (e.g. individuals). Indicator should be easy to understand and connection to practical performance. Selection criteria´s described above, they all have affect to effort needed for measurement and to benefit achieved with measurement. (Fogelholm & Karjalainen 2001, 41.)

Vehmanen & Koskinen (1998, 363) is dealing with purpose of the indicators. it should be also considered that is the purpose to provide information to attract attention or to support decision making. These types of indicators are typically process specific, but cost calculation methods can help to define the options that should be evaluated.

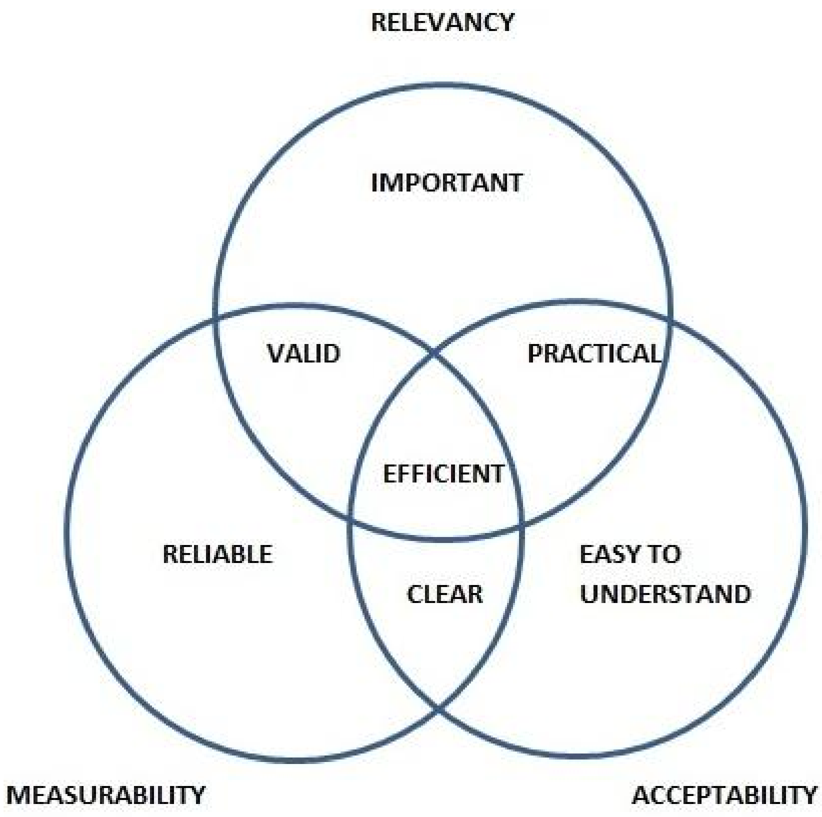


Figure 9. Selection criteria’s of indicators (Fogelholm & Karjalainen 2001, 40)

3.4.2 Drivers used for controlling the engineering

Indicators and measurement doesn’t control the costs or doesn’t keep the project in budget (Vehmanen & Koskinen 1998, 351). Controlling the costs means that our goal is to keep the costs in planned level. Cost control should not be mixed with cost reduction, which is a totally different approach and will be dealt later in chapter of Value engineering. (Wilson 1975, 43.)

With new project or product, the cost management starts already before any design or any engineering have been done. In order to perform cost management during the engineering process, determination of design related drivers is essential. (Sandström 2001, 36.)

When determining the drivers, detailed information about product cost is not relevant for the cost control, instead the most important information is that which of the causes are reason for the majority of the costs and which of those are controllable (Fogelholm & Karjalainen 2001, 102).

When determining the number of drivers, theory of Pareto comes handy. Originally theory of Pareto was invented when Pareto founded out that 20 % of population had the 80 % of the assets. Later on the conclusion made of this same theory was that there are only few causes for the majority of the costs. This is true also when setting the drivers for cost management. (Kharbanda, Stallworthy & Williams 1980, 61.)

Number of cost drivers is related to accuracy of control, but also on the other hand, especially in complex processes too many drivers can be harmful for the control by making the control too confusing and too difficult to use and maintain. (Sandström 2001, 32-35.)

Wilson (1975, 91) also refers to Pareto’s Law and writes about concentrating to the most critical drivers and warns to have too much control over the process by setting too many drivers. According to Wilson, four to six critical drivers are suitable number for the drivers. Wilson states that success will be achieved by implementing these four to six drivers extremely well.

During the examination of Sandström (2001, 66), she defined the cost critical activities by modeling the manufacturing process using activity chains. Activity chain defines the direct costs of each manufacturing phase, i.e. manufacturing work and material used for manufacturing. These cost critical activities were exploited to define cost drivers guiding the designers work.

3.4.3 Reporting

Wilson (1975, 98-100) emphasizes that reports should be always made for individuals not for departments. Reports should provide information to support decisions and actions, not provide figures for accounting purposes. Affect that report should have, is to give thoughts and something to think about. One of the features that report should have is the information of reasons behind the results. When relevant, report should be built such a way that the information flows both ways in organization. Suitable number of review meetings to be held in order to interpret the reports and execute required actions. When possible and relevant, charts should be used due to their possibility to provide large amount of information with one look. (Wilson 1975, 117-118.)

As stated above, report should reach also those who have been measured. One of the corner stone of reporting is that individuals knows what are expected from them and how did they performed. When setting the expectations, plan or the instructions for achieving the target must be in place in order to provide points of reference to practical tool to point the areas of improvements and eliminate possible excuses for poor performance. (Wilson 1975, 83-84.)

3.5 Value engineering

Value engineering is an endless process which questions the current solution by looking more affordable solution to produce the same or even higher value. Typical questions that value engineering is asking concerns that, what it is, is it worth of its function, can it be replaced and what is the cost of alternative. Value engineering requires certain kind of mindset with combination of engineer, salesman and psychologist having possibility to see the issues through the eyes of customers, management and production. It might be a challenge for management to find a person with all the required skills and provide the needed accesses and adequate amount of control or resources of the organization. (Kharbanda, Stallworthy & Williams 1980, 54-58.)

According to Sandström, (2001, 37) Value Engineering is a tool used in target costing. Sandström also refers to a book by James Brown, Value Engineering – A Blueprint, (1992, 20. Industrial Press Inc., New York) which says that:

> “Value engineering is an organized effort to get more for your money. It applies recognized techniques and tests to measure value and thus eliminate unnecessary costs in design, development, and manufacturing. It differs from cost control because it is directed toward

> analyzing value, not costs. In other words, value engineering is concerned with finding the lowest cost to achieve a required function.”

Company can also develop an own Value engineering process, where the points where the costs can still be affected are defined and who are the person responsible of these points (Vehmanen & Koskinen 1998, 355).

3.6 Affect costing

Also an Affect costing is a tool to be used with target costing. When there is an indicators showing that the costs are exceeding the budget, tool called affect costing can be used to find a way to achieve the budget. Affect costing utilizes Pareto philosophy to define the cause of the exceeded cost. With Pareto, Affect costing defines key cause(s) of the costs and by eliminating these key causes. Affect costing aims to halve the overshoot by going through the process until the goal is achieved. (Vehmanen & Koskinen 1998, 357.)

3.7 Cost consciousness of design engineers

Sandström (2001, 50) has studied the cost consciousness of design engineers and ended up to develop a model where the difficulty of cost consciousness has been defined in relation of the life cycle of the project and type of the design.

Figure 10 shows how the difficulty of formulating the cost information for the use of design engineers is increasing when the products are non-standard and when the product life cycle is shorter, i.e. when there is no cost information available from former products and when the products are one-time-only type of products. According to Sandström (2001, 51), cost consciousness of design engineers is on good level, if the cost consciousness takes place on the half way of the line, meaning that they have cost information available from existing products and some sort of parametric cost estimation or design rules have been developed.

With her studies, Sandström (2001, 82-83) becomes to a conclusion that cost consciousness is one of the desired skills of design engineer, but finds it problematic to formulate cost information to be useful for them. Sandström deals also target costing as one of the possible cost management method when processing cost information for design engineers. Sandström concludes that features, required by customer are too subjective to be converted to cost drivers (such as “painted with pleasant colors”). Instead, target costing where cost drivers provided from engineers point of view, Sandström finds suitable. These types of drivers are physical, performance or functions based attributes which are helping design engineers to lower costs while fulfilling the required features.

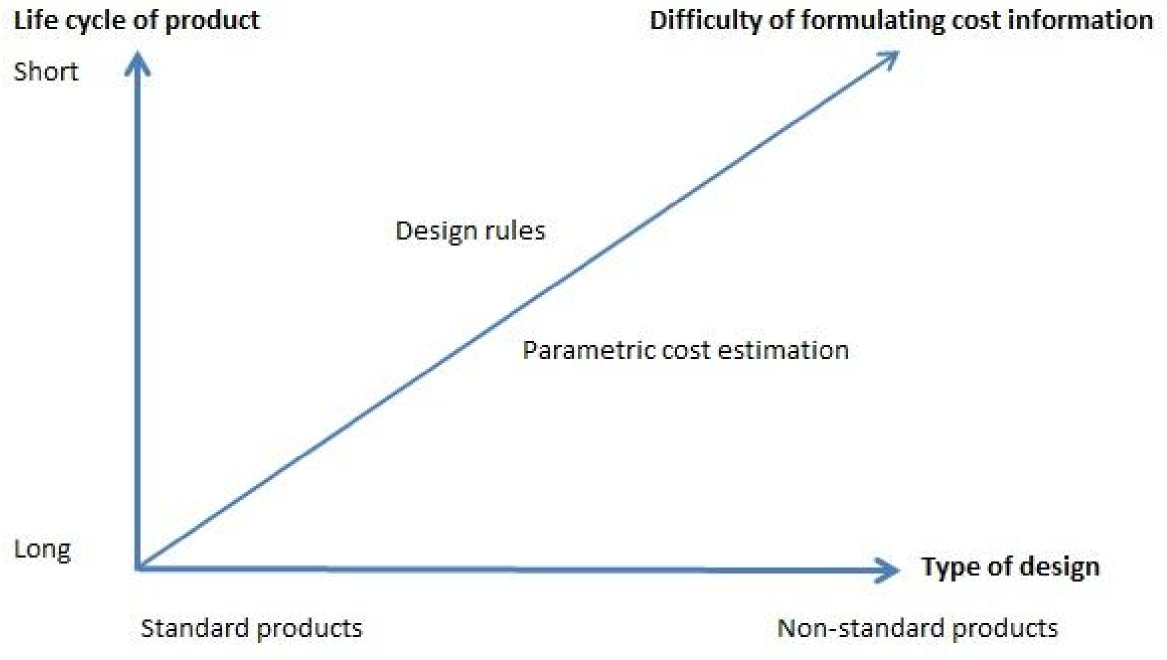


Figure 10. Difficulty of formulating cost information (Sandström 2001, 51)

3.8 Responsibility of cost management

Responsibility of cost management belongs to everyone who is involved with the project. Project manager has the final responsibility, but costs should be controlled by those who are causing them. Every member of project team must be cost conscious, in order to be able to evaluate and judge. Whatever the resources allocate d for cost management are, it should be constant and continuous effort through the whole project. (Kharbanda, Stallworthy & Williams 1980, 54-58.)

Start of the cost management is the design, so the persons involved with design and especially in the beginning of design process are in key position of cost control. But it should also be acknowledged that persons with cost as a main concern (e.g. accountant) cannot be controlling the costs, hence this might cause lack of fulfilling the other requirements. (Kharbanda, Stallworthy & Williams 1980, 54-58.)

Wilsons (1975, 45) approach is in line with Kharbanda etc. saying that costs should be controlled by person who has initiated and approved the cause for the costs. Wilson also emphasizes that costs can be controlled effectively only when individuals are responsible of them. One of the questions that Wilson asks is that what sort of control exists over the initiation of each cost which refers to the drivers that are dealt earlier in this thesis.

Kharbanda etc. (1980, 96) states that system must be the slave, not the master. When determining the effort to be used for the installation cost management, it should be evaluated that is the purpose of control and monitoring to serve the management system or should the system support the management.

3.9 Process development

When we are talking about process development or improvement of existing process, it’s commonly understood to consider only company’s internal processes. Instead, only of setting the cost target for supplier, we should participate in supplier’s process development. (Järvenpää, Länsiluoto, Partanen ja Pellinen 2013, 201).

4 CREATING THE INSTALLATION COST MANAGEMENT MODEL

4.1 Cost structure of power plant project

4.1.1 Civil, Mechanical and Electrical costs

Already the Figure 4 in chapter 2, shows the rough cost split of power plant project. Depending on the size and type of the project, portion of installation costs are 16-37% of the total costs of a power plant project. Total installation costs split discipline wise means 66% for Civil construction, 22% for mechanical and 12% for electrical installation costs.

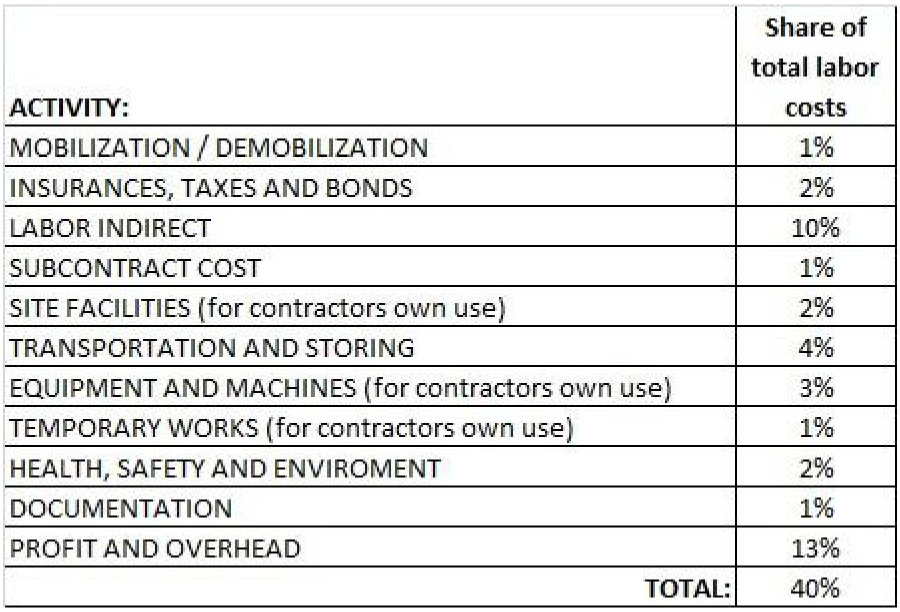
Installation costs in power plant project are generated and handled with unit prices already from the sales phase of the project. Content of unit price is not dealt in same way in all three disciplines. The difference between disciplines comes with indirect costs of the installation work. In Civil discipline, unit price of locally purchased materials are including material, labor costs and indirect costs. In case of off shore material installation is purchased locally and unit price of installation includes the direct and indirect work costs. Mechanical and electrical disciplines handle the direct costs, indirect costs and material costs separately. Material and direct work cost is priced with separate unit prices and indirect costs are priced separately according to Table 1.

The reason for these two different practices is mainly the portion of material costs in different disciplines. On Civil discipline, majority of costs are material costs and it has lead to a practice that direct and indirect labor costs are baked to same unit price with material. On mechanical and electrical discipline the costs of material is smaller. Typically material, direct labor and indirect labor is each representing 1/3 of the costs and for this reason mechanical and electrical industry prices them separately.

Table 1 shows the content of the indirect costs. Share of each item varies from project to project depending of the location of the power plant construction site.

For example the mobilization costs varies according the distance to nearest city, labor indirect are bigger at remote location due to accommodation costs and certain customers may have expensive requirements regarding the HSE.

Table 1. Structure of indirect costs for mechanical and electrical disciplines



ACTIVITY:	Share of total labor costs
MOBILIZATION / DEMOBILIZATION	1%
INSURANCES, TAXES AND BONDS	2%
LABOR INDIRECT	10%
SUBCONTRACT COST	1%
SITE FACILITIES (for contractors own use)	2%
TRANSPORTATION AND STORING	4%
EQUIPMENT AND MACHINES (for contractors own use)	3%
TEMPORARY WORKS (for contractors own use)	1%
HEALTH, SAFETY AND ENVIROMENT	2%
DOCUMENTATION	1%
PROFIT AND OVERHEAD	13%
TOTAL:	40%

When considering the installation cost management, are the indirect costs affected by process design? Indirect costs are mainly fixed costs, affected by the location of the construction site, not with amount of the installation works. Labor indirect costs could be interpreted so that e.g. number of supervisors is dependable of amount of work. The question is, should indirect costs be somehow connected to the installation costs management model. Most of the indirect costs are fixed, and those which are not fixed are somehow dependent on the amount of installation work. So if the installation cost managing model is somehow affecting the amount of installation work, also the supervisor costs are affected indirectly.

4.1.2 Installation costs in different type of projects

In the next chapters the installation costs are handled discipline wise divided into Core EPC (Engineering, Procurement and Construction) and Full EPC projects, which are the terms used to indicate the delivery limits. Due to the different type of cost structure, Gas and Diesel plants are handled separately. Figure 11 shows the different areas and buildings of a power plant. Power plant in Figure 11 represents

Diesel power plant. In full EPC, Wärtsilä delivers each and every building and structure that are shown in the Figure 11 plus the process units inside of the buildings and in site area. In case of core EPC, following areas and structures are in customer’s scope of supply; unloading station, storage tank area, high voltage switchyard area, Admin. building, social facility building, workshop & warehouse and guard house. One of the major items that are under customer scope of supply in core EPC projects is all the civil works below 0-level, such as foundations and earthing networks. In core EPC also the access roads, parking areas, fences are in customer scope of supply.

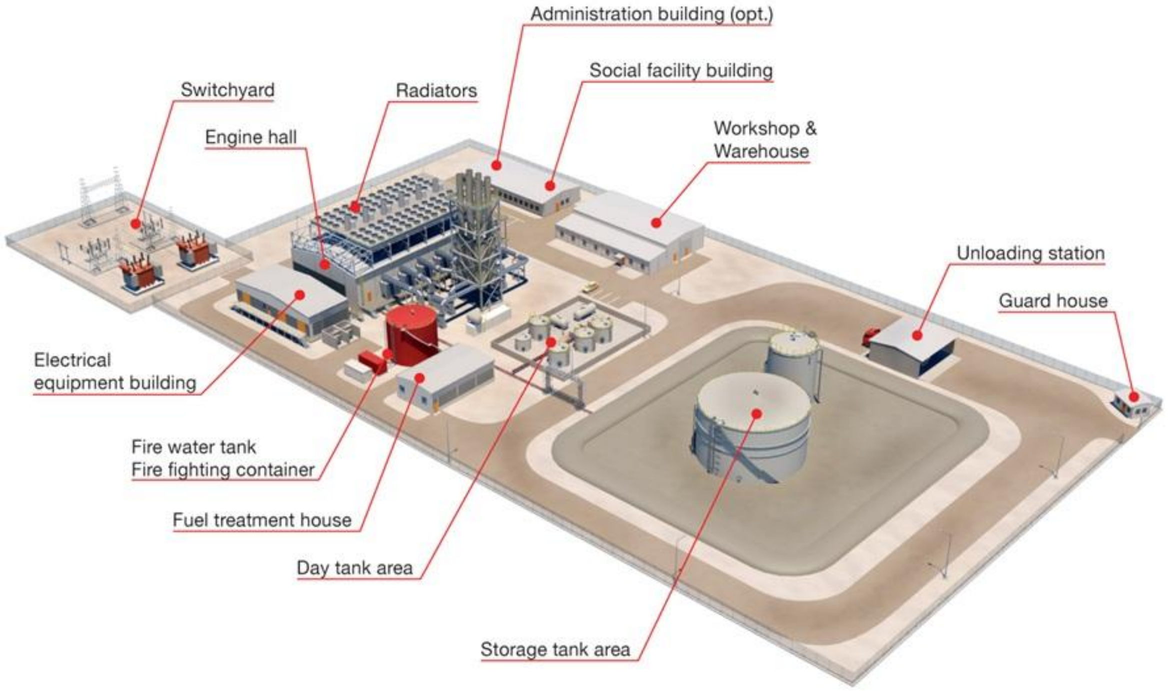


Figure 11. Power plant area (Wärtsilä 2014)

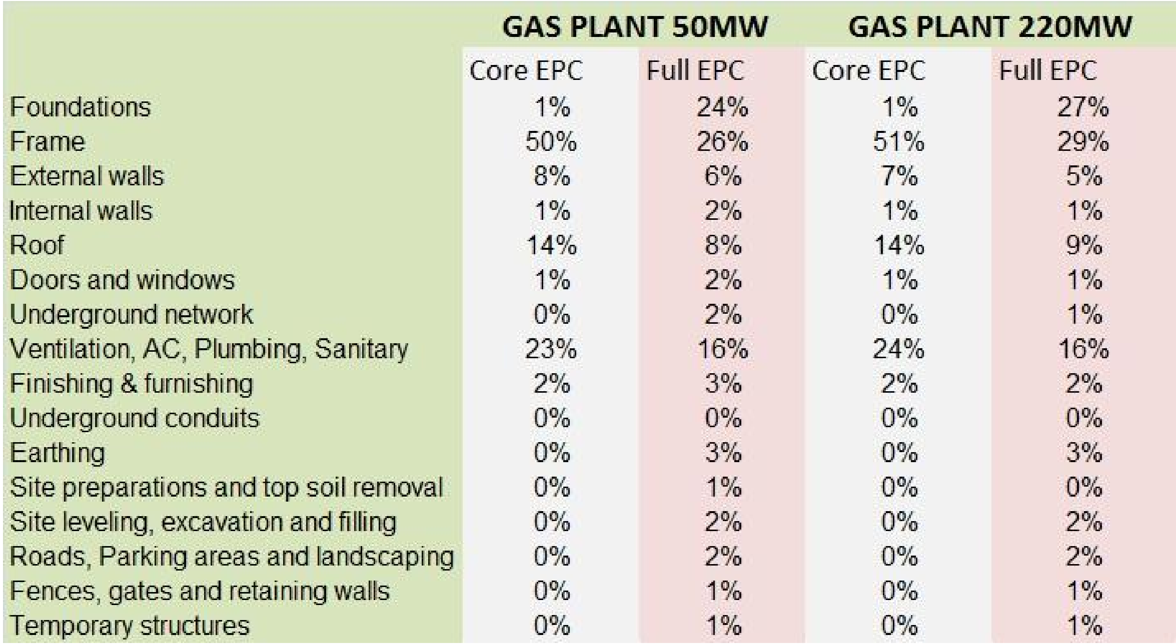
In gas power plant the fuel is gas, which is delivered to power plant through the pipeline and therefore there is no need for unloading station. Gas is neither stored at site, so there is no use for storage tanks either. Fuel treatment house which is used with diesel power plant to process the fuel is also needless at gas plant. Otherwise the scope split between core and full EPC are as in Diesel power plant.

As described above, the type and the delivery limits of power plant project has certain variations, also the order of magnitude in cost structure is affected by the delivery limits and by the type of the plant. Tables in next chapters are determining the cost structure of small and large, diesel and gas plants with core and full EPC scopes. Purpose of the cost tables are to understand where costs are consist of and which of those could be considered as major costs. Installation costs in tables in following chapters are including the material, work and the indirect costs. Tables are prepared by using Wärtsilä´s installation cost budgeting tool, with Helsinki – cost level and with assumption of good soil quality.

4.1.3 Civil discipline cost structure

In Table 2 there are two sizes of gas plants with core and EPC scopes. In all the four cases the major of civil costs are coming from frame structures of different building and structures. Hence the foundations are not in Wärtsilä delivery in case of core EPC the costs are minor for Wärtsilä, but with full EPC scope the foundations are the second biggest cost. As a third biggest cost, in all four cases of gas power plant is the HVAC, plumbing and sanitary. Roof structures as a fourth biggest cost in all four cases can be explained with cooling radiators, which are located on roof.

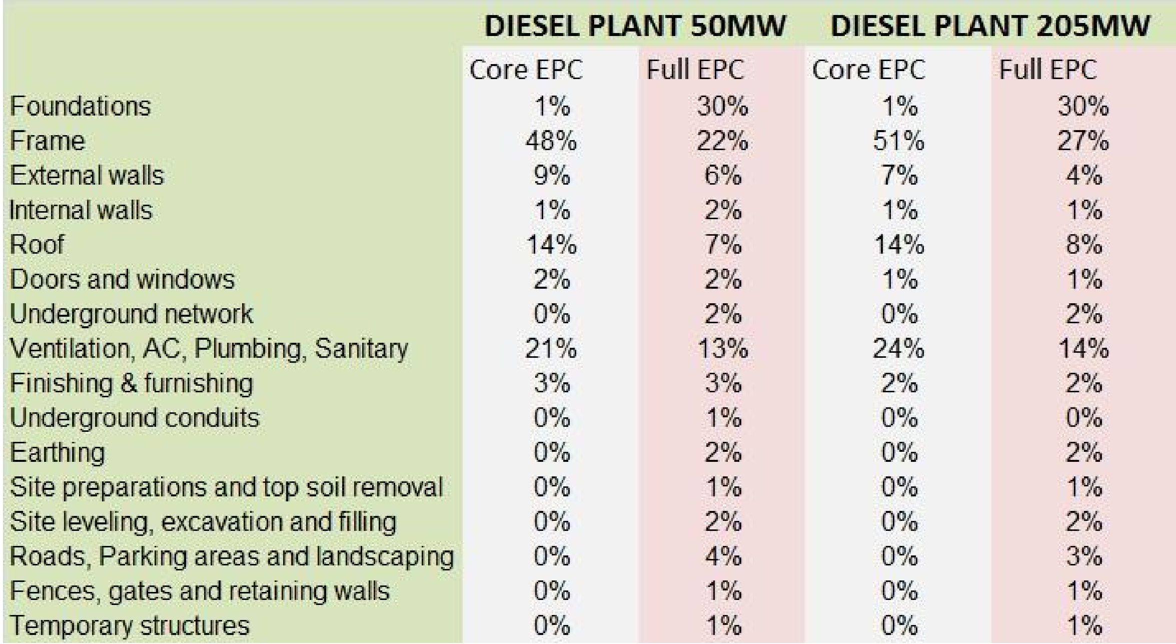
Table 2. Civil cost structure of typical Gas plant with good quality of soil



	GAS PLANT 50MW		**GAS PLANT 220MW**	
	Core EPC	Full EPC	Core EPC	Full EPC
Foundations	1%	24%	1%	27%
Frame	50%	26%	51%	29%
External walls	8%	6%	7%	5%
Internal walls	1%	2%	1%	1%
Roof	14%	8%	14%	9%
Doors and windows	1%	2%	1%	1%
Underground network	0%	2%	0%	1%
Ventilation, AC, Plumbing, Sanitary	23%	16%	24%	16%
Finishing & furnishing	2%	3%	2%	2%
Underground conduits	0%	0%	0%	0%
Earthing	0%	3%	0%	3%
Site preparations and top soil removal	0%	1%	0%	0%
Site leveling, excavation and filling	0%	2%	0%	2%
Roads, Parking areas and landscaping	0%	2%	0%	2%
Fences, gates and retaining walls	0%	1%	0%	1%
Temporary structures	0%	1%	0%	1%

In order of magnitude, the costs are similar with four cases of Diesel power plant in Table 3. Also the costs that are representing the minor costs are same with Diesel and gas power plants. Causes behind the major costs will be handled more when determining the cost drivers for the design work.

Table 3. Civil cost structure of typical Diesel plant with good quality of soil



	DIESEL PLANT 50MW		DIESEL PLANT 205MW	
	Core EPC	Full EPC	Core EPC	Full EPC
Foundations	1%	30%	1%	30%
Frame	48%	22%	51%	27%
External walls	9%	6%	7%	4%
Internal walls	1%	2%	1%	1%
Roof	14%	7%	14%	8%
Doors and windows	2%	2%	1%	1%
Underground network	0%	2%	0%	2%
Ventilation, AC, Plumbing, Sanitary	21%	13%	24%	14%
Finishing & furnishing	3%	3%	2%	2%
Underground conduits	0%	1%	0%	0%
Earthing	0%	2%	0%	2%
Site preparations and top soil removal	0%	1%	0%	1%
Site leveling, excavation and filling	0%	2%	0%	2%
Roads, Parking areas and landscaping	0%	4%	0%	3%
Fences, gates and retaining walls	0%	1%	0%	1%
Temporary structures	0%	1%	0%	1%

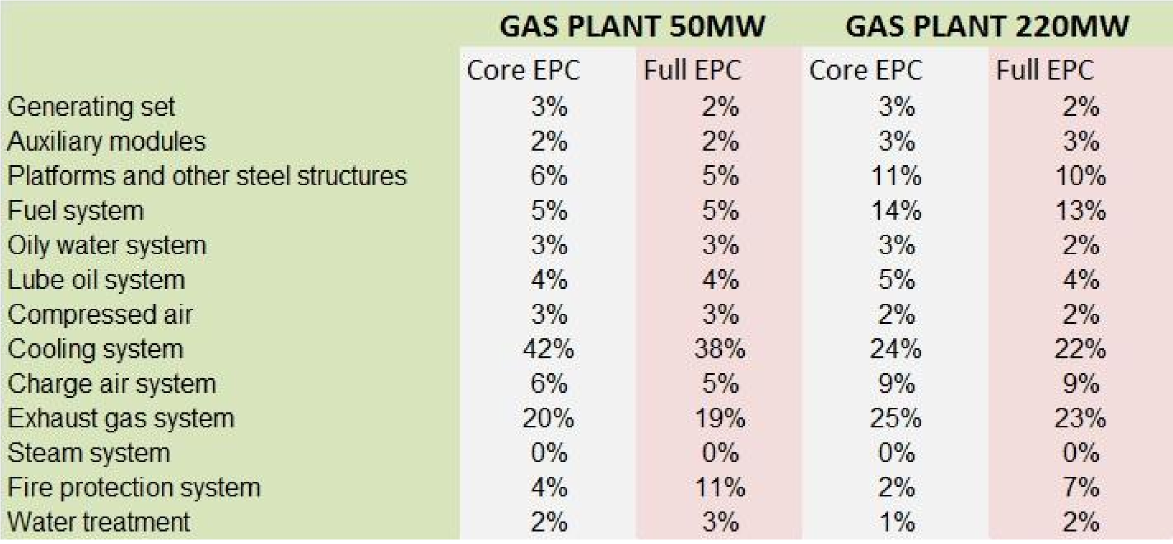
4.1.4 Mechanical cost structure

On gas power plant the majorities of mechanical installation costs are concentrated to cooling system and exhaust gas system piping. Lifting of cooling radiator modules and welding work of big cooling system and exhaust gas pipes are the main cause of these costs. With platforms and other steel structures the material and complex installation costs are third biggest cost in the mechanical installation.

On mechanical disciple the difference of cost split is remarkable between diesel and gas plant. Major difference is caused by the piping installations of fuel system of Diesel plant. And in case of full EPC the assembling work and material costs of the fuel tanks increases the costs on Diesel plant. Also the steam system, which is traditionally used for the fuel heating in Diesel plant is costly to install and changes the costs split between gas and Diesel plant.

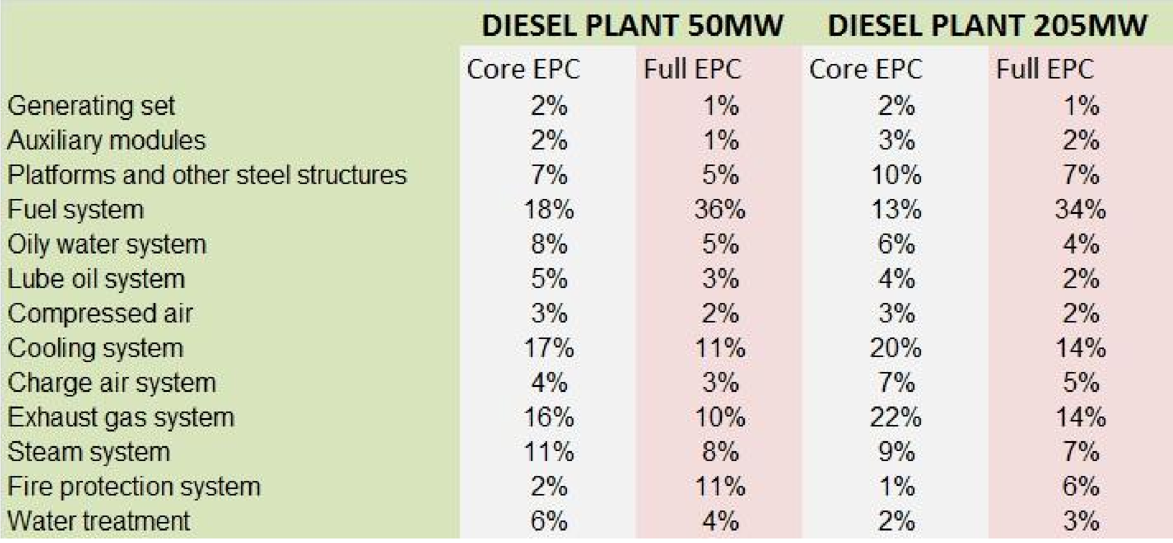
When determining the drivers for the mechanical installation costs, it should be noticed that in most of the systems there are several different types of works included, such as piping and tank manufacturing, which can have significant affect to the cost split. Some installation section (e.g. piping) which is common for several systems could be causing the majority of the installation costs of the whole plant, but the original cause for this installation section is totally different in different systems.

Table 4. Mechanical cost structure of typical Gas plant



	GAS PLANT 50MW		GAS PLANT 220MW	
	Core EPC	Full EPC	Core EPC	Full EPC
Generating set	3%	2%	3%	2%
Auxiliary modules	2%	2%	3%	3%
Platforms and other steel structures	6%	5%	11%	10%
Fuel system	5%	5%	14%	13%
Oily water system	3%	3%	3%	2%
Lube oil system	4%	4%	5%	4%
Compressed air	3%	3%	2%	2%
Cooling system	42%	38%	24%	22%
Charge air system	6%	5%	9%	9%
Exhaust gas system	20%	19%	25%	23%
Steam system	0%	0%	0%	0%
Fire protection system	4%	11%	2%	7%
Water treatment	2%	3%	1%	2%

Table 5. Mechanical cost structure of typical Diesel plant

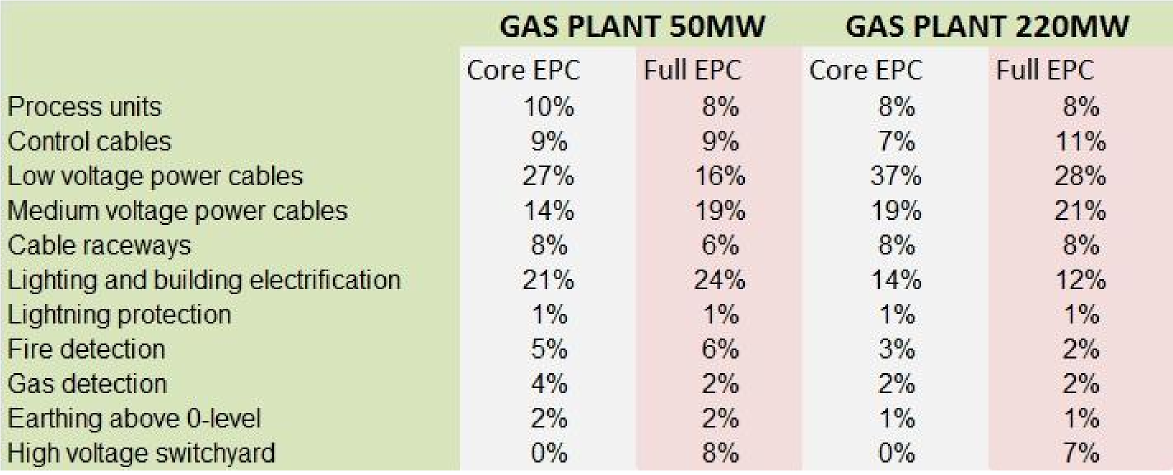


	DIESEL PLANT 50MW		DIESEL PLANT 205MW	
	Core EPC	Full EPC	Core EPC	Full EPC
Generating set	2%	1%	2%	1%
Auxiliary modules	2%	1%	3%	2%
Platforms and other steel structures	7%	5%	10%	7%
Fuel system	18%	36%	13%	34%
Oily water system	8%	5%	6%	4%
Lube oil system	5%	3%	4%	2%
Compressed air	3%	2%	3%	2%
Cooling system	17%	11%	20%	14%
Charge air system	4%	3%	7%	5%
Exhaust gas system	16%	10%	22%	14%
Steam system	11%	8%	9%	7%
Fire protection system	2%	11%	1%	6%
Water treatment	6%	4%	2%	3%

4.1.5 Electrical cost structure

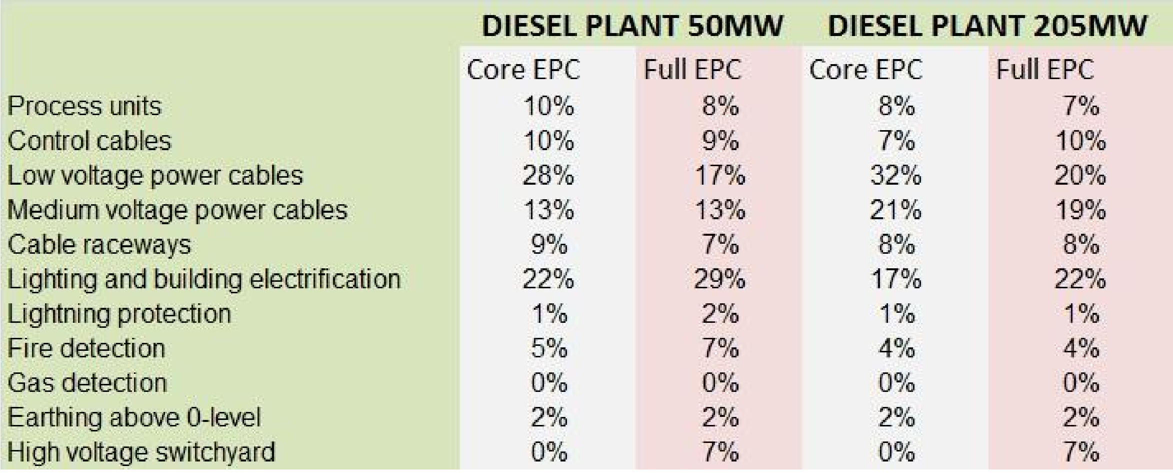
Summary of electrical installation costs can be found from Table 6 and Table 7. Installation costs of the electrical discipline consist the installation of Process units (panels, cubicles, switchgears), cables, cable raceways, fire and gas detection, lighting and building electrification, earthing and lightning protection. Biggest difference on electrical discipline with core and full EPC shows with high voltage switchyard.

Table 6. Electrical cost structure of typical Gas plant



	GAS PLANT 50MW		GAS PLANT 220MW	
	Core EPC	Full EPC	Core EPC	Full EPC
Process units	10%	8%	8%	8%
Control cables	9%	9%	7%	11%
Low voltage power cables	27%	16%	37%	28%
Medium voltage power cables	14%	19%	19%	21%
Cable raceways	8%	6%	8%	8%
Lighting and building electrification	21%	24%	14%	12%
Lightning protection	1%	1%	1%	1%
Fire detection	5%	6%	3%	2%
Gas detection	4%	2%	2%	2%
Earthing above 0-level	2%	2%	1%	1%
High voltage switchyard	0%	8%	0%	7%

Table 7. Electrical cost structure of typical Diesel plant



	DIESEL PLANT 50MW		DIESEL PLANT 205MW	
	Core EPC	Full EPC	Core EPC	Full EPC
Process units	10%	8%	8%	7%
Control cables	10%	9%	7%	10%
Low voltage power cables	28%	17%	32%	20%
Medium voltage power cables	13%	13%	21%	19%
Cable raceways	9%	7%	8%	8%
Lighting and building electrification	22%	29%	17%	22%
Lightning protection	1%	2%	1%	1%
Fire detection	5%	7%	4%	4%
Gas detection	0%	0%	0%	0%
Earthing above 0-level	2%	2%	2%	2%
High voltage switchyard	0%	7%	0%	7%

Majority of the costs are coming from process units, cabling, raceways and building electrification. As tables are showing, rests of the items are representing the 8% of the installation costs. Depending on the delivery limits, the position of biggest cost varies between low voltage cabling, medium voltage cabling and lighting and building electrification. Variation of lightning and building electrification between core and full EPC can be explained with amount of buildings in Wärtsilä scope of supply and area of outside lighting in case of full EPC. Varying portion of Medium voltage cabling is a result of difference between core and full EPC, but has connection to plant size as well. In full EPC the medium voltage cabling from medium voltage switchgear is in Wärtsilä scope of delivery which increases the portion of Medium voltage cables drastically. Also the bigger size of power plant causes long distances between generators and Medium voltage switchgear.

Controlling the causes for the installation costs of the lightning protection, fire detection, gas detection and the installation costs of the earthing wont have remarkable affect for the total installation costs. Cost split in these tables needs to be taken into account when determining the drivers in chapter 4.5.

4.2 Engineering processes

4.2.1 Process description

Process for the engineering is similar for the Civil, Mechanical and Electrical disciplines. Details of engineering processes of different disciplines are dealt in coming chapters. Process descriptions in following chapters are based to Wärtsilä´s internal process description document (Wärtsilä 2013). Process description was introduced for the researcher by Engineering Managers and General Managers of each discipline.

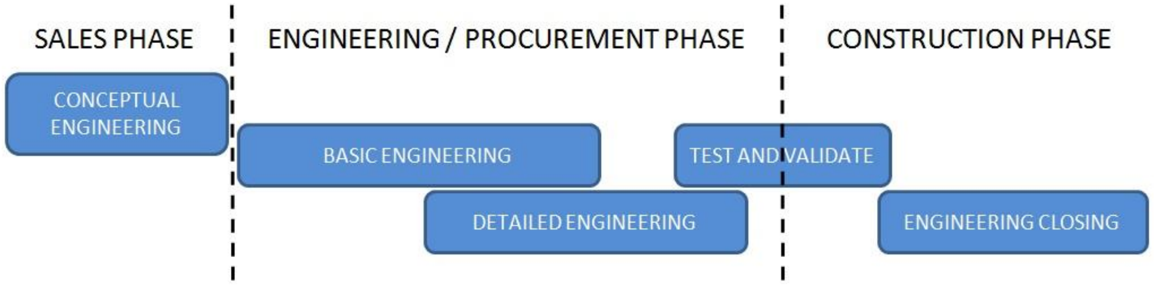


Figure 12. Engineering process of Civil, Mechanical and Electrical disciplines (Wärtsilä 2013)

Conceptual engineering is an element of sales phase of the power plant project. Conceptual engineering can be based on a standard solution or it can be a modified version to fulfill project requirements. Sales phase calculations and budgeting, including installation cost calculations are based on this conceptual engineering. Outputs of conceptual engineering are as follows:

- Main layouts (Site layout, power house and electrical equipment building)
- Electrical Main single-line diagram
- Mechanical Main process flow diagrams

Basic engineering is part of project planning phase and is typically started when project has been sold and handed over from sales to project management. Project execution kick-off meeting will work as an initiator for the basic engineering. Depending of discipline, basic engineering is typically carried out by internal resources or by external engineering company. Wärtsilä project team is accountable for the specification and for ordering the basic engineering. Typical inputs required for basic engineering are:

- Scope of supply
- Technical specification
- Applicable codes, standards, norms and regulations
- Site survey documents
- Possible preliminary design made during conceptual engineering
- Project main data, (Project name, location etc.)

And as an output of basic engineering, project team will receive following drawings:

- Site layout drawing (Mech)
- Power house layout and section drawings (Mech)
- 3D rendering drawing of power house and site
- Main process flow diagrams and device lists (Mech)
- Main single line diagrams
- Main electrical cabinet layouts
- Stationary power plant performance data
- Stationary power plant heat balance
- Dimensional drawings of major equipment (Mech)
- Generating set drawings

In Basic engineering phase, participation of all the disciplines is required. Mechanical process with location of tanks and equipments is connected to layout drawings prepared by civil discipline, as well as electrical discipline with location of panels, switchgears and transformers.

As Figure 12 shows, detailed engineering is done partly simultaneously with basic engineering. Basic engineering works as a input for detailed engineering and for project documentation. As output of detailed engineering, project team will receive design package including material lists and detailed drawing required in order to start procurement of installation material and installation works (site subcontracting).

Also during the detailed engineering, co-operation between disciplines is required. Mechanical process sets requirements for electrical & automation system (e.g. power supply’s and control cabling for process units) and for civil structures as well (e.g. steel structures for process units and foundations for tanks).

When detailed design is completed, design will be tested and validated before the closing of engineering. Validation is done according to separate test and validation plan, including e.g. factory and on-site tests. Closing of design can be done when issues found during the test and validation phase have been clarified and approved.

4.2.2 Civil engineering

Main drawings of conceptual engineering of Civil discipline is the site layouts, power house section and layout drawings and 3D drawing of power plant site and buildings. These drawings are typically prepared by engineering partner.

Main purpose of basic engineering on civil discipline is to provide required drawings for the building permits. Drawings required for the building permits vary between countries, but typically required drawings are site layout and layout and section drawings of all the buildings at site. Basic engineering is initiated with kick-off meeting with project team, including representatives of each discipline. Basic engineering of Civil discipline is performed by external engineering partner, so chief design engineers of engineering partner will participate to kick-off meeting of basic engineering. Main difference from Civil basic engineering to mechanical and electrical basic engineering is, that civil basic engineering is not aiming for the procurement package. As mentioned earlier, goal is to provide drawings for building permit process and to provide plan drawings for mechanical and electrical engineering (e.g. for determinations of equipment locations).

Detailed engineering will be started with kick-off meeting with project manager, civil chief project engineer, engineering manager and chief design engineer of external engineering company. Typically first engineering kick-off meeting is common for all disciplines, so also corresponding persons from mechanical and electrical disciplines are participating. As an input for detailed engineering will be drawings of basic engineering and soil investigation results. Also requirements set by the nature such as temperature, wind load, weather conditions, noise regulations and possible seismic data.

Civil detailed engineering is aiming to provide following drawings, specifications and material lists:

- Earthworks
- Earthing network
- Plumbing
- Conduits
- Foundations
- Steel structures of buildings
- Walls, doors, windows
- Roof
- Finishing and furnishing
- HVAC (Heating, ventilation, air conditioning)

Detailed engineering package is initiating procurement and manufacturing of building materials and sub-contractor for construction works.

4.2.3 Mechanical engineering

Conceptual engineering of mechanical discipline is consisting master layout drawings, meaning site layout, power house layout and section drawing of power house showing the location of tanks and main process equipments. Layout drawings in conceptual engineering are basically common with civil, mechanical and electrical disciplines and are prepared by external engineering partner. On mechanical discipline conceptual engineering also includes process main flow diagram for the fuel system. Depending of the workload of project engineers, main flow diagram is prepared by Wärtsilä or by external engineering company.

On mechanical discipline Basic engineering is started with kick-off meeting between the project team members, including Project manager and Chief project engineers of each discipline. Mechanical basic engineering is aiming to define the power plant operation, define the location of process equipments and to prepare procurement package for process equipments. As a output of basic engineering, next drawings or lists are developed:

- Device list
- Generating set configurations and dimensional drawings
- Auxiliary unit configuration and dimensional drawings
- System process description
- Process component dimensional drawings
- Fire protection layout drawings

Device list and dimensional drawings of process components are prepared by Wärtsilä with sub-supplier of each component. Configurations for generating set and for auxiliary units are prepared by Wärtsilä and dimensional drawings of these are made by supplier of the unit or by the external engineering company.

As stated above, basic engineering aims to define the main equipments and component in order to proceed with purchasing. As shown in Figure 12, Basic engineering is overlapping with detailed engineering. Typically this means that there are devices and components which are not possible to be defined for the procurement, without certain information prepared in detailed engineering. Main principle of detailed engineering is to define the process piping with its supplies between the main equipments and components in fuel, lube oil, cooling, starting & instrument air, exhaust gas, intake air, water treatment and for the fire protection. Drawings and material lists below are the outputs of detailed engineering:

- Pipe layouts
- Assembly drawings
- Manufacturing drawings
- Pipe isometrics
- 3D Model
- Material lists

Detailed engineering enables procurement and delivery of bulk material and finalizes site subcontract negotiations.

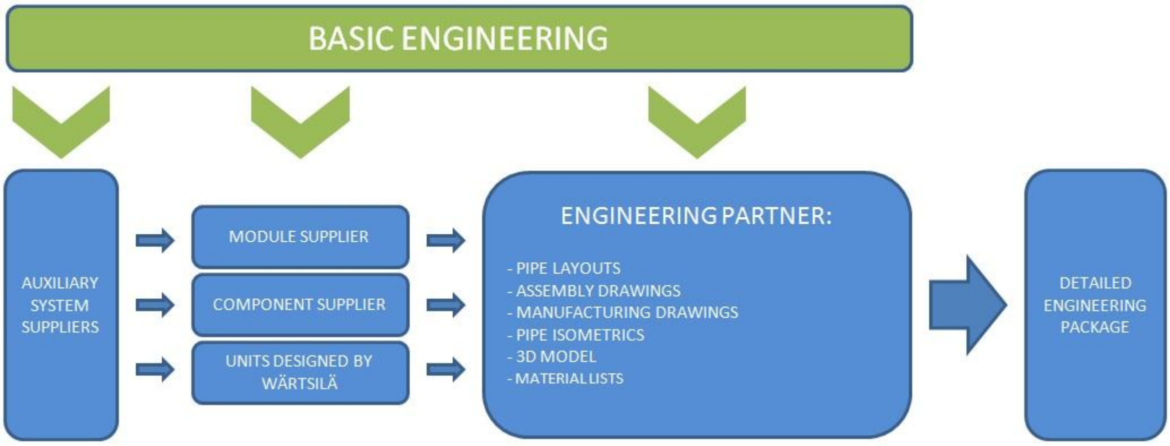


Figure 13. Mechanical detailed engineering in execution phase of power plant (Wärtsilä 2013)

As shown in Figure 13, basic engineering works as a input for the detailed engineering affecting to auxiliary system suppliers, module suppliers, component suppliers, to units designed by Wärtsilä and for the process engineering performed by external engineering partner.

4.2.4 Electrical engineering

In conceptual engineering the drawings produced by electrical discipline are the main single line diagram indicating how the main components are connected to each other on high, medium and on low voltage distribution. SLD (Single Line Diagram) defines the size of transformers, generators, breakers, bus bars and cabling between equipments. Also some electrical protection devices are defined in SLD. SLD is typically prepared by Wärtsilä´s project engineers.

Basic engineering is part of the project execution phase. Basic engineering is started with kick-off meeting held between the members of Wärtsilä´s project team. Representatives of engineering partner are typically not participating to basic engineering kick-off meeting. Purpose of basic engineering kick-off meeting is to specify the requirements set for the plant and bring those requirements to the basic design and possible to update the scope of supply and conceptual engineering which were used in sales phase of the power plant.

Aim of basic engineering on electrical discipline is to define that how the power plant will operate, define the location of electrical equipments and to prepare procurement package of the electrical equipments. In order to have required information for purchasing, electrical basic engineering defines the main components of electrical processes such as main transformers, MV-switchgears, LV-switchgear, auxiliary transformers and control panels. These equipments are defined by the required features, such as power, voltage level, quantity of inputs and outputs and size and quantity of power feeders.

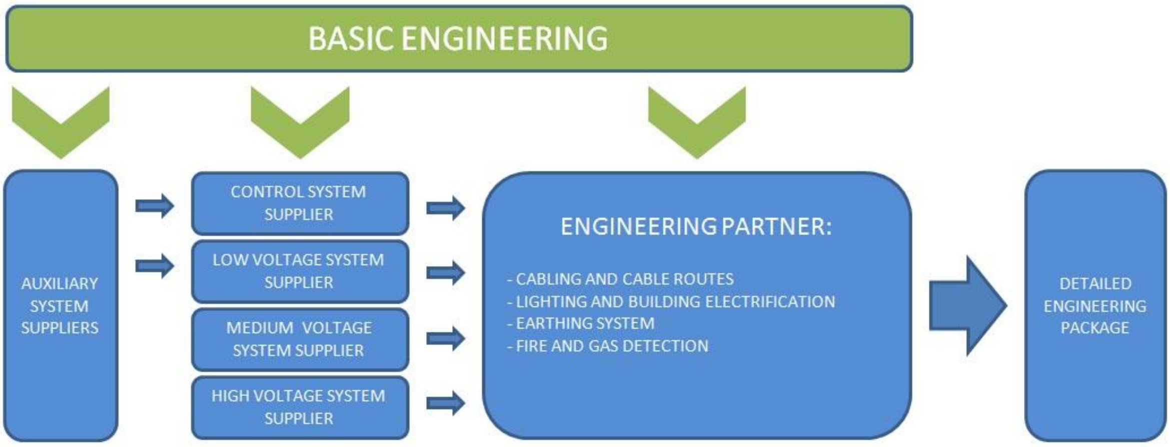


Figure 14. Electrical detailed engineering in execution phase of power plant (Wärtsilä 2013)

When basic engineering defines requirements for the electrical equipments, detailed engineering defines the details of those equipments and the details of process cabling, lighting and building electrification, earthing networks and fire and gas detection. Detail engineering starts with kick-off meeting. On electrical discipline the detailed engineering is out sourced for external partner companies and suppliers. Participants of kick-off meeting of detail engineering are Wärtsilä´s Chief project engineer and Project engineer of electrical discipline. Input of detailed engineering is the outputs of basic engineering. As a output of detailed engineering, project team will receive detailed process engineering of each system mentioned earlier including material lists of cables, cable ladders, building electrifications and fire and gas detection in order to make procurement of material and installation subcontracts.

As it is shown in Figure 14, basic engineering works as a base for the detailed engineering. Basic engineering is affecting to auxiliary system suppliers, control system supplier, low voltage system supplier, medium voltage supplier, high voltage supplier and for the work done by external engineering partner.

4.3 Cost consciousness of project team and design engineers

Cost consciousness of design engineers was dealt in chapter 3.7 of this thesis. Sandströms model of difficulty of formulating consciousness can be used to define the theoretical aspiration level of cost consciousness of project team and design engineers, i.e. meaning the level of cost consciousness which can be reached in terms of product life cycle and type of design.

As Sandström defines in her model, cost consciousness is related to product life cycle and type of design. Wärtsilä has delivered modularized power plant projects several decades without any major changes to the main concept, so the life cycle of the product can be discovered to be relatively long. Design updates for process modules have disturbing affect to this long life cycle, which decreases the length of life cycle. In type of design, modularization means standard products, but as described in chapter 2, due to varying requirements set for the power plant, process design can have large amount of differences between power plant projects.

Sandström also came to a conclusion that cost consciousness can be found from good level if there are design rules and some parametric cost estimation models in place. As it was discovered during the study of engineering process, there are several design rules in place. Parametric cost estimation is available only for sales process.

Based to product life cycle, design type and existing design rules, realistic aspiration level of cost consciousness of design engineers and project team was defined according Figure 15.

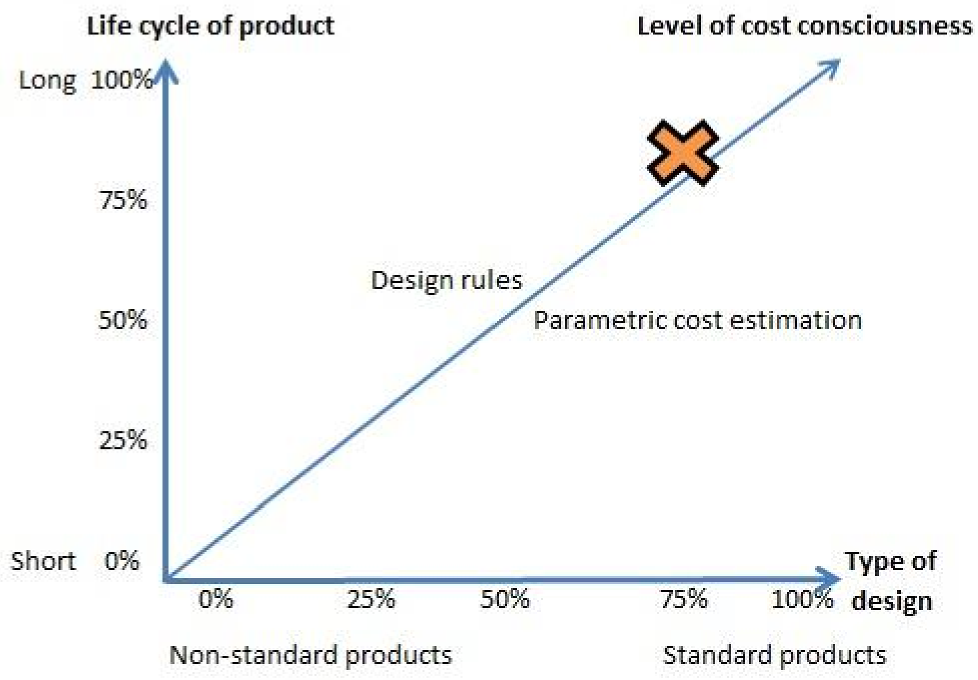


Figure 15. Aspiration level of cost consciousness of design engineers and project teams (adapt from Sandström 2001, 51)

In Figure 15, aspiration level of cost consciousness marked with “X” defines the level of cost consciousness which is possible to achieve in terms of product life cycle and type of design, so it doesn’t give any indication of current state of cost consciousness of project teams or design engineers.

As concluded, current state of product life cycle and type of design gives possibility to set aspiration level of cost consciousness on high level. Of course, cost consciousness of project team members and design engineers might increase by the experience. But in order to build up good conditions for cost consciousness, actions to provide guidance are needed. From cost management point of view, sources in chapter 3.4.2 conclude that costs should be managed with project specific drivers, which are representing the activities that are causing the major of the costs. These drivers are dealt more in detail on coming chapter, but with those drivers, especially the costs consciousness of project team members will be increased.

When it comes to Value engineering, which was dealt in chapter 3.5, detailed cost information comes to the picture. Detail design is in the working area of design engineers and utilizing detail cost information the main goal of Value engineering can be achieved. Achieving the required function with lowest cost requires, beside the description of function also the cost information needs to be available. Required functions are known by the design engineers, but as discovered in study of engineering processes, there is no detailed cost information available for the design engineers. In order to aim for the lowest cost, some sort of detailed information of installation costs should be available for the design engineers. One or more of the following should be considered:

- Unit prices used in budgeting phase
- General unit prices based e.g. Finnish cost level
- Standard prices of installation material
- Working hours required by each installation unit

Most suitable of the cost information types above would be the unit prices used for the budgeting, but Wärtsilä´s policy regarding sharing the cost information sets certain limits for the sharing of cost information with partners and sub suppliers. Also to ensure pure possibilities to seek for affordable solutions the cost information regarding different solutions and materials should be wide enough.

Good combination of cost drivers and value engineering would increase the cost consciousness of chief project engineers as well. Higher level requirements (values) are recognized by chief project engineers and by exploiting cost drivers (engineering) to achieve those requirements with lower costs would ensure the optimized solution.

4.4 Responsibility of installation cost management

As studied in chapter 3.8 main conclusion was that cost responsibility should be on that individual who has initiated and approved the cause of the cost. In power plant project the requirements are typically set by the customer that the sales teams are fulfilling by developing a configuration with modularized equipments and standardized solutions. In implementation phase of the power plant the responsibility is transferred for the project team. Typical structure of core project team is Project manager, Project controller and Chief project engineers of each discipline (Civil, Mechanical and Electrical). Supporting functions such as project engineers, HSE, Quality, purchasing, legal, financial and installation & construction services are working as matrix organization. Final responsibility belongs to Project manager, but Chief project engineer of each discipline are the responsible for the costs and the technical solution of the discipline in charge.

One of the causes for the costs is installation. As described in chapter 2, number of the cost related selections has been made already in the budgeting phase of the power plant project. Certain installation costs related selections have been made in installation costing phase and this being, person behind the installation cost budget can be kept as initiator of certain costs of the installation.

As dealt earlier, also the design engineer has cost related responsibilities for the installation costs. Cost drivers set by cost engineer and project team, design engineer is able to pay attention for the parts of the design where the majority of the costs are generated. Besides the drivers, design engineers will have use for detailed cost information of installation work. Detailed cost information provides possibility to utilize Value engineering for the design work and seek for the most affordable solution.

4.5 Cost drivers and focus areas

4.5.1 Focusing on the main costs

Cost structure of typical, small and big - gas and diesel plants was dealt in chapter 4.1. As the tables were indicating, there is 3-4 main cost elements recognized from each discipline. Paretos theory, which was dealt in chapter 3.4.2 says that 80 % of costs are caused by 20 % of initiators. Of course, that cannot be taken too literally, but it seems to be valid with cost structure Table 2 - Table 7. Fogelholm and Karjalainen, dealt in chapter 3.4.2, stated that detailed cost information of product is not relevant. Instead, controlling should be concentrated for the causes of majority of the costs. In case of power plant installation costs, this can be considered so that when determining the main causes for the costs, there is no benefit to focus on areas or systems that are representing e.g. 1 % of the total costs.

Also Sandströms and Wilson statements were dealt in chapter 3.4.2, with conclusion that number of drivers should be kept small. According to Wilson, suitable number of drivers is between four and six. According to these principles, the drivers and focus areas of civil, mechanical and electrical disciplines will be selected in following chapters.

As it was shown in Table 2 - Table 7, main cost elements cannot be assumed to be same with different types of power plants. For that being, both the driver and focus areas cannot be locked to be same in every project. When determining the drivers, also the engineering process during the execution phase, which is consisting two main stages, basic and detailed, needs to be taken into account.

4.5.2 Civil discipline

As shown in Table 2 and Table 3, majority of costs are caused by foundations, frames, walls, roof and building services (e.g. HVAC, plumbing and sanitary). These costs are originally caused by different buildings and structures. It should be highlighted that the topography and quality of soil is of the critical factors in civil cost structure. Examples in Table 2 and Table 3 are calculated with good quality of soil, but in case of bad soil quality or difference in site levels are causing massive soil replacements or blasting, the cost structure can be totally different, meaning that the soil replacements and blasting are representing clearly the biggest portion of the civil costs.

Buildings and structures to be delivered for the customer are defined in the contract scope of supply, in technical requirements and in approved layout drawings. Typically this scope of supply and layout drawings has been the base for the installation cost budgeting, but there are cases where the scope of supply and layouts have been modified during the final negotiations and the installation costs have not been updated by the installation costing team. Instead installation costs might be updated by the sales person negotiating the contract or the installation cost update has not been done at all.

Engineering process during the execution phase starts with basic engineering. As dealt in chapter 4.2, basic engineering is initiated with kick-off meeting with the project team. As it is dealt in chapter 4.4, Cost engineers can be treat as some sort of initiators for the installation costs and should be participating to engineering meetings when it can be seen necessary. In basic engineering phase the role of the cost engineer would be to bring the cost estimate up to date and prepare forecast for the installation costs, meaning that cost estimation will be updated with possible changes in scope of supply and in layouts that have been committed after the last installation cost estimation. Especially the most important input of cost engineer is to explain the reason and selected solutions behind the installation cost estimations made in sales phase of the power plant. On civil discipline this would mean following items working as cost drivers for the basic engineering when preparing drawings for building permits:

- buildings
- other structures
- tank yard
- switchyard
- transformers
- site leveling
- access roads

Unit prices of different works and materials can be used as cost drivers as well in order to optimize the costs by locating structures differently (e.g. the gravel cost in project country or in that certain part of the country can be so high, that piling may be more affordable solution even when the depth of unsuitable soil is low). Good example of Value engineering is dealing with site leveling. Established practice is that site topography with plant layout and with local unit prices are used for optimizing the site leveling in terms of costs.

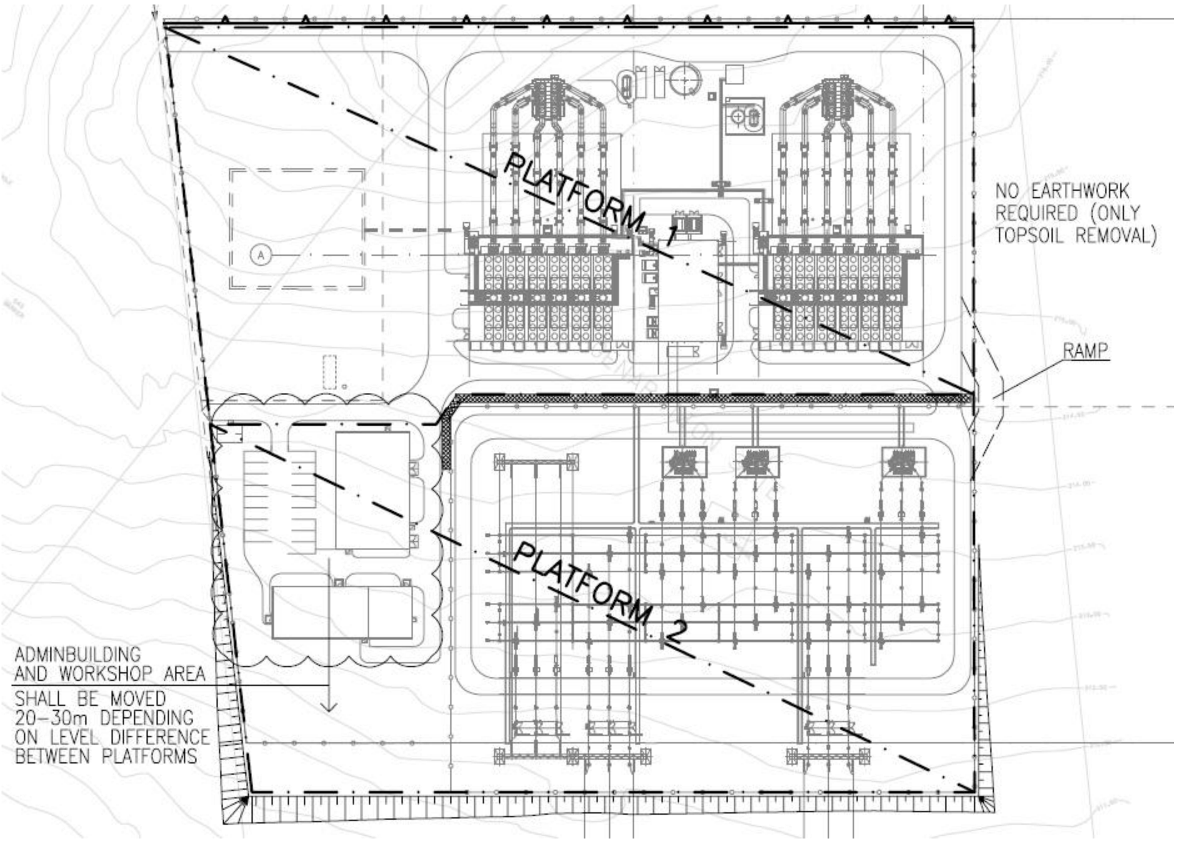
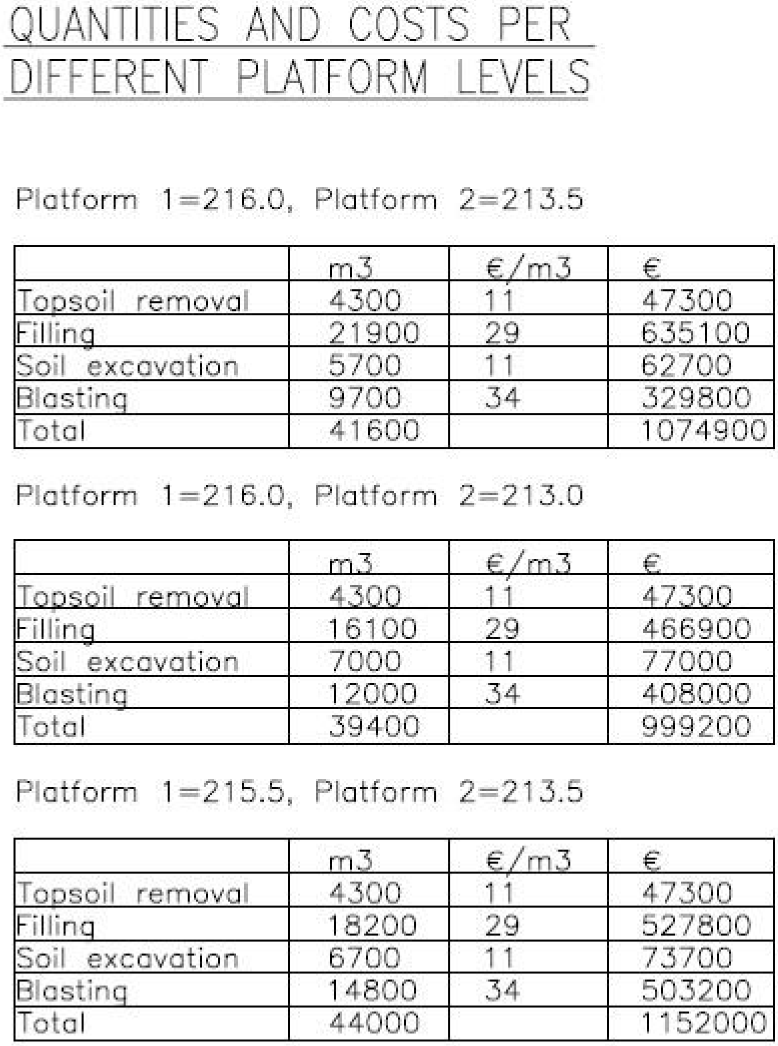


Figure 16. Example of Site leveling

In Figure 16, is an example of site which was located on the hillside of the mountain, meaning that half of the site was needed to be cropped and another half was needed to be filled. Taking into account the local unit prices of blasting, excavation, filling and top soil removal, design engineer made a calculation that on which level the site would be optimal to balance. The result of the optimizing can be found from Table 8. As it can be seen in Table 8, the most optimized option would be the one in the middle. Balancing the platform 1 to level of 216 m from the sea level and the platform 2 to level 213 m from sea level would be the most affordable solution. Depending on the unit prices on installation country, the result could be totally different. Referring to chapter 3.7, this wouldn’t be possible without design engineer having access to cost data.

Table 8. Optimizing the costs of leveling



QUANTITIES AND COSTS PER DIFFERENT PLATFORM LEVELS

Platform 1=216.0, Platform 2=213.5

	m3	€/m3	€
Topsoil removal	4300	11	47300
Filling	21900	29	635100
Soil excavation	5700	11	62700
Blasting	9700	34	329800
Total	41600		1074900

Platform 1=216.0, Platform 2=213.0

	m3	€/m3	€
Topsoil removal	4300	11	47300
Filling	16100	29	466900
Soil excavation	7000	11	77000
Blasting	12000	34	408000
Total	39400		999200

Platform 1=215.5, Platform 2=213.5

	m3	€/m3	€
Topsoil removal	4300	11	47300
Filling	18200	29	527800
Soil excavation	6700	11	73700
Blasting	14800	34	503200
Total	44000		1152000

As an output of basic engineering kick-off, cost engineer would prepare updated installation cost estimation, which would work as a forecast for the installation costs.

Detailed engineering as well, starts with kick-off meeting, where cost engineer would use the updated cost estimation as an input for the detailed engineering phase. As it was dealt in chapter 4.2, detailed engineering is prepared by the design engineers in external engineering company. When talking about detailed engineering, buildings and structures cannot be used any more as cost drivers. Instead, in civil discipline, cost drivers for detailed engineering should be things that designer can directly measure and have cost information available (Dealt in chapters 3.4.2 and 3.7). This type of drivers on civil discipline for example are amount of excavation and filling, amount of concrete, weight of steel structures and area of wall and roof material etc. Based on updated cost estimation on basic engineering kick-off, cost engineer would prepare project specific list of the most cost affecting activities and works and set those to be as a cost drivers for the design engineers during the detailed engineering phase.

These drivers for the detailed engineering are project specific and must be selected based on criteria's dealt in chapter 3.4.2. As it was dealt in chapter 3.7, Sandström had found out that in order to utilize value engineering (dealt in chapter 3.5), detailed cost information must be available for design engineers. Primary purpose of the cost management is to keep costs in budgets or even when the costs are exceeded; it will be done under control. But especially when there is a possibility for the overruns, value engineering (looking for more affordable solutions to achieve required value) is to be utilized by the design engineers to decrease the costs.

4.5.3 Mechanical discipline

Involvement of mechanical cost engineer to engineering process, shares the main principles with civil discipline. Mechanical basic engineering aims for the specification of the main equipments and components in order to start procurement activities. These equipments and component specifications with possible changes to SoS, layout and to technical requirements are to be updated to mechanical installation cost calculations during the basic engineering kick-off meeting. Cost drivers for mechanical basic engineering are location of main equipments, size and quantity of tanks, location and size of the cooling radiators. These are drivers to be used by the mechanical chief project engineer in order to control the basic engineering process. As a conclusion of basic engineering kick-off meeting, cost engineer will prepare forecast for the installation costs and defines the most effective cost drivers to control the basic engineering.

Detailed engineering kick-off is to be held with external engineering company. In detailed engineering kick-off meeting outputs of basic engineering kick-off meeting will be presented. Project specific focus areas of cost management will be selected by utilizing methods and principles introduced in Table 4 - Table 5 and cost drivers for the detailed engineering will be set according to rules and recommendations dealt in chapter 3.4.2. Cost drivers for the detailed engineering will be items like welding, pipe installation, tank fabricating etc. However, the drivers are project specific and will be defined in detailed engineering kick-off meeting. As a output of detailed engineering kick-off meeting, cost engineer will prepare report of those cost drivers set for the design engineers and updated installation cost forecast with possible corrective actions that were decided in detailed engineering kick-off meeting.

4.5.4 Electrical discipline

Main principles for the participation of electrical cost engineer are the same as for the civil and for the mechanical cost engineers. Installation cost calculation update during the beginning of basic engineering follows the same rules as on civil and mechanical discipline. Electrical installation cost calculation is affected by:

- layout drawing
- single line diagram
- building and structures
- scope of supply

As it was dealt in chapter 4.2, basic engineering aims to specify the main equipments in order to start the procurement activities. These equipment specifications may have affect to the installation costs and needs to be updated to the installation cost calculation. Also the layout and location of buildings are affecting the length of cable routes. In scope of supply most critical cost affecting items are mechanical and electrical process units, number of tanks, size and quantity of transformers and structure of high voltage switchyard. In order to have installation costs under control during the basic engineering process, these equipments and process units needs to be utilized to cost drivers. Same way as in civil and mechanical discipline, electrical cost engineer prepares installations cost forecast based on the contracted SoS, layouts and technical requirements.

In detailed engineering kick-off meeting project specific cost drivers and focus areas for electrical detailed engineering will be defined by electrical cost engineer. Drivers that are used for electrical cost management are to be selected according rules and recommendations dealt in 3.4.2. Most affecting drivers according to Table 6 and Table 7 are concentrating to control, low voltage and medium voltage cabling, but as well the lighting and building electrification is representing the big part of the costs. Focus will be set for the process equipments and auxiliary units where e.g. the cabling costs are high. Cost savings are found by utilizing value engineering, meaning for example complaining signals to use only one cable instead of two between panels or by re-evaluating the power consumption and cable sizing (i.e. finding more affordable solutions to produce required value).

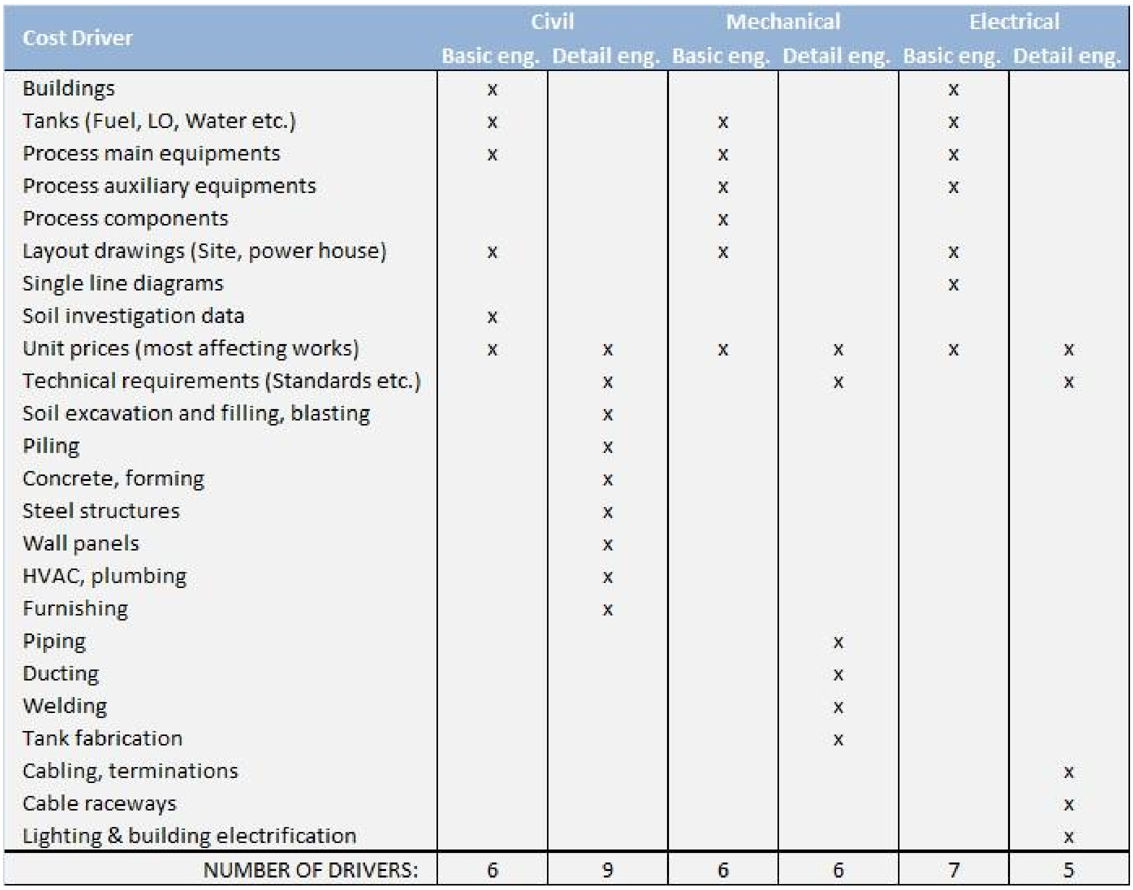
As an output of detailed engineering kick-off meeting, electrical cost engineer will prepare an update for the installation cost forecast and make a list of cost drivers to be utilized during the detailed engineering. In case that installation costs are to be exceeded, cost engineer defines, together with chief project engineer and with chief design engineer a list of corrective actions to limit the overrun of the costs. Final decision of corrective actions will be on Chief project engineer.

4.5.5 Summary of cost drivers and focus areas

As a conclusion of cost drivers and focus areas of different disciplines, it can be said that they are all following the same main guidelines. In basic engineering kick-off meeting cost estimations made in sales phase are updated to be in line with contracted scope of supply, technical requirements and the power plant layout. Cost drivers for basic engineering will be set to guide the basic engineering.

From the installation cost management point of view, process of detailed engineering is similar between the disciplines. Detailed engineering concentrates to design the process in detailed level, meaning that also the cost drivers are more detailed. In detailed engineering the cost drivers are set by the cost engineer with CPE and CDE. These drivers will guide and give targets for the design engineer, but it also means that design engineer is having more power to make decisions to achieve cost savings, but also more responsibility of the cost management.

Table 9. Cost drivers for basic and detailed engineering processes



Cost Driver	Civil		Mechanical		Electrical	
	Basic eng.	Detail eng.	Basic eng.	Detail eng.	Basic eng.	Detail eng.
Buildings	x				x	
Tanks (Fuel, LO, Water etc.)	x		x		x	
Process main equipments	x		x		x	
Process auxiliary equipments			x		x	
Process components			x			
Layout drawings (Site, power house)	x		x		x	
Single line diagrams					x	
Soil investigation data	x					
Unit prices (most affecting works)	x	x	x	x	x	x
Technical requirements (Standards etc.)		x		x		x
Soil excavation and filling, blasting		x				
Piling		x				
Concrete, forming		x				
Steel structures		x				
Wall panels		x				
HVAC, plumbing		x				
Furnishing		x				
Piping				x		
Ducting				x		
Welding				x		
Tank fabrication				x		
Cabling, terminations						x
Cable raceways						x
Lighting & building electrification						x
NUMBER OF DRIVERS:	6	9	6	6	7	5

Cost drivers and corrective actions will be dealt more in concrete level during the test phase of installation cost management model.

4.6 Indicators and reporting of installation cost management

4.6.1 Type and features of indicators

Features of good indicator were dealt in chapter 3.4.1. Indicators can be result of direct measurement and indirect measurement. With cost drivers in engineering process, there were indirect and direct cost drivers. Drivers set in basic engineering phase can be considered as indirect drivers and cost drivers used during detailed engineering phase were more like direct cost drivers.

Selection of indicators is in connection with reporting that were dealt in chapter 3.4.3. According to Wilson, reports should be always made for individuals, not for the departments. It was also stated that reports should provide information to support decision making, not numbers for accounting purposes. When selecting indicators for installation cost management, drivers that are used for a controlling the engineering would be natural selection as indicator. It must be understood that for design engineers, direct indicators based an quantities, areas and weights of different systems would be suitable and concrete way to express the results. But for the persons, such as project manager, chief project engineer or for project controller, the quantity of piping, cabling or concrete doesn’t give clear picture of the status of the costs, so the indirect indicators are to be used for reporting by converting direct indicators to currency.

As a introduction for chapters 4.6.2 and 4.6.3, it can be concluded that both, direct and indirect indicators are needed for reporting the status of installation costs during the engineering process.

4.6.2 Basic engineering

Cost updates and forecasts prepared in basic engineering kick-off, are suitable indicators to be reported for the project management. Updated installation cost estimation as a forecast, provides clear information of the status of installation costs. High level cost drivers and recommendations for corrective actions to guide basic engineering as an output from basic engineering kick-off, also gives concrete indication that installation cost management is under control. It can also be the case that during the basic engineering kick-off, it has been found out that with certain changes to layout or to power plant equipments, remarkable cost savings could be achieved. This kind of case could be some poor soil quality in certain parts of site area or changing the location of unloading station would cause savings on pipelines. This type of information and cost calculations are supporting the project management with decisions or with negotiations with customer to change the layout etc.

4.6.3 Detailed engineering

With detailed engineering, cost drivers were more in detailed level and can be used as such as an indicator as well. But as it was with basic engineering, the indications and reports should be made for individuals. Detailed cost drivers such as quantities, weights and areas are suitable to provide suitable results for design engineers, but not for the project management, who would like to have the indications such a way that those can be compared against the cost budgets and forecasts.

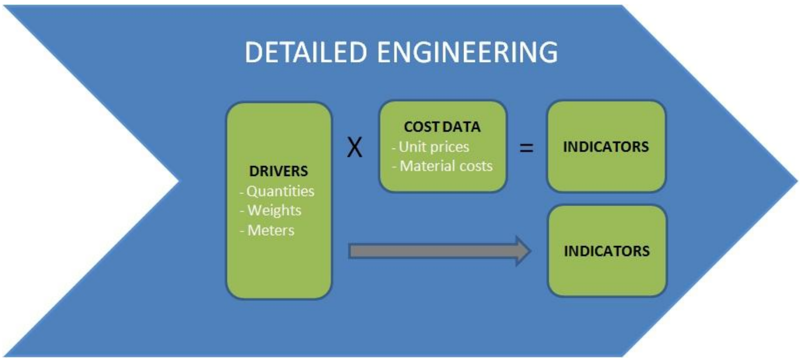


Figure 17. Direct and indirect indicators

As shown in Figure 17, cost drivers set for design engineers can be taken as target, such as weight of steel structures, meters of piping or number of luminaries. Design engineer can easily compare these targets for the designed values. For the project management quantity of material is probably not good enough, and the material quantities need to be converted to costs by using project specific unit prices.

4.7 Model integration to engineering process

4.7.1 Process plan

As it was dealt in chapter 3.8, system must serve the process, not process serving the system. In order to improve level of acceptance of installation cost management model and to optimize required effort, installation cost models needs to be integrated to existing engineering process. Integration can be implemented by exploiting kick-off meetings and engineering review meetings held during the process.

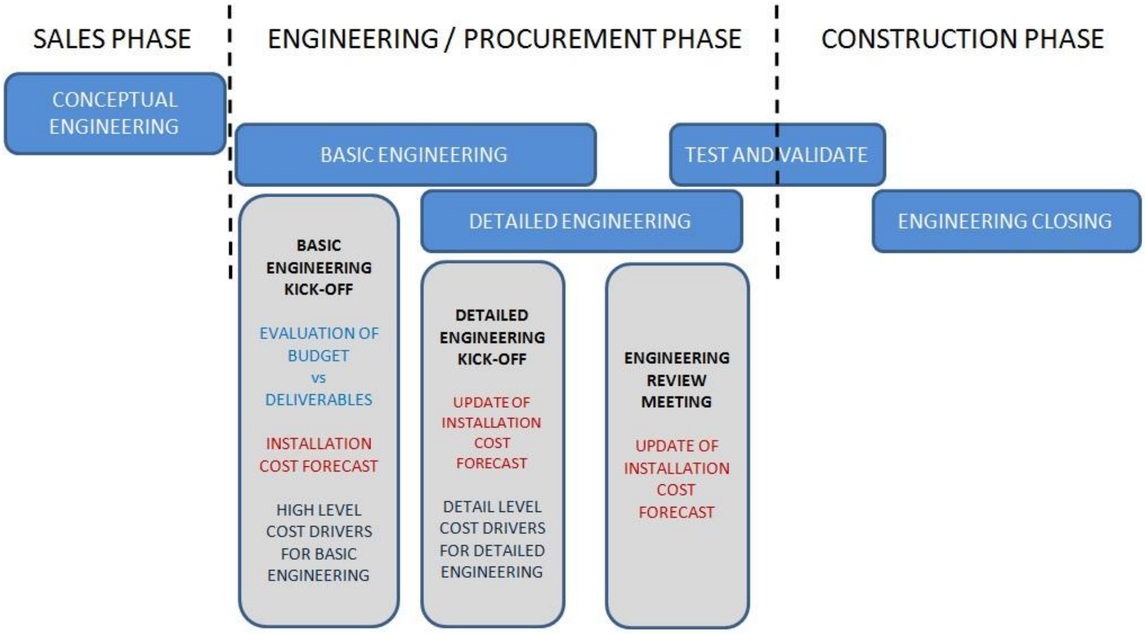


Figure 18. A Model for installation cost management in engineering process (adapt from Wärtsilä 2013)

4.7.2 Basic engineering

As an output of basic engineering kick-off, installation cost forecast for each discipline is prepared by updating the installation cost calculation with contracted scope of supply, layouts available, technical requirement and discipline specific design, such as main flow diagram and single line diagram. When the installation cost calculation is updated, cost drivers for basic engineering are selected from the most affecting systems, from installation unit prices of project country and by utilizing the soil investigation data. As it was dealt in chapter 4.5, these drivers depending of discipline could be:

- Type and areas of building (as budgeted)
- Dimensions of tank yard (area as budgeted)
- Size of the tanks (as budgeted and sold)
- Type and quantity of process equipments (as budgeted and sold)
- Distances between areas and building (as budgeted and sold)

In other words, purpose of these drivers above is to control the basic engineering to be as close to budgeted as possible, but taking into account the possible differences between budgeted and sold solution. This will be supported by exploiting costs (unit prices) used for the budgeting, in order to find cost-effective solution. If cost-effectiveness related findings are made during the kick-off, which requires some fundamental changes to layout or scope of supply, these findings are reported for the management as suggestion of corrective actions.

Installation cost forecast, cost drivers and possible suggestions for corrective actions will be reported for project management and for the engineers preparing the basic engineering.

Activities above, requires participation of cost engineers of each discipline to update the installation cost calculation, to provide support with determination of cost drivers and with evaluation of corrective actions to be proposed.

Since the basic engineering is executed or at least the decision related to content of basic engineering is made by Wärtsilä representatives, the responsibility of implementation of cost drivers belongs for the Wärtsilä representatives as well. This was concluded in chapters 4.3 and 4.4 by evaluating the cost management responsibility and cost consciousness of project team members and design engineers.

4.7.3 Detailed engineering

Detailed engineering starts with kick-off meeting with project team and representatives of external engineering company. In detailed engineering kick-off meeting, installation cost forecast will be updated according to basic engineering available. Outputs and possible decisions based on outputs of installation cost management activities made in basic engineering kick-off meeting are to be used for the input of kick-off meeting of detailed engineering process. As it was done in basic engineering kick-off, also in detailed engineering kick-off, the cost drivers will be defined for the detailed engineering process. Depending on the discipline, as it was dealt in chapter 4.5, cost drivers for detailed engineering can for example:

- Soil excavation and filling
- Piling
- Concrete, forming
- Steel structures
- HVAC, plumbing
- Piping
- Ducting
- Welding
- Tank fabrication
- Cabling
- Cable raceways
- Lighting & building electrification
- Unit prices of installation

And as it was dealt in chapter 4.5, for successful value engineering, detailed cost data needs to be available for design engineers. This detailed cost data is consisting installation unit prices used for budgeting, but also the suitable cost data available of alternative solutions.

Since the detailed engineering is prepared by external engineering company, chief design engineer and design engineers are responsible of implementing cost drivers. But as it was dealt in chapter 3.9, Wärtsilä should give strong support for the external engineering company to develop its processes. As a output of kick-off meeting, report of installation cost forecast and selected drivers will be prepared.

There could be several engineering review meetings during the engineering process and cost engineer should be participating when needed (i.e. when cost affecting items are to be discussed). Engineering review meeting held before engineering and material lists are handed over for procurement purposes, cost engineer will participate. Role of the cost engineer is to collect feedback from the engineering process and update the cost forecast. It should be also discussed and documented, that how the agreed cost drivers were affecting and how those target quantities were met. It might also be the case, that due to value engineering, there might be some solutions found that comparison of quantities is not relevant anymore and the attention should be more in the cost of the installation.

4.7.4 Conclusion

Participation of cost engineer is the key element in installation cost management model. With basic engineering, the cost management related inputs can be very similar between the projects, but the inputs and outputs of detailed engineering are project specific and needs to be defined project wise. It can be also concluded, that specially in detailed engineering phase, that not only the quantity of installation material should be followed. Due to affect of value engineering, it can be that quantities are not necessarily affected, but the costs have reduced. Related to value engineering, availability of detailed cost data for design engineers can be kept as essential.

It should be also kept in mind that main purpose of installation cost management model is to manage the installation costs during the engineering process by following the initial data used in budgeting phase. If there are mistakes made during the sales phase regarding installation cost budgeting, it might be that the budget will be exceed. With installation cost management model budget cannot be reached if the mistakes made in budgeting phase are vital. In other words, purpose is not to make miracles, but even if the budget is exceeded, project team can be prepared already from the beginning of basic engineering. Participation of cost engineer will ensure that reasons for overruns are defined and feedback is directed to the original cause of under budgeting and the corrective actions are taken in order to prevent the recurrence.

5 TEST OF INSTALLATION COST MANAGEMENT MODEL

5.1 Selecting the test projects

During the testing workshop held with representatives of civil, mechanical and electrical disciplines, it was decided that projects which will be selected for the testing purposes of the installation cost management model, are actual projects, which are executed and handed over for the customer. This decision was based on fact that information required for the testing would only be available from executed projects. Creating virtual project or selecting sales project for the base of testing would the initial information be limited only to conceptual engineering. For the testing of installation cost management model, initial data of basic engineering is required, such as soil investigation data and project contract with its requirements.

Selected projects are two different type and different size of projects. Purpose of selecting two unequal projects was to point out the differences between the cost drivers and indicators between these projects.

However, information utilized in testing of model was limited to conceptual engineering and for the inputs of basic engineering. Otherwise the model or its results were not compared against the actual engineering of these projects. Comparison was not made, hence the engineering for projects used for the testing of model are completed and installation cost management model were not utilized during the engineering. Comparing the actual engineering against the drivers developed with the installation cost management model wouldn’t give any value for the testing.

Second workshop regarding the testing of model was held with representatives of Civil, Mechanical and Electrical estimators. Purpose of the workshop was to define the changes on layouts and the scope of supply during the engineering process and update the cost calculations accordingly. In other words, the purpose was to simulate the kick-off and engineering review meetings during the engineering process by performing the installation cost management related tasks which are planned to be part of those meetings.

5.2 Case 1 – 200MW Diesel power plant

5.2.1 Configuration of power plant

First project to test the installation cost management model was 200MW Diesel power plant consisting 10 pieces of W20V32 engines. Wärtsilä´s scope of supply is including following main equipments, buildings and structures:

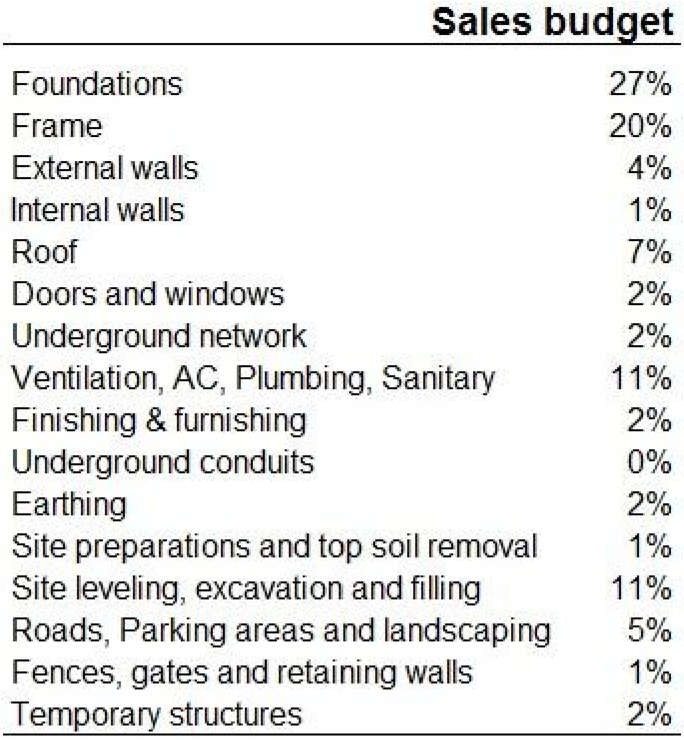
- Engine hall
- Utility block
- Fuel treatment house
- Workshop & Warehouse
- Unloading station
- Storage tank area
- Day tank area
- Site preparation, Landscaping, Paving and surfacing, Site accessories
- Earth works below 0-level
- Steam production system (For fuel heating)
- Process equipments (Fuel, Lube oil, compressed air, steam system)
- Process piping
- Power transformers
- Medium and Low voltage distribution
- Control system
- Building electrification

5.2.2 Sales budget

Project has been estimated during the sales phase based on conceptual engineering (see chapter 4.2). Project is located in Kenya and installation unit prices of Kenya were used for the budget cost calculations of Civil, Mechanical and Electrical disciplines.

Civil costs in sales phase in Table 10 shows the cost structure of Case 1. Due to improper quality of soil, the portion of Site leveling, excavation and soil filling costs are bigger than in example in Table 3, meaning that the improper soil needs to be replaced e.g. with gravel. Otherwise the order of magnitude is more or less similar with Table 3, meaning that the Foundations and Frame is causing the biggest part of the costs. Ventilation, AC, Plumbing and Sanitary costs as well are on remarkable.

Table 10. Civil installation cost structure in Sales phase

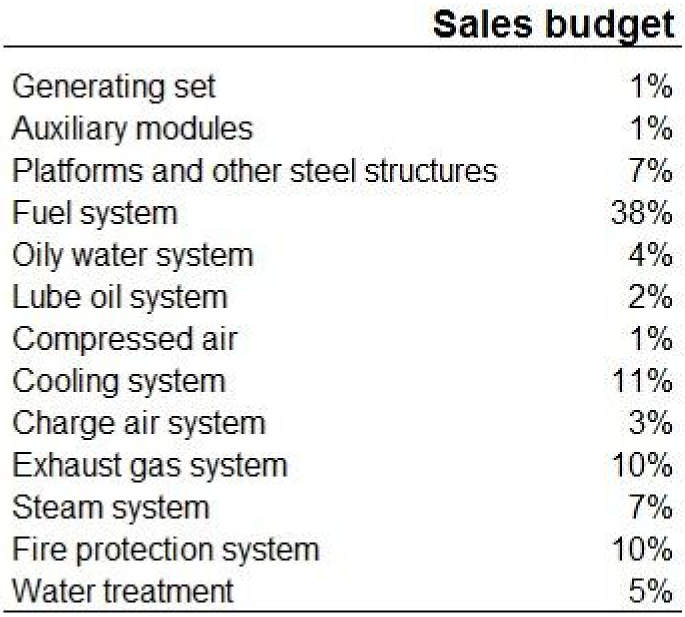


	Sales budget
Foundations	27%
Frame	20%
External walls	4%
Internal walls	1%
Roof	7%
Doors and windows	2%
Underground network	2%
Ventilation, AC, Plumbing, Sanitary	11%
Finishing & furnishing	2%
Underground conduits	0%
Earthing	2%
Site preparations and top soil removal	1%
Site leveling, excavation and filling	11%
Roads, Parking areas and landscaping	5%
Fences, gates and retaining walls	1%
Temporary structures	2%

Mechanical cost structure of Case 1 shown in Table 11, is similar to cost structure in Table 5. Biggest portion of the installation costs are caused by fuel system including fuel tanks, process piping, module installation and insulation works. Cooling, exhaust gas and fire protection are also representing the costs with 10% share.

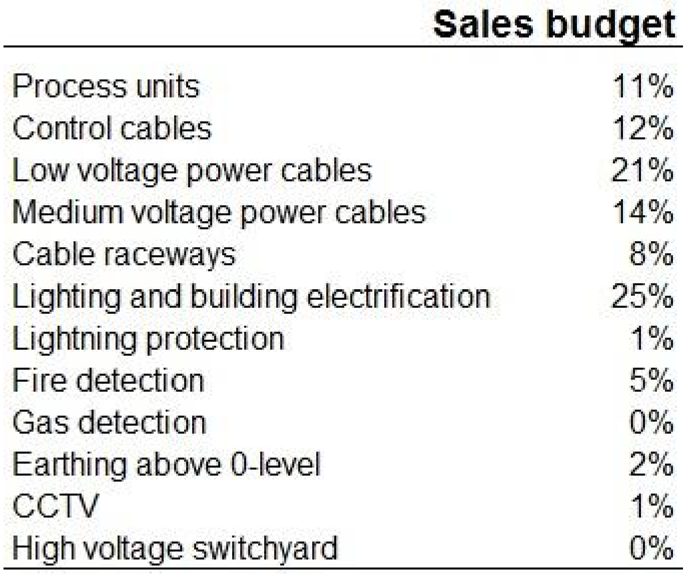
Electrical installation cost budget in Table 12 shows that the biggest portions of installation costs are coming from Lighting and building electrification, Low voltage cables and Medium voltage cables.

Table 11. Mechanical installation cost structure in Sales phase



	Sales budget
Generating set	1%
Auxiliary modules	1%
Platforms and other steel structures	7%
Fuel system	38%
Oily water system	4%
Lube oil system	2%
Compressed air	1%
Cooling system	11%
Charge air system	3%
Exhaust gas system	10%
Steam system	7%
Fire protection system	10%
Water treatment	5%

Table 12. Electrical installation cost structure in sales phase



	Sales budget
Process units	11%
Control cables	12%
Low voltage power cables	21%
Medium voltage power cables	14%
Cable raceways	8%
Lighting and building electrification	25%
Lightning protection	1%
Fire detection	5%
Gas detection	0%
Earthing above 0-level	2%
CCTV	1%
High voltage switchyard	0%

5.2.3 Basic engineering kick-off meeting

Installation cost forecasts

Basic kick-off meeting (simulated) with cost calculators of Civil, Mechanical and Electrical disciplines was started with review of scope of supply and layout. Also signed contract of power plant delivery was gone trough. As a result of the contract, scope and layout review, cost calculators noticed that the layout was changed during the negotiations with customer. It was also noticed that there were one additional Heavy fuel oil unloading pump added to scope of supply.

Typically, if the quality of soil is not known during the sales phase cost calculation, it may cause some surprises with extra costs when the soil investigation data is available. Luckily in this case, the soil investigation was done during the sales phase, so quality of soil was taken into account during estimation process.

Anyhow, installation costs after these changes were not calculated on non off the disciplines. Possible reasons for this failure were discussed during the meeting and the conclusion was that these kinds of failures are not unusual and reason for these failures is typically the lack of time or unconsciousness of the affects of the changes.

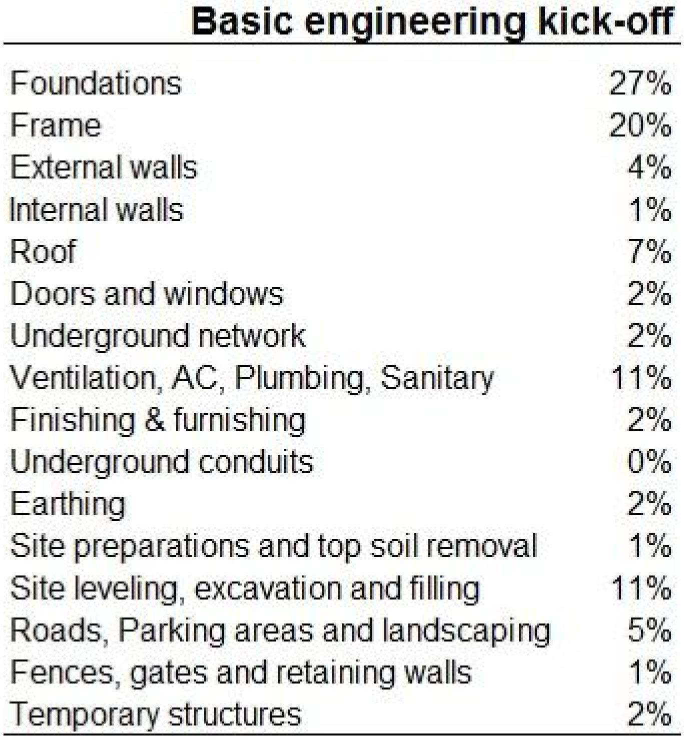
Update of installation cost calculation was started from change on the layout. In the layout drawing the location of unloading station was changed. During the update of the installation costs it turned out that the major cost impact was on mechanical and electrical disciplines. Since the area or the structure of the unloading station didn’t change and there is no difference on the soil quality, there is no cost affect on civil discipline. On mechanical side the cost change is related to the piping of unloading pumps. Due the increased distance from storage tanks to unloading station, the length of the pipes increased slightly. Also on the electrical discipline the costs were increased due to increased distance from unloading pumps to Fuel treatment house where the electricity for the pumps are feed, meaning that the length of the cables are increasing.

The second change was related to increased number of Heavy fuel oil unloading pumps. According the signed Scope of Supply, the number of HFO unloading pumps was increased from 2 to 3 pieces. On Civil discipline, adding one unloading pump caused an extension of one lane to unloading station structures and extra foundation for the extra pump. On mechanical discipline additional HFO unloading pump caused an installation of additional pump unit and the process piping works for it. Electrical discipline was affected also by extension of unloading station with additional luminaries, earthing and lightning protection. And also with the cabling works of the additional pump.

Due to extra unloading pump, the feeder cable from main Low voltage switchgear to Sub-Low voltage switchgear was recalculated. With recalculation it turned out that the feeder cable for the Sub-Low voltage switchgear was no longer capable to carry out the power which was increased due to additional unloading pump. Also this increased size of the feeder cable was included to update of installation cost calculation.

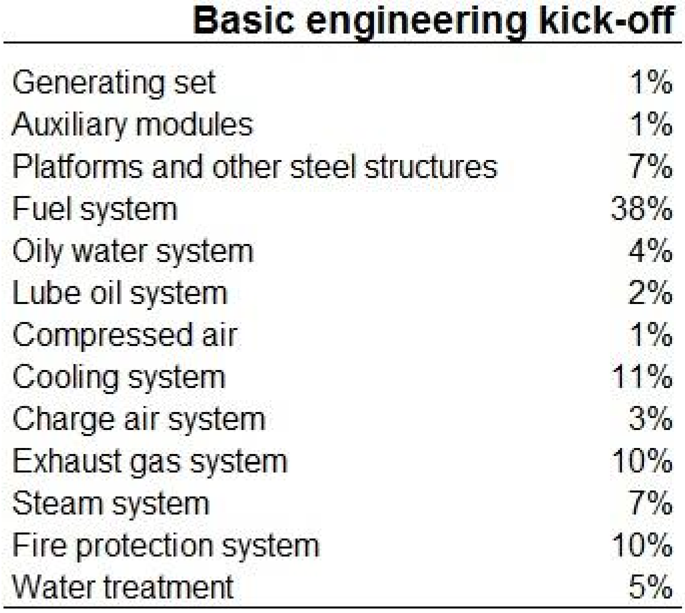
Updated installation cost calculations in Table 13 – Table 15 are showing that the cost structure was changed slightly, but in the order of magnitude was not affected.

Table 13. Civil Inst. Cost structure after basic Engineering kick-off meeting



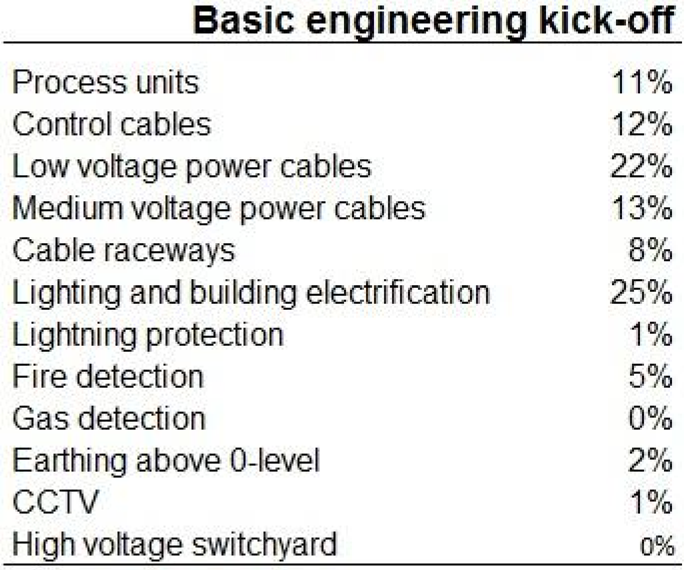
	Basic engineering kick-off
Foundations	27%
Frame	20%
External walls	4%
Internal walls	1%
Roof	7%
Doors and windows	2%
Underground network	2%
Ventilation, AC, Plumbing, Sanitary	11%
Finishing & furnishing	2%
Underground conduits	0%
Earthing	2%
Site preparations and top soil removal	1%
Site leveling, excavation and filling	11%
Roads, Parking areas and landscaping	5%
Fences, gates and retaining walls	1%
Temporary structures	2%

Table 14. Mech. Inst. Cost structure after Basic engineering kick-off



	Basic engineering kick-off
Generating set	1%
Auxiliary modules	1%
Platforms and other steel structures	7%
Fuel system	38%
Oily water system	4%
Lube oil system	2%
Compressed air	1%
Cooling system	11%
Charge air system	3%
Exhaust gas system	10%
Steam system	7%
Fire protection system	10%
Water treatment	5%

Table 15. Elec. installation cost structure after Basic Engineering kick-off meeting



	Basic engineering kick-off
Process units	11%
Control cables	12%
Low voltage power cables	22%
Medium voltage power cables	13%
Cable raceways	8%
Lighting and building electrification	25%
Lightning protection	1%
Fire detection	5%
Gas detection	0%
Earthing above 0-level	2%
CCTV	1%
High voltage switchyard	0%

Basic engineering cost drivers for Civil discipline

During the Basic engineering kick-off meeting, several installation cost related improvements were discussed. One of the improvements was dealing with harmonization of Wait house to be equal to with two guard houses on site. This improvement would bring savings with engineering and construction costs. This proposal for improvement was added to Installation costing report together with Installation cost forecast (Appendix 1).

Also an idea of removing the road around the Storage tank area was discussed, but idea was rejected due to fact that fire regulations require access for the fire truck around the tank yard.

In sales layout, medium voltage cables from utility block to power transformers are determined to be installed to the trench. Other standard solution for running the cables from medium voltage room to power transformers is to use underground conduits. Typically trench, which requires walls and floor made from concrete, is more expensive compared to conduits which are buried directly to the ground. But from the electrical point of view, due to cable warmth, conduit installation requires more cabling than trench installation where the cable cooling is better and less cabling is needed. Civil and electrical cost affect were calculated with both options and trench installation was found more feasible solution.

As it was concluded in chapter 3.4.2, drivers should not be the costs itself; drivers should be those which are causing the costs. Selection of cost drivers to control especially the Basic engineering was dealt in chapter 4.5. On civil discipline it was decided that following items should be set as drivers for the Basic engineering:

- Roads, Pavement areas
- Size of buildings, tank yards → as budgeted
- Location of equipments
- Soil investigation data for site leveling

By verifying that the roads and areas with pavements are kept as they were determined during the budgeting phase, costs will stay in budget. Same applies with size of the buildings, tank yards and equipments.

As it was dealt in chapter 4.5.2, the real optimization and value engineering during Basic engineering will be done with site leveling. On civil discipline, one of the drivers that were set was unit prices related to site leveling. Unit prices such as cost of excavation, blasting and cost of the gravel, will guide design engineer to optimize the site leveling.

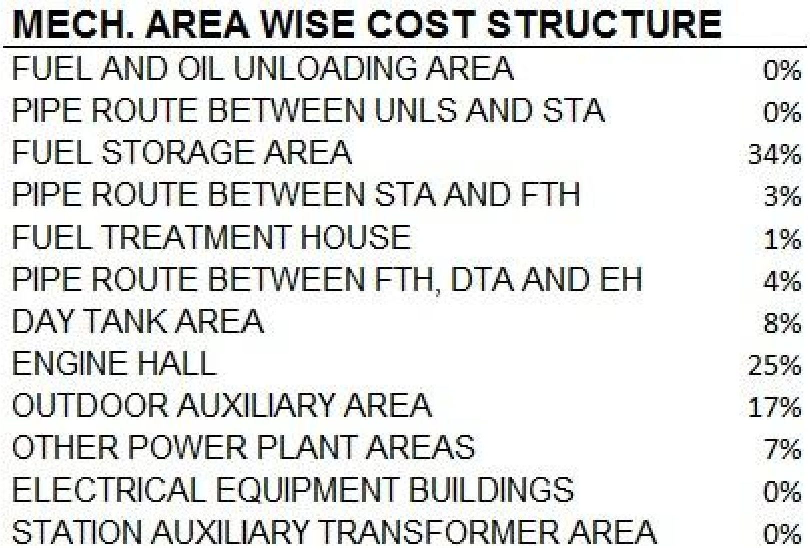
Basic engineering cost drivers for Mechanical discipline

On mechanical discipline it was concluded that basic engineering is dealing with selection of components and modules and with preparing the system process description. Only one, directly to installation costs related drawing is fire protection layout. It was decided with mechanical cost calculation engineer, that for the driver of fire protection layout engineering would be selected the size and location of the tank, size and location of the fire fighting pump and also the budgeted quantity and location of the fire hydrants. These drivers were evaluated according criteria's dealt in chapter 3.4.2 and was found to be those that are causing the costs such as piping, welds and pipe supports.

Since the location of process equipments and structures are determined in the site layout drawing, it can be assumed that those won't be changed. Anyway, it was discussed in the meeting that there are areas where the majority of the process costs are concentrated and it would be practical to point out those areas to pay designers attention to those areas. Installation costing tool were used search the areas where the majority of costs are located.

As it can be seen from Table 16, the majority of the costs are on fuel storage tank area, on engine hall and on outdoor auxiliary area. These three areas were evaluated and the reason for the mechanical installation costs on storage tank area is the massive HFO tanks. On the engine hall, the installation costs are caused by piping works related to auxiliary equipments and on outdoor auxiliary area, the costs are caused by installation of exhaust gas ducting. Selection of drivers was started from storage tank area, meaning that the size and quantity of storage tanks was set as a driver. On engine hall it was concluded that the quantity and location of auxiliary equipments are affecting to the process piping which is the cost itself. With modularized power plant solutions, quantity of these auxiliary equipments is connected to quantity of generating sets and cannot be affected that much. Also due to modularized solutions, the location of auxiliary equipments is standardized and possibilities to affect are limited. Anyhow, the location of auxiliary units was selected as a driver number two. In other words, location used for budgeting calculation should be kept as driver for the location. Exhaust gas ducting, which is the cost caused by the distance of exhaust gas stack from the engine hall, was taken for the third driver of mechanical discipline, meaning that this distance should be kept as short as possible or at least kept on same as it was budgeted,

Table 16. Mechanical areawise cost structure



MECH. AREA WISE COST STRUCTURE	
FUEL AND OIL UNLOADING AREA	0%
PIPE ROUTE BETWEEN UNLS AND STA	0%
FUEL STORAGE AREA	34%
PIPE ROUTE BETWEEN STA AND FTH	3%
FUEL TREATMENT HOUSE	1%
PIPE ROUTE BETWEEN FTH, DTA AND EH	4%
DAY TANK AREA	8%
ENGINE HALL	25%
OUTDOOR AUXILIARY AREA	17%
OTHER POWER PLANT AREAS	7%
ELECTRICAL EQUIPMENT BUILDINGS	0%
STATION AUXILIARY TRANSFORMER AREA	0%

After the selection of mechanical drivers it was concluded that aiming to some of these selected drivers may feel obvious, but by following these drivers 75% of the installation costs are kept under control. And if there comes up a need to modify the site layout so that these drivers are affected, driver will work as a signal to consult cost engineers.

It should be noticed that also in Table 16 the Paretos theory dealt in chapter 3.4.2, is more or less valid (25/75). Also the quantity of drivers, dealt in same chapter can be utilized.

Basic engineering cost drivers for Electrical discipline

As shown in Table 15, majority (25%) of electrical costs are the costs of lighting and building electrification. It was defined with installation costing tool that 65% of the lighting and building electrification costs are caused by luminaries. Different building and shelters have standard requirements regarding the lighting power. So it can be concluded that number of luminaries are dependable of size of the buildings and areas. For the driver of Lighting and building electrification, it was decided that keeping the size of the buildings and areas as they were budgeted, will ensure the cost control as well.

The second highest cost in Table 15 is the Low voltage power cables. The costs of the power cables are caused by the equipments feed by Low voltage supply. The main driver for the cost of Low voltage power cables are the number of supplied equipments. Low voltage power cables are affected by the power of those equipments, but according the studies made with installation costing tool, the cost affect is not high, since the small variations with equipment power is tolerated by the cable and in case of changing the cable size to size bigger, the cost affect is not big either. Also the length of the cables has an affect for the Low voltage cable cost. Length of the cables is dependable of site layout and as it was dealt earlier with mechanical drivers, the site layout with its distances should be kept as it was in sales phase. Number of equipments to be feed with Low voltage supply was selected to be the driver for Low voltage cables.

According the Table 15, the third highest cost is the Medium voltage cabling, which is caused by the Medium voltage cabling from the generators to Medium voltage cubicle in utility block and the cabling from the Medium voltage cabling from the Medium voltage cubicle to power transformer. There is also Medium voltage cabling from Medium voltage cubicle to Auxiliary transformer, but representing only the 4% of the Medium voltage cabling. Since the Medium voltage cables are dimensioned in detailed engineering phase, only suitable driver for the Medium voltage cables in Basic engineering phase is the distance between Medium voltage cubicle and the power transformer. And as it was dealt earlier in this chapter, the cables between Medium voltage cubicle and power transformer were found to be most affordable to be installed to trench, not to underground conduits.

In Table 15, the Control cables are representing the portion of 12% of the electrical installation costs. Amount of control cables are dependable of the number of panels and on the distance between the equipments, panels and areas. Keeping the number and location of panels as same as it was in budgeting phase was selected to be the cost drivers for the basic engineering.

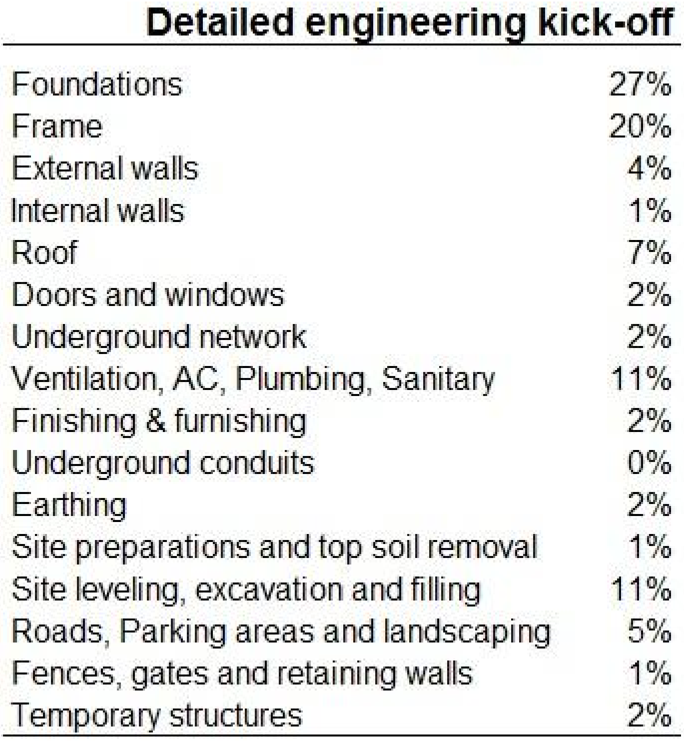
As it was dealt in chapter 4.6.2, in case of Basic engineering the selected cost drivers are suitable to serve as a indicators as well. It was also concluded that the number of drivers were kept on level as it was defined in chapter 3.4.2 and indicators are fulfilling the requirements specified in Figure 9.

Installation cost report of Basic engineering kick-off meeting was decided to be prepared and it can be found from attachment 1.

5.2.4 Detailed engineering kick-off meeting

(Simulated) Kick-off meeting of detailed engineering was started with update of installation cost forecast. Basic engineering was used as an input for the installation costs update and it was concluded that the drivers set in Basic engineering kick-off meeting were followed, meaning that there were no variations from the drivers set. Hence the topography and soil data was available already in budgeting phase, site leveling plan during the Basic engineering didn’t bring any surprises. Indicators of basic engineering were included to Cost report of detailed engineering kick-off meeting.

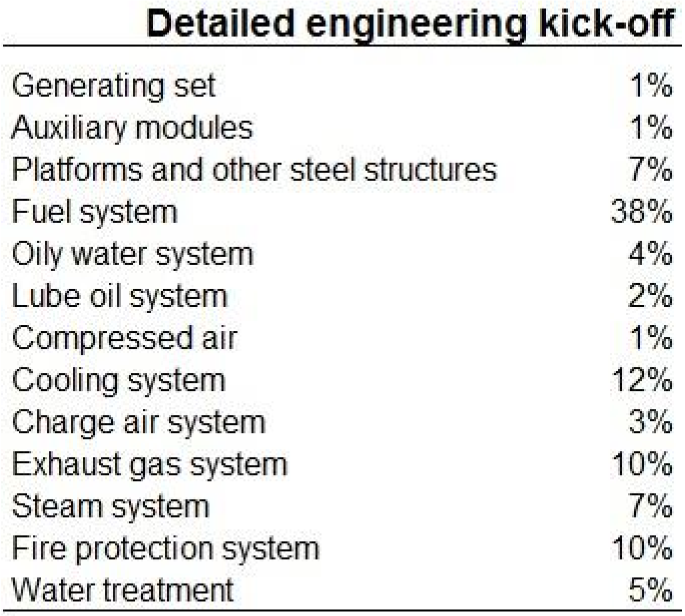
Table 17. Civil Inst. Cost structure after Detailed engineering kick-off meeting



Detailed engineering kick-off	
Foundations	27%
Frame	20%
External walls	4%
Internal walls	1%
Roof	7%
Doors and windows	2%
Underground network	2%
Ventilation, AC, Plumbing, Sanitary	11%
Finishing & furnishing	2%
Underground conduits	0%
Earthing	2%
Site preparations and top soil removal	1%
Site leveling, excavation and filling	11%
Roads, Parking areas and landscaping	5%
Fences, gates and retaining walls	1%
Temporary structures	2%

During the Basic engineering review, it was found out that on Civil discipline there was extra roof plates added between the radiators of engine hall 1 and engine hall 2. This extra roof was designed to be installed on top Utility block to prevent the cooling air from the top of the radiator to circulate back under the radiator and causing reduction for the efficiency of the cooling radiators of generating sets 5 and 6. It also turned out that Civil installation cost calculator was consulted with this matter and the updated cost forecast was available. See Table 17.

Table 18. Mech. Inst. Cost structure after Basic engineering kick-off

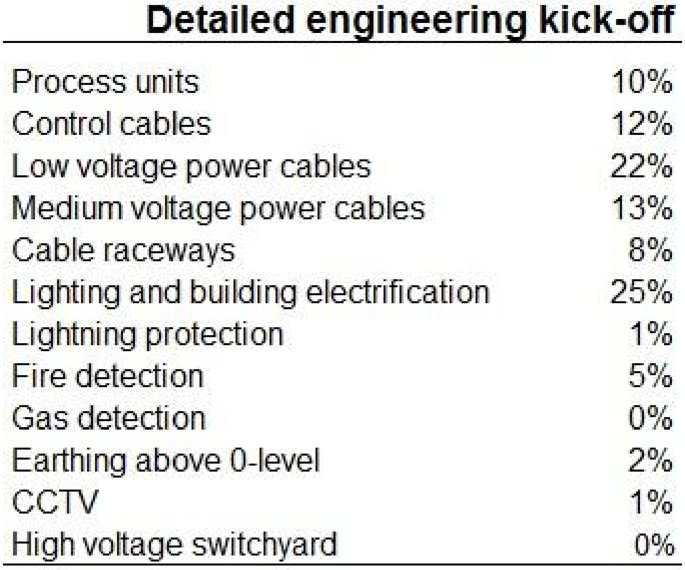


Detailed engineering kick-off	
Generating set	1%
Auxiliary modules	1%
Platforms and other steel structures	7%
Fuel system	38%
Oily water system	4%
Lube oil system	2%
Compressed air	1%
Cooling system	12%
Charge air system	3%
Exhaust gas system	10%
Steam system	7%
Fire protection system	10%
Water treatment	5%

On mechanical discipline, during the Basic engineering, it had turned out that the capacity of cooling radiators was miscalculated in sales phase. In sales phase it was calculated that four radiator modules per engine would be enough, but in Basic engineering phase the number of radiator modules per engine was increased to five per engine. Mechanical installation cost calculator was not consulted about this change and affect for the installation costs was calculated during the meeting. See installation cost forecast in Table 18.

On electrical discipline, there were no changes made during the basic engineering. But the increased number of radiator modules affected to number of radiator cooling fans. Due to additional cooling radiator fans, costs of Low voltage power cables increased slightly, but didn’t affect to the cost structure.

Table 19. Elec. Inst. cost structure after Detailed engineering kick-off meeting



Detailed engineering kick-off	
Process units	10%
Control cables	12%
Low voltage power cables	22%
Medium voltage power cables	13%
Cable raceways	8%
Lighting and building electrification	25%
Lightning protection	1%
Fire detection	5%
Gas detection	0%
Earthing above 0-level	2%
CCTV	1%
High voltage switchyard	0%

Detailed engineering drivers for Civil discipline

As it can be seen from Table 13, the biggest costs are the foundation costs. It was defined with installation costing tool, that in this project, 80% of foundation costs are coming from the concrete, reinforcement and forming works. Drivers for foundation design were decided to be following:

- Concrete, 4600 m^3
- Reinforcement, 390 000 kg
- Formwork, 8150 m^2

Second biggest cost according Table 13 was the Frame. Steel frames of the buildings were defined to be 59% of the frames and outdoor steel structures portion was 29%. Rest of the frame costs (12%) was formed of ladders, stairs and gratings. Cost drivers for the frame decided to be following:

- Building frames, 328 919 kg
- Outdoor frames, 157 924 kg

It was discussed during the driver selection that according the comparisons made between same type and size of buildings in different projects, the variation of steel structure weight, can be +/- 20%. Due to these findings, the weight of steel frame was decided to be good driver for the design engineer.

Third biggest portion of Civil costs was the Ventilation, AC, plumbing and sanitary works. Portion was equal with site leveling works, but as dealt in chapter 5.2.3, site leveling plan was prepared in Basic engineering phase. During the driver determination, it turned out that 78% of the ventilation, AC, plumbing and sanitary costs are caused by the engine hall ventilation units and roof-top cooling units. Roof-top cooling units are priced according the cooling capacity, so the cooling capacity was set as a driver for the roof-top cooling units. Drivers were selected to be as following:

- Ventilation aux. unit 12 m^3/s, 10 pcs
- Ventilation unit 18 m^3/s, 10 pcs
- Roof-top unit, 200 kW
- Centralized roof-top system, 80 kW

Drivers were set to work as indicators as well. Reported units will be the drivers above and in order to indicate the costs, the drivers are multiplied with unit prices of installation.

Detailed engineering drivers for Mechanical discipline

Since the fire protection system was designed in Basic engineering phase, the three biggest costs are Fuel system, Cooling system and the Exhaust gas system. With installation costing tool, it was defined that the main cause for the costs in fuel system is the Heavy fuel oil (HFO) storage tanks representing 63% of the costs of the fuel system. Portion of Light fuel oil (LFO) tanks and Day tank for HFO are minor costs compared to HFO Storage tanks. Also the portion of piping was representing only 17% of fuel system costs with approx. 150 pcs of small components. Driver of the Fuel system was selected to be:

- HFO Storage tanks, 451 000 kg

Cause for the costs of cooling system was defined to be the pipe welds, which were representing the 30% of the installation costs of the cooling system. Another cause for the installation costs of cooling system was the piping costs with 25% of the installation costs. Drivers for the cooling system:

- Welds, 3505 pcs
- Steel pipes, 1817 m
  - DN 40, 451 m
  - DN 50, 467 m
  - DN 100, 416 m
  - DN 150, 483 m

Since the number of welds and sizes of pipes are estimates, it was decided to give the unit prices as well, to support the engineering and to enable Value engineering.

On the exhaust gas system the costs are caused by the ducting. With installation costing tool, it was defined that ducting and stack pipes are causing 50% of the costs of the ducting. Primary support steels and insulation for ducting is representing 15% each of the ducting costs. Drivers for ducting design were selected to be as following:

- Stack pipes, 140 m
- Pipe primary support steels, 15 400 kg
- Exhaust gas ducting, 260 m
- Insulation of exhaust gas ducting, 260 m (600 m^2)

It was also discussed that since the length of ducting is strongly depending on the stack location (Layout), it might be difficult to find more affordable solution (i.e. utilize value engineering). But as it was concluded in chapter 3.4.2, engineering control requires targets and same applies for design engineers as well.

Detailed engineering drivers for Electrical discipline

As shown in Table 19, majority (25%) of electrical costs are the costs of lighting and building electrification. It was defined with installation costing tool that 79% of the lighting and building electrification costs are caused by luminaries. Cabling related to lighting and building electrification is representing 21% of the lighting and building electrification costs. This being, the number of luminaries, total and per building was selected to be the driver for the lighting and building electrification.

- Luminaries, 820 pcs

During the detailed engineering, there is a possibility to evaluate the lighting requirements of different buildings in order to achieve savings.

It was defined with installation costing tool that 60% of Low voltage power cable costs are caused by big Low voltage feeder cables. Especially the cabling from Station transformer to Low voltage switchgear and from Main low voltage switchgear to sub-low voltage switchgear in Fuel treatment house are causing 35% of the Low voltage cabling costs. Drivers for Low voltage cabling were decided to be as following:

- Feeder cables from Station transformer to Low voltage switchgear, 7x3x1x400+4x1x400, 1050 m per transformer, Total meters 2100 m
- Feeder cables from main Low voltage switchgear to sub-Low voltage switchgear, 2x3x1x400+2x1x400, Total meters 1540 m
- Feeder cable for auxiliary units 3x95+50. 1200 m
- Feeder cable for auxiliary units 3x120+70, 1900 m
- Feeder cable for auxiliary units 3x150+70, 560 m

Selection of feeder cables was based to a fact that selected cables are relatively big and expensive, but the length of these cables is relatively short. Meaning that small change to the length may have big cost affect. On the other hand the costs of smaller cables were almost equal to big cables, but the quantity of small cables are big, meaning that there is bigger change required for small cables to have same cost affect than small change in big cables. Big change in small cables was evaluated to be more unlike than small change with big cables.

According to Table 19, medium voltage cables were the third biggest cost of electrical installation costs. With medium voltage cables 65% is coming from Generator main cables and 30% from the outgoing feeder cables. Distances from the generators to Medium voltage switchgear and from Medium voltage switchgear to power transformer cannot be affected during the detailed engineering. Reason for this is that generator cables are running in underground conduits using the most direct route and the route and the installation method (trench or conduit) is decided already in Basic engineering. But dimensioning of the cables should be used as a driver for the detailed engineering. Following drivers were selected for the Medium voltage cables:

- Generator MV cabling, 2x3x1x400mm^2 per generator, total length of generator cabling for the plant 2400 m
- Outgoing feeder cables, 5x3x1x400mm^2 per feeder, total length outgoing feeder cables 1320 m

With MV-, LV- and Control cables, providing the unit prices for different size of cables is essential for proper engineering. In order to evaluate the optimized size of the cable and to keep the total cable costs in budget, unit prices also for other size of the cables than used in budgeting phase is needed.

Table 19 shows that also the cost of control cables is remarkable. Suitable driver for control cables was discussed in detailed engineering meeting and the conclusion was that It was that the total length of Control cables was decided to be the driver for the control cables. Driver for control cables:

- Control cable, total length 41 520 m

It was also discussed in the Detailed engineering kick of meeting that, number of cables per panel as driver would work, but currently this information is not available from installation costing tool with reasonable effort.

5.2.5 Review meeting of detailed engineering

Since the engineering was completed already when this model was tested and the installation cost management model was not utilized for the engineering, comparing of engineering results against estimation and to drivers set would not be relevant or would not give any information about the effectiveness of the drivers. Instead, the group that participated to kick-off meetings when the drivers were defined discussed about the possible items that could have been developed to be more cost efficient.

One of the issues discussed was the frame of the buildings. Typically the frames are budgeted using average size of the structures adjusted with project specific parameters such as wind load, temperature and seismic data. As it was dealt in chapter 5.2.3, the variation of weight of the frame can vary +/- 20%.

As it was dealt with mechanical drivers, the installation costs are strongly connected to the location of buildings, structures, tanks and equipments (i.e. Site layout). So it means that the installation cost affecting decisions are mainly done when the site layout is developed. But as it was dealt with cooling system drivers, the process piping costs are mainly caused by number of welds. It also came up during the meetings that process piping is typically including several bends and flanges which is causing the big number of welds. But it was also discussed that due to compact solutions the length of the single pipes is relatively short. Depending on the system, the longest, straight piece of pipe is typically around 2 m. As a one “trick” to decrease number of welds could be to avoid bends in the pipeline by locating the needed valves directly after the bends to avoid one weld per valve.

On electrical discipline, especially the big power distribution cables are typical items of optimizing. Good examples of big power distribution cables are Generator Medium voltage cable, Outgoing feeder cables and Low voltage power cables of Station transformers, Sub Low voltage switchgears and big auxiliary equipments. Dimensioning of these cables in sales phase is conservative and leaves room for optimizing in engineering phase.

5.2.6 Conclusion

During the kick-off meetings, it was noticed that cost drivers especially for detailed engineering could have been set for areas and buildings, but it was accepted that currently the installation costing tools are not supporting that feature and determination of those drivers manually would been too time consuming for testing purposes.

Site leveling, Sub-Low voltage switchgear feeder cable dimensioning and comparison of different solutions in basic engineering kick-off meeting were good examples of Value engineering which were dealt in chapter 3.5 and 4.5. As it was concluded, it´s not easy to give instructions how to utilize Value engineering. It requires inventiveness, experience and maybe also some luck.

5.3 Case 2 – 20MW Gas power plant

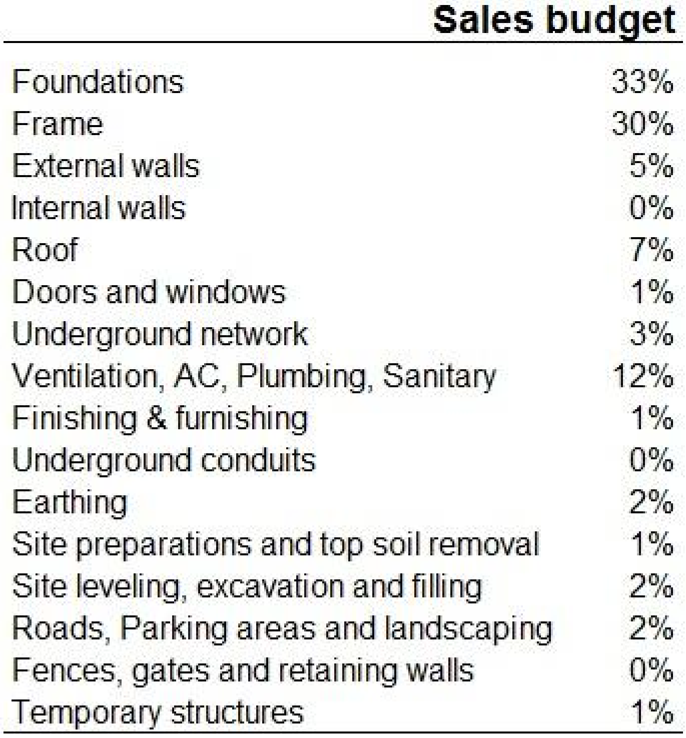
5.3.1 Configuration of power plant

Second power plant project that was selected to test the installation cost management model was 20MW Gas plant. Scope of delivery for the selected project was including following building, structures and equipments:

- Engine hall
- Utility block
- Day tank area
- Site preparation, Landscaping, Paving and surfacing, Site accessories
- Earth works below 0-level
- Process equipments (Fuel gas, Lube oil, compressed air)
- Process piping
- Power transformers
- Medium and Low voltage distribution
- Control system
- Building electrification

5.3.2 Sales phase estimation

Table 20. Civil installation cost structure



	Sales budget
Foundations	33%
Frame	30%
External walls	5%
Internal walls	0%
Roof	7%
Doors and windows	1%
Underground network	3%
Ventilation, AC, Plumbing, Sanitary	12%
Finishing & furnishing	1%
Underground conduits	0%
Earthing	2%
Site preparations and top soil removal	1%
Site leveling, excavation and filling	2%
Roads, Parking areas and landscaping	2%
Fences, gates and retaining walls	0%
Temporary structures	1%

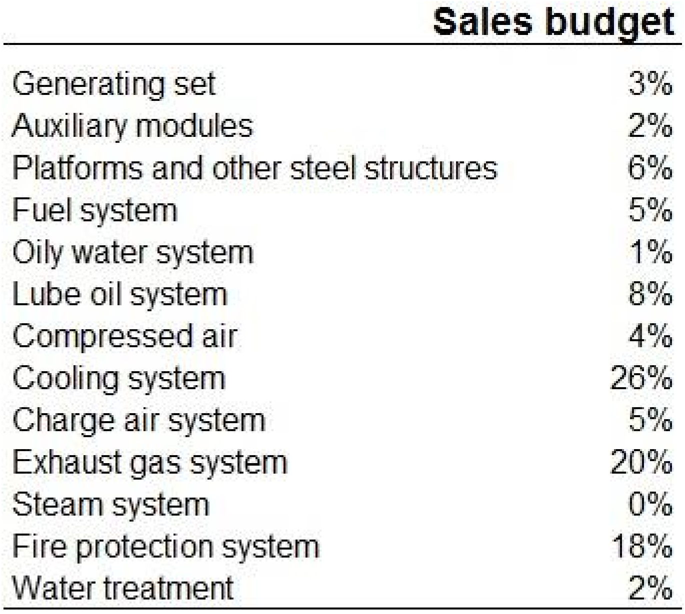
Project was estimated during the sales phase based on conceptual engineering (See chapter 4.2). Since this project is located in Thailand, local unit prices were used in order to define the installation cost budget for Civil, Mechanical and Electrical disciplines.

Civil installation cost structure looks similar with example in Table 2. Foundations and Frame are two most expensive systems. Third biggest cost is the Ventilation, AC, Plumbing and Sanitary installation costs. Due to good quality of soil, Site leveling, excavation and filling costs are low.

Mechanical installation costs in Table 21 shows that in mechanical installation the main costs are coming from Cooling system, Exhaust gas system and from Fire protection system. Cost structure is totally different that it was with test case 1 in chapter 4.1.4, but similar with the example in Table 4.

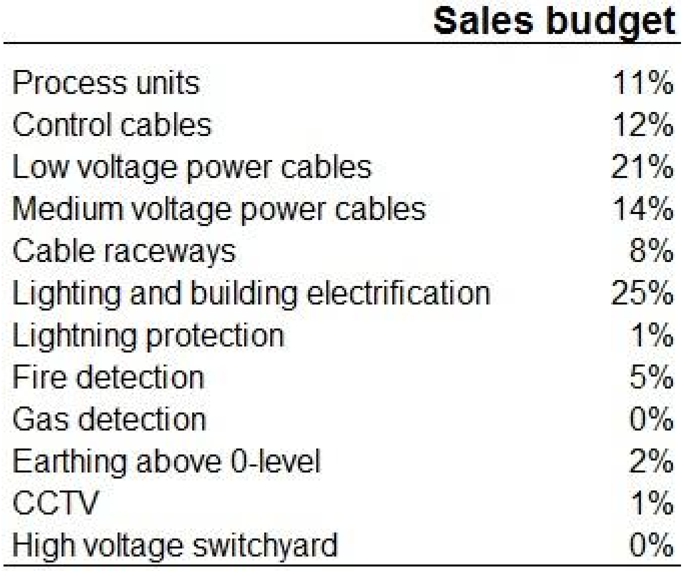
As it can be found from Table 22, in electrical discipline the biggest portions of installation costs are coming from Lighting and building electrification and from Low voltage power cabling. Also the installation costs of MV system are remarkable with portion of 14%. Like it was with Mechanical installation cost structure, it differs from cost structure of Case 1, but is similar with example in Table 6.

Table 21. Mechanical installation cost structure



	Sales budget
Generating set	3%
Auxiliary modules	2%
Platforms and other steel structures	6%
Fuel system	5%
Oily water system	1%
Lube oil system	8%
Compressed air	4%
Cooling system	26%
Charge air system	5%
Exhaust gas system	20%
Steam system	0%
Fire protection system	18%
Water treatment	2%

Table 22. Electrical installation cost structure



	Sales budget
Process units	11%
Control cables	12%
Low voltage power cables	21%
Medium voltage power cables	14%
Cable raceways	8%
Lighting and building electrification	25%
Lightning protection	1%
Fire detection	5%
Gas detection	0%
Earthing above 0-level	2%
CCTV	1%
High voltage switchyard	0%

5.3.3 Basic engineering kick-off meeting

Installation cost forecast

(Simulated) Basic engineering kick-off meeting was held with cost estimators of Civil, Mechanical and Electrical disciplines. Scope of supply, layout drawing and technical specification were checked and the conclusion was that there was no difference between the engineering used for estimation and the one that was agreed with customer. It was also discussed with estimators, that there is no sings that the cost level of project country have been changed since the budget was calculated. Budget calculated in sales phase is remaining as a forecast as well.

Basic engineering drivers for Civil discipline

By verifying that the roads and areas with pavements are kept as they were determined during the budgeting phase, costs will stay in budget. Same applies with size of the buildings, tank yards and equipments. On civil discipline it was decided that following items should be set as drivers for the Basic engineering:

- Roads, Pavement areas
- Size of buildings, tank yards → as budgeted
- Location of equipments

On Civil discipline with Case 1, one of the drivers that were set was unit prices related to site leveling. With Case 2, the plant is to be build next to existing plant where the site leveling have been done during the construction works of existing plant.

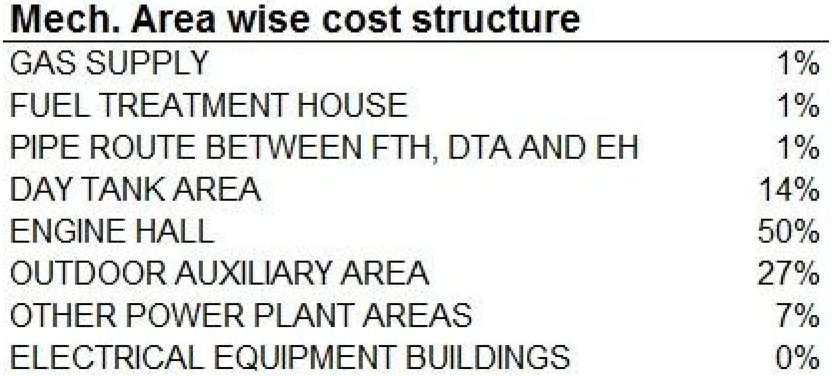
Basic engineering drivers for Mechanical discipline

As it was dealt in chapter 4.2.3, Fire protection design takes place in Basic engineering process. Suitable drivers for fire protection system engineering were defined to be location and quantity of Fire water hydrants and Hose cabinets. Reason for this was that the number of hydrants and Hose cabinets is the one causing the piping costs. Budget for fire protection installation will be met by keeping the number and location of hydrants and hose cabinets on budgeted level.

Exhaust gas piping and cooling system is located on outdoor auxiliary area on Table 23. Since the pipe and ducting lengths are not directly affected during the Basic engineering, the location of the Exhaust gas stack was set to be one of the cost drivers. By keeping the location of stack on place where it was budgeted, also the ducting lengths are not affected. Same goes with cooling system. As long as the radiators are located in the place where they are budgeted the amount of piping is not increased.

As it can be seen from Table 23, Engine hall is representing 50% of the installation costs of the whole power plant. It was defined with installation costing tool that piping and valves causes 1/3 of those cost under engine hall. It was discussed, that by keeping the location of equipment on the place where those was budgeted, the piping and valve quantities will not be exceeded.

Table 23. Mechanical area wise cost structure



Mech. Area wise cost structure	
GAS SUPPLY	1%
FUEL TREATMENT HOUSE	1%
PIPE ROUTE BETWEEN FTH, DTA AND EH	1%
DAY TANK AREA	14%
ENGINE HALL	50%
OUTDOOR AUXILIARY AREA	27%
OTHER POWER PLANT AREAS	7%
ELECTRICAL EQUIPMENT BUILDINGS	0%

It was also discussed and stated to Installation cost management report that if the location of these equipments is to be changed, cost engineers should be consulted.

Basic engineering drivers for Electrical discipline

As shown in Table 22, majority (25%) of electrical costs are the costs of lighting and building electrification. It was defined with installation costing tool that 65% of the lighting and building electrification costs are caused by luminaries. Different building and shelters have standard requirements regarding the lighting power. So it can be concluded that number of luminaries are dependable of size of the buildings and areas. For the driver of Lighting and building electrification, it was decided that keeping the size of the buildings and areas as they were budgeted, will ensure the cost control as well.

The second highest cost in Table 22 is the Low voltage power cables. The costs of the power cables are caused by the equipments feed by Low voltage supply, but also by the Low voltage cabling of Station transformer. The main driver for the cost of Low voltage power cables was decided to set the distance from Station transformer to Low voltage switchgear in Low voltage room. Length of the cables is dependable of site layout and the site layout with its distances should be kept as it was in sales phase.

According the Table 22, the third highest cost is the Medium voltage cabling, which is caused 30% by the Medium voltage cabling from the generators to Medium voltage cubicle in utility block and 55% by the cabling from the Medium voltage cabling from the Medium voltage cubicle to power transformer. There is also Medium voltage cabling from Medium voltage cubicle to Auxiliary transformer, representing the 15% of the Medium voltage cabling. Since the Medium voltage cables are dimensioned in detailed engineering phase, only suitable driver for the Medium voltage cables in Basic engineering phase is the distance between Medium voltage cubicle and the power transformer.

5.3.4 Detailed engineering kick-off meeting

Installation costs forecasts

(Simulated) Kick-off meeting of detailed engineering was started with review of Basic engineering results. It was found out that during basic engineering there have not been any changes that would affect to installation costs of Civil, Mechanical or Electrical discipline. Conclusion was that the drivers set for basic engineering have been followed and the original budget will remain as a forecast for the installation.

Detailed engineering drivers for Civil discipline

As it can be seen from Table 20, Foundations, Frame and Ventilation, AC and Plumbing are the biggest costs. Driver for Foundation works (representing 75% of Foundation costs) was defined with installation cost estimation tool:

- Concrete, 900 m^3
- Reinforcement, 75 000 kg
- Piling, 1500 m
- Formwork, 1550 m^2

Second biggest cost according to Table 20 is the Frame. Steel frames of the buildings were defined to be 49% of the frames and outdoor steel structures portion was 32%. Rest of the frame costs (19%) was formed of ladders, stairs and gratings. Cost drivers for the frame decided to be following:

- Building frames, 85 400 kg
- Outdoor frames, 58 200 kg

Third biggest portion of Civil costs was the Ventilation, AC, plumbing and sanitary works. During the driver determination, it turned out that 76% of the ventilation, AC, plumbing and sanitary costs are caused by the engine hall ventilation units and roof-top cooling units. Roof-top cooling units are priced according the cooling capacity, so the cooling capacity was set as a driver for the roof-top cooling units. Drivers were selected to be as following:

- Ventilation aux. unit 12 m^3/s, 2 pcs
- Ventilation unit 18 m^3/s, 2 pcs
- Exhaust fan EH 30m^3/s, 2 pcs
- Wall unit system, 50 kW

Drivers were set to work as indicators as well. Reported units will be the drivers above and in order to indicate the costs, the drivers are multiplied with unit prices of installation.

Detailed engineering drivers for Mechanical discipline

Fire protection system was designed in Basic engineering phase, the two biggest systems in terms of installation costs are exhaust gas system and cooling system.

With installation costing tool it was defined that 80% of Exhaust gas system costs are caused by the ducting, including welds, insulation and supporting structures. Cost drivers were defined to be:

- Stack pipes, 45 m
- Pipe primary support steels, 3500kg
- Exhaust gas ducting, 55 m
- Insulation of exhaust gas ducting, 55 m

Selection of cooling system drivers was made with installation costing tool as well. Piping with welds, bends and with flanges are causing 74% of the costs of the cooling system. Lifting of radiator modules is representing 16% of the cooling system installation and the rests of the costs are caused by expansion vessel and railings on the roof. Cost drivers for the cooling system will be following:

- Welds, 800 pcs
- Steel pipes, 400 m
  - DN 40, 83 m
  - DN 50, 73 m
  - DN 100, 68 m
  - DN 150, 176 m

Drivers with unit prices were added to the installation cost management report.

Detailed engineering drivers for Electrical discipline

As it is shown in Table 22, Lighting and building electrification is the major cost of the electrical installation. With installation costing tool it was defined that the quantity of luminaries is 180 pcs and luminaries are representing 55% of the costs. It was also noticed that portion of lighting panels are relatively big concerning the size of the plant and also representing 25% of Lighting and building electrification costs. Drivers for Lighting and building electrification will be following:

- Luminaries, 180 pcs
- Lighting panels, 4 pcs

With Low voltage power cables the concentration will be on big feeder cables. According to installation costing tool the Low voltage cabling from Station transformer and from Black start unit to Low voltage switchgear is representing 58% of the Low voltage cabling of the plant. As a driver for Low voltage cabling was selected:

- 3x3x1x400mm^2+2x1x400mm^2, 550 m per Station transformer
- 2x3x1x400mm^2+1x1x400mm^2, 550 m for Black start unit

According to Table 22, medium voltage cables were the third biggest cost of electrical installation costs. With medium voltage cables 30% is coming from Generator main cables and 55% from the outgoing feeder cables. Portion of MV cables for Station transformer is 15%. Distances from the generators to Medium voltage switchgear and from Medium voltage switchgear to power transformer are defined in Site layout and cannot be affected during the detailed engineering. But dimensioning of the cables should be used as a driver for the detailed engineering. Following drivers were selected for the Medium voltage cables:

- Generator MV cabling, 2x3x1x400mm^2 per generator, total length of generator cabling for the plant 381 m
- Outgoing feeder cables, 3x3x1x400mm^2 , length of outgoing feeder cables 675 m
- Station transformer feeder cables, 3x1x400mm^2 , length of Station transformer feeder cables 180 m

Table 22 shows that also the cost of control cables is remarkable. Suitable driver for control cables was discussed in detailed engineering meeting and the conclusion was that the total length of Control cables was decided to be the driver for the control cables. Driver for control cables:

- Control cable, total length 10 500 m

It was also discussed in the Detailed engineering kick of meeting that, number of cables per panel as driver would work, but currently this information is not available from installation costing tool with reasonable effort.

With MV-, LV- and Control cables, providing the unit prices for different size of cables is essential for proper engineering. In order to evaluate the optimized size of the cable and to keep the total cable costs in budget, unit prices also for other size of the cables than used in budgeting phase is needed.

5.3.5 Review meeting of detailed engineering

As with Case 1, model was not utilized for the engineering of the Case 2, there was no point to compare the actual design to budget. But instead, cost engineer had discussion about the possible affect of the drivers. Results was similar with Case 1, but it was noticed that with Gas plant the majority of the costs are concentrated only to very few systems and areas, which is limiting the possible actions to control the engineering.

5.3.6 Conclusion

Drivers of Gas plant are concentrated to smaller area or affecting to a few systems compared to Diesel plant. When the number of areas and systems is smaller, the number of drivers for these systems tends to be bigger. On Civil discipline the soil quality can be vital factor in cost structure and it can change the order of magnitude of the installation costs, but the same 3-4 systems remains biggest.

5.4 Conclusion

5.4.1 Cost structure and drivers

In both cases the cost structure remained same through the engineering process, meaning that the order of magnitude of the cost of systems or areas didn’t change within the project, but between projects there are some differences. This was discussed with cost calculating engineers of different disciplines and the conclusion was that changes in cost structure is depended on the accuracy of the cost calculations made in the sales phase. Especially on civil discipline, the magnitude of soil excavation and filling is in key position. If the quality of soil will turn out to be worse than it was assumed in budgeting phase, consequences can be massive, regarding the soil replacement or piling.

With driver selection the most challenging phase where the Basic engineering kick-off meeting. As it was found out already in model determination, drivers for Basic engineering are related to size of the buildings, tanks and to number of equipments and typically those are the items which has been already agreed with the customer and have been stated in contract. Changing of these items means negotiation with customer, which may lead into some sort of compensation for the customer or for Wärtsilä, if changes are approved.

Main finding with drivers were that the cost drivers cannot be assumed to be same with all types of the plants. References of this showed up already in chapter 4.1, with studying the cost structure of different types of plants and it was proven to be right with these two test cases.

With some drivers it was noticed that the driver could be building, area or equipment specific. Example Frame weight could be indicated building and structure wise. Same with concrete, tanks, luminaries, cables and with exhaust gas ducting. But now days, such information is not available automatically from installation costing tool and collecting detailed information manually would be too time consuming.

5.4.2 Indicators and reporting

Installation cost management reports were created as a result of the installation cost management model testing. Reports and indicators were prepared by following the theory dealt in chapter 3.4. Main principle was to provide information to support the decision making and to provide information for different stakeholders, such as Project teams and design managers and engineers. Information provided for different stakeholders is varying from quantities and masses to monetary values, which means that both, direct and indirect indicators needs to be used.

As a conclusion it also came up during the testing workshop that engineering partners processes and personnel would need some cost consciousness related training in case of implementation. This same conclusion was covered in chapter 3.9.

5.4.3 Cooperation between disciplines

It was noticed that due to engineering kick-off meetings, where all the disciplines were participating, the cooperation between disciplines was increased to the good level. This was shown mostly on comparison between different solutions and the cost affect of certain change on scope or on layout was possible to evaluate immediately.

5.4.4 Installation cost management after engineering process

Corner stone of installation cost management model is to set the cost drivers to guide the engineering work through the whole process. One of the topics that came up in arranged workshop that setting the drivers should not stop to engineering process. Most affecting items and unit prices related to them should be defined in review meeting of detailed engineering and taken to drivers for subcontract negotiations. Procurement is limited to be outside of this thesis and won’t be dealt any further.

6 SUMMARY

6.1 Structure of created installation cost management model

The research problem with the installation cost management was the missing link between the budgeted installation costs and the project design. When the theoretical framework for this study was built, the studied main theories behind the created model concentrate on cost control, cost monitoring and value engineering.

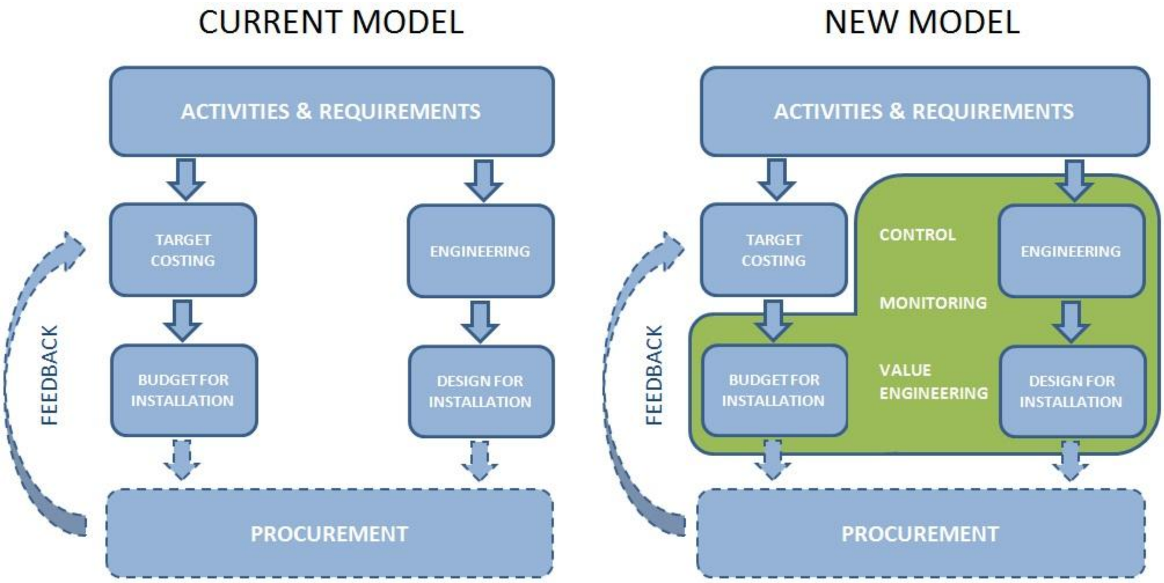


Figure 19. Theoretical framework

The main principle that rose up during the studies was the Pareto´s rule, which was selected to be the core of the model. The model concentrates on the main costs and searches the cause of those costs to be the drivers to control the engineering. Concentration on the main costs has a fundamental effect on the effort required for the cost management. A too detailed cost management model would make the process too hard to maintain.

The structure for the installation cost management model was defined by integrating the theoretical framework to the existing engineering process. The integration was started by studying the engineering process, its inputs and outputs and the performing parties of each process. Also from the resourcing point of view, it was effective to integrate the installation cost management with the engineering management. The effectiveness of the installation cost management model and the synergy between disciplines is also achieved through the cost engineer participation in the engineering management related meetings.

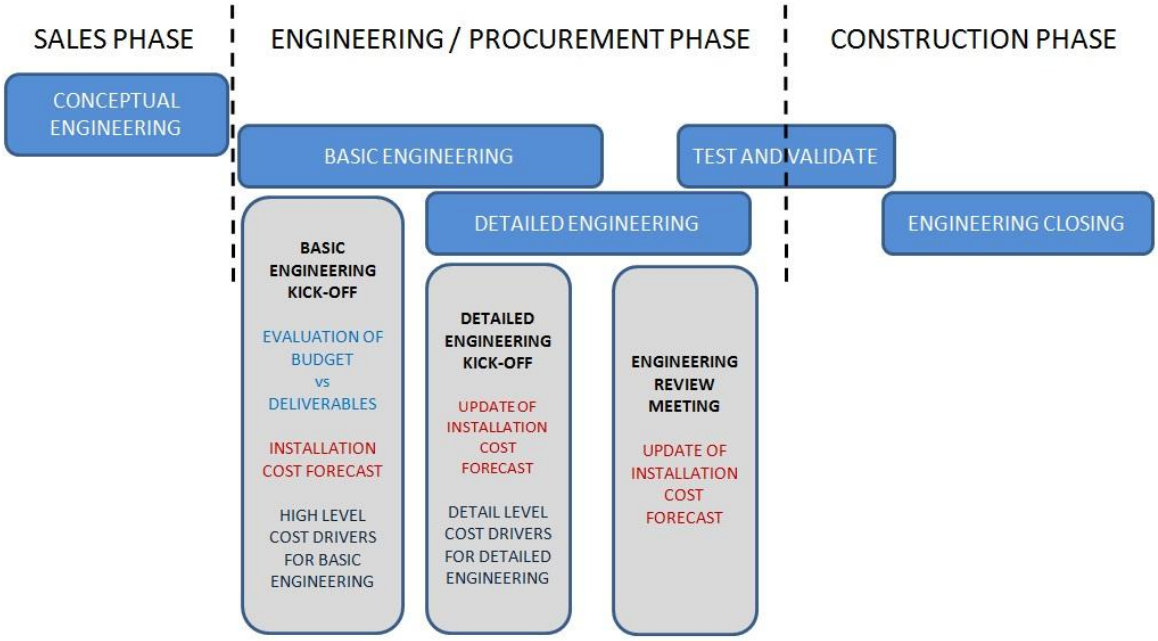


Figure 20. A Model for installation cost management in engineering process

6.2 Drivers and indicators

With installation cost management model, drivers to control the engineering work in different phases of engineering process are selected from the most affecting systems of each discipline. Implementation of drivers is based on a theory which defines the criteria for the driver selection and the suitable number of drivers in order to keep the control manageable. The main principle with selection of drivers is to keep the number of drivers low and select the drivers extremely well.

With the determination of indicators, different interests of the stakeholders have been taken into account. The installation cost model uses direct and indirect indicators to serve project management and design engineers. When direct indicators serve design engineers with quantity, volume and mass of installation material, indirect indicators serve project management by multiplying the direct indicator with the unit price of the installation units. During the creation of the model, there was also a cost management report created in order to communicate the information to the stakeholders in a correct way. The most useful information to be provided for the project management was found to be the information that supports the project engineering related decision making. The information that consist just numbers for the accounting purposes doesn’t support the engineering management.

6.3 Cost consciousness

One of the main findings during the study was the model for the design engineers´ cost consciousness. The model of cost consciousness defines the aspiration level of the design engineers´ cost consciousness in terms of product life cycle and type of design.

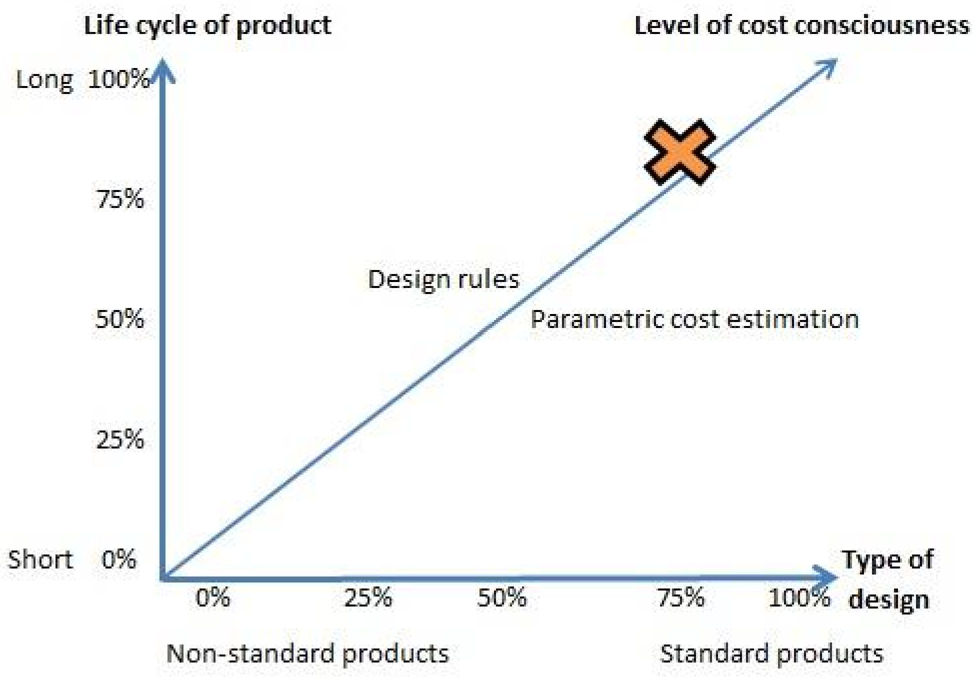


Figure 21. Aspiration level of cost consciousness

The model defines the achievable level of cost consciousness of engineering process in power plant projects. Due to long life-cycle and standard type of engineering, the aspiration level of the cost consciousness can be assumed to be relatively high with the traditional power plant projects. Instead, for example with LNG projects the situation can be considered to be opposite. It was also found that the cost consciousness of design engineers is essential to be able to utilize value engineering for the design.

6.4 Implementation and further research

Possible implementation of the installation costing model would be a demanding project as well. Full utilization of the installation costing tool to support the determination of cost drivers and to be used as reporting tool, would require preparations and some programming work.

A suitable starting point for the implementation of the installation cost management model could be the development of the cost consciousness of design engineers and project teams. The first issue to be solved would be the sharing of Wärtsilä´s cost information with the engineering partners.

The created installation cost management model is based on Pareto´s theory and it concentrate on the causes of the majority of the costs. After the possible implementation of this model, it should be considered if the ultimate goal should be a more comprehensive cost management system. A comprehensive cost management would require continuous control and monitoring and also development of engineering tools with built-in cost knowledge.

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APPENDIXES

Appendixes are confidential and are not included to public version of this thesis.