RES | THE SCHOOL for RENEWABLE ENERGY SCIENCE

Landsvirkjun Cost Estimating and Assessment for Small Hydropower Plants

Methodology and Basis for Estimating Cost

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Viðar Helgason

A 30 ECTS credit units Master´s thesis

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<u>Colonel</u> *Schmidle: "You can't predict the exact behavior of a complex system" he explains, "but there are ways to understand how the system is likely to end up". In other words, you can't choose which sequence of events will lead to a given result, but that doesn't mean you can't choose the result* (Freedman 2000).

Abstract

This research is in the field of Project Management and it examines the process leading to the development of a Cost Estimate. The focus of the research is on the application of the tools and techniques that are part of the cost definition process. Consideration is given to what methodology is applied for the development of a Cost Estimate.

Purpose – This research aims to document the current status of Project Cost Estimation within Landsvirkjun. The research also documents best practice in relation to Project Cost Estimation.

Approach – To begin with, a literature review was performed where best practice for defining Project Cost was established. The review covered Project Management technics used for Private and Public Project Management.

Next, a case study of available documents from Landsvirkjun was performed. It was intended to explain how cost estimation was performed by the company.

Finally, another case study was performed were the subject for review was Small Hydropower Plant projects. The case study finding helped document current definitions and main cost elements of such projects.

Findings – Regarding Landsvirkjun, it was concluded that more information was needed to make any definite conclusions regarding the management of project in connection to cost estimation. However it was possible to state what methods were applied to estimate cost, as well as issues regarding the WBS, Risk Management and contingency were identified.

For Small Hydropower Plants (SHP), the definition of such project was clarified and as a result a classification system for SHP projects in Iceland was proposed. The main cost elements of SHP project were also discussed and the main categorise identified. Finally a CBS for small hydro was proposed.

Key words – Landsvirkjun/ Energy Framer/ Cost Estimation/ WBS/ Contingency.

Acknowledgement

I want to thank my family:

Tinna, I thank you for your moral support and countless encouragements during long nights and days, you being there got me through this.

Mom and Dad, without your support (in countless ways) I would not be doing any of the things I do today. I cannot thank you enough.

I thank all other members of my immediate family that have supported me during this time. Also, I note that this thesis was allowed to use small parts of a previously performed thesis by me at the RU, titled *Project scope management*.

Preface

This is a master thesis in Hydropower at the School for Renewable Energy Science. This thesis is the result of discussion with Mr. Jóhannesson at Landsvirkjun Power and Mr. Júlíusson at Mannvit Engineering. The research topic is in the field of cost estimation and analysis with special emphases on hydropower structures. Cost analysis in medium and large hydro is a well-established practice at Landsvirkjun and other engineering firms in Iceland. This is of no surprise in light of the islands history, location and economic development.

The Innovation Center of Iceland (ICI) has recently made available a simple model for a feasibility study of small hydropower stations. This model offers on-line guidance to interested parties such as landowners, who with the help of the model can roughly estimate what potential their land has for producing electricity. This model that ICI has made available is named in the native language "Orkubóndinn" or the Energy-Farmer (EF).

In relation to the EF-project a noticeable vacuum has been created on the market for readily available cost estimation or support that is of similar nature to the EF-model (i.e. cost analysis for small/micro hydro). That is where the idea for this project came from.

The original idea was to create a simple cost model that could be used to estimate the cost of a small/micro hydropower station. The result from this model could then be used as an input into a feasibility study like EF-model. This would give the owner of the potential hydro power station a better view of the feasibility of his endeavor.

This raised the following questions:

- What approach shall be taken to create such a cost model?
- How can its quality be validated?
- How does it compare to what other counties do?

The conclusion was that to be able to make an adequate cost model the methodology, attributes and theoretical framework need to be sufficiently defined.

The opportunity to work with Landsvirkjun and Mannvit Engineering offers the opportunity to research how cost modeling in Iceland is conducted, and therefore to define the main attributes that need to be included in hydropower cost analysis. Along with the methodology that is being applied, and a theoretical review of literature to establish a 'best-practice' comparison to gives a solid base which then could be used as a reference for the creation of a cost model.

Abbreviations and Acronyms

ABM	Activity-Based Management
CBS	Cost Breakdown Structure
CER	Cost Estimation Relationship
DBM	Deliverable-Based Management
EV	Earned Value
EVM	Earned Value Management
NPD	New Product Development
OBS	Organizational Breakdown Structure
O&M	Operations and Maintenance
PFI	Private Finance Initiative
PM	Project Management
PMI	Project Management Institute
PO	Project Owner
PPP	Public Private Partnerships
UK	United Kingdom
WBS	Work Breakdown Structure

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1. Introduction

1.1. Background

Cost engineering became a profession in the 1950s, around the same time when Project Management was gaining ground. Cost engineering is based on applying experience and scientific methods to estimate a likely cost of a project. The objective of cost engineering and cost estimation is to give the investors an idea of what will be the likely cost of a project. Some consider cost engineering to be an addition to traditional engineering. Since cost engineers must consider the relationships between the physical elements being designed and what they are to likely cost, to some, cost engineering is viewed as an art not a science.

In Iceland the title Cost Engineer is seldom used, the reasons for that are unclear. Also, there is no special Cost Engineer Association, but there is a Project Management Association in Iceland. Estimation of cost is just what some engineers seem to take on depending on their interest, and those successful make it their profession.

Cost Estimation has always been an important area for the Icelandic energy company Landsvirkjun. That is not surprising as the investments they make are usually large and a small error in estimates of cost can literally be a project killer. Landsvirkjun has been developing a cost estimation model for many decades, the first version of the model that is being considered in this research dates back to 1990´s.

1.2. Statement of problem

The problem that has been identified is; there is lack of guidance existing for the creation of a cost model for small hydropower plants.

There is a need for a simple cost estimation model for small hydropower projects in Iceland. The only model being used in practice in Iceland is by Landsvirkjun, and their cost models have been used to estimate cost for at least twenty years. Therefore it would prove useful to document what approach Landsvirkjun has taken in this respect, and how it compares to what literature describes.

Landsvirkjun's uses its model for the estimation of cost for large hydropower plants. That is clearly something that needs to be kept in mind. Such models are much more elaborate and complex than a model specifically intended for small hydro. Therefore a review of Landsvirkjun's model should provide sufficient insight into what methodology could be applied, and what not.

It is not easy to get the opportunity to study Landsvirkjun's cost model. The company is very secretive and closed to outsiders, especially when it comes to sensitive information like estimation of cost. Consequently it has been decided to use this opportunity well, and give the Landsvirkjun review much weight in this research.

1.3. Research questions

There will be one research question for this research. At outset of this research no information has been obtained about the processes or performance regarding project management at Landvirkjun. The main research focus will be in the theoretical field of project cost management for construction projects.

Cost estimation is performed in the Identify stage of a project. This is the first stage that the project enters after the 'need' for the project has been confirmed. In respect to cost the greatest potential to influence its development is at the beginning. Therefore the preparation and work put into preparing a detailed cost estimate will have much influence on the cost development of the project.

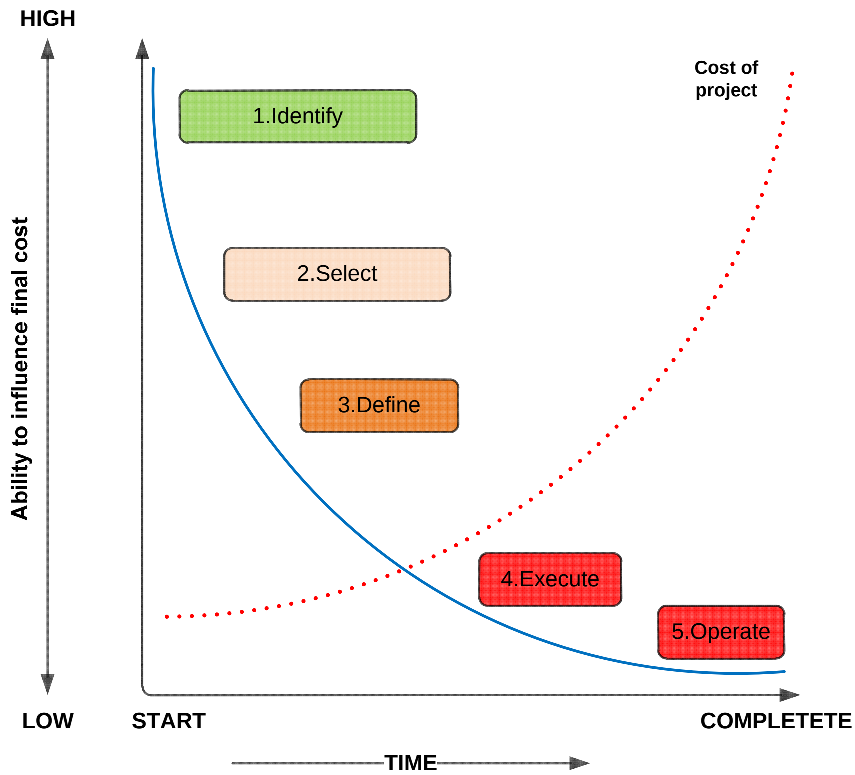


Figure 1: Ability to influence final cost over projects life. Adapted from; (Anderson and Tucker 1990) and (Atkin 2010).

Figure 1 shows that the work put in at the *Identify Stage* (in some articles referred to as conceptual stage) has the greatest influence on new product development (NPD) projects cost (Anderson and Tucker 1990). As the project moves forward the ability to influence cost drops quickly. Therefore, if waste is to be minimized and value for money maximized, the potential for the greatest gain is in the betterment of the processes at the Identify Stage. Not much is known at outset about how Landsvirkjun manages it project in respects to cost estimation and that is one of the main things this research hopes to document.

The following research hypothesis has been adopted: Tools used to estimate cost of Landsvirkjun's projects are, for all practicable purposes, consistent with best practice.

The research question: How is initial project management at Landsvirkjun handled for hydropower projects with respect to Cost Estimation?

1.4. Aim

The aim is to define how cost management is generally managed in Iceland i.e. by the firm Landsvirkjun (power producer), this will be done in a case-study of the companies work guide. Also a reference will be established for comparison of "best practice" attained from theoretically sound sources. The desired outcome is a write-up clearly reporting how, in reality, planning is conducted in respects to Cost Estimation and if that varies from what can be considered to be best-practice. If called for recommendations to help correct any differences will be put forth. The main aim is to bring to light pros and cons and find solutions for future implementation.

At identify stage in the project life cycle the scope starts to emerge and if it is decided to go-ahead with the project a preliminary project scope statement is issued. The main aim will be to look closely at the Landsvirkjun's process and see how Cost Estimation is performed at this time in the project life cycle.

1.5. Objectives

It is not possible within the timeframe of this thesis to define, create, test, and implement an exhaustive system or a standard complete in nature. Instead, a manageable tactical goal for this thesis is the subject of Cost Estimation at the Identify Stage.

The main objective is to look at project initiation stage, when the decision and scope are clearly defined. In this phase there are numerous components that need attention however this research will mainly focus on the topics of Cost Estimating and Work breakdown structure. The desired result is the identification of the methodologies used to perform an adequate cost estimate. It is the hope that attributes will be identified that will help create a strong base for the creation of a cost-model, specifically in connection to the EF-Project.

It is possible that the hierarchies and decision-making processes at Landsvirkjun need to be better defined, so that project efficiency may reach its full potential. This will be one of the points that this research hopes to illuminate. It should be possible to have a Mechanistic Structures[1] process for most public agencies and companies, where NPD teams work on the Identify Stage to define the project. Only truly special and "one of a kind" NPD projects need an Organic Structure[2] i.e. where there is a high level of uncertainty regarding the project demands flexibility (Eisenhardt and Tabrizi 1995, Büschken and Huth 2009). It is not clear at the outset of this research weather the organizational structures used by Landsvirkjun fall within any of the defined structures mentioned in Figure 2. Although it does not directly relate to the main objectives, it is important to make a note of these different types of structures because they influence one's perception of the public process as a whole.

Objectives of research:

1. Identify what methodology is applied at Landsvirkjun for cost estimation.
2. Create a best-practice comparison by review of theory.
3. Recommend an approach to creating a cost model for the EF-project.
4. Establish what the main cost estimation attributes are for Small hydropower plants.

[1] A Mechanistic Structure is defined in Figure 2.
[2] A Organic Structure is defined in Figure 2.

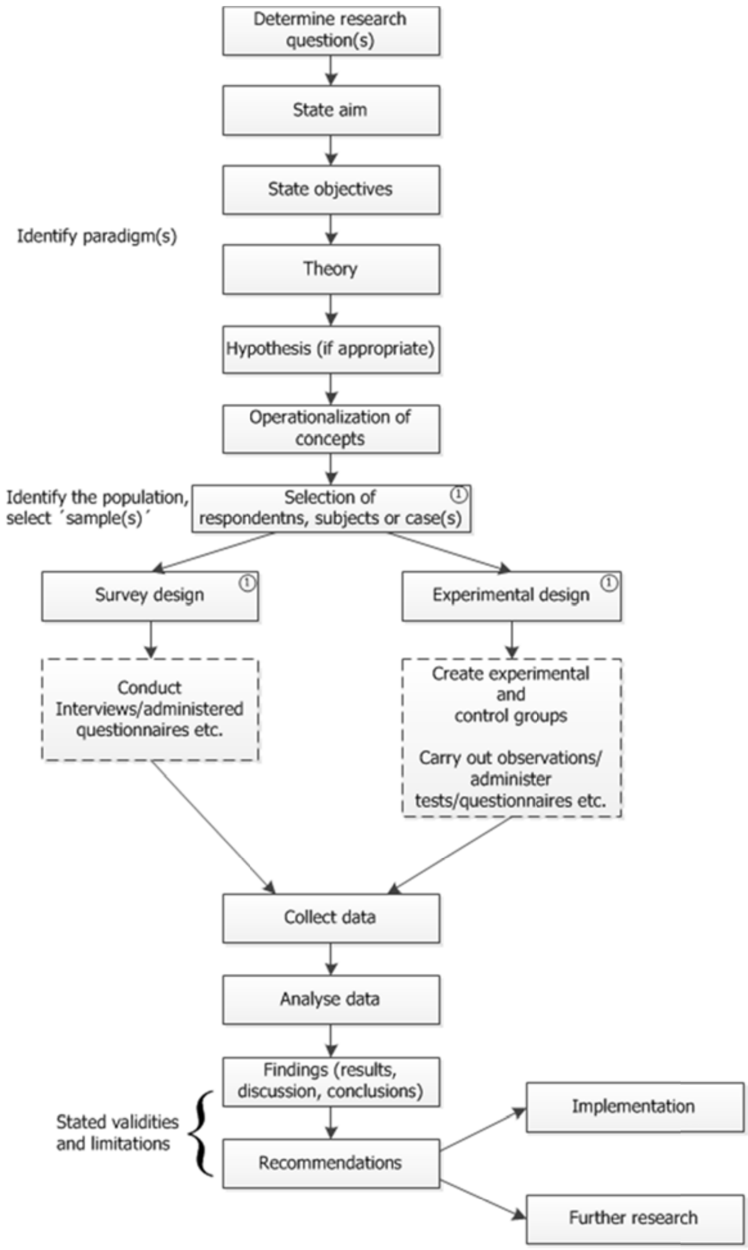
Organizational antecedents	Defined as
Organic Structures	
Decentralized decision-making structures	...the extent to which project decisions can be made without referring to higher management / escalation levels.
Participative decision-making within the team	...the extent to which team members are involved in the decision-making processes.
Central budget	...budget provided by a central function and not by an operational unit.
Physical proximity	...the extent to which team member are easily reachable on foot and the extent to which it is easy to get together for spontaneous meetings.
Mechanistic Structures	
Rewards	...the extent to which team members are rewarded for their participation and/ or the extent to which working in the project is captured in target agreements.
Project formalization / structuring	... the extent to which the project is planned by clear and specified guidelines and the extent to which the execution of the project follows a structured approach.
Steering committees	...the number of meetings and the relevance of this mechanism for the project management.
Boundary Management	
Integration with functional departments	... the extent to which information with internal functional units is exchanged and the quality of the cooperation and coordination with internal functional units.
Top management support	...the extent to which the top management supports cross-functional teamwork and takes part in the project by providing resources and giving feedback.

Figure 2: Role of organizational structures in the initiation ("early") and the implementation ("late") stage of the innovation process (Büschken og Huth 2009).

1.6. Limitations

The research focus of the thesis will be in the field of project management for construction projects, specifically in the public sector. This research will be restricted to the Identify Stage of a project, more specifically to the methodology used for identification of project cost. The Identify Stage has been confined to the client's/owner's perspectives, not those of the broad spectrum of other participants who may be involved in the project delivery. In order to simplify the research, the view will be taken that the project lifecycle stages and phases are consecutive, although in reality this may vary. This research is limited only to the Landsvirkjun and their projects.

1.7. Research strategy



Note: ① It may be advisable to carry out these activities in revers sequence to that show: Identify the population and possible `samples(s)´ and select and design the survey(s) or experiment(s) then select the `samples(s)´ to be used (from theoretical and practical considerations).

Figure 3: The research process (Bryman and Cremer 1994)

The research strategy is based on a well-established practice (Fellows and Liu 2008) that is depicted in Figure 3. In this particular research the path that will be taken is the one of surveys, interviews and case-studies. Experiments and observations are not suitable for the research undertaken for this thesis. The short time and nature of the study was the deciding factor when choosing the best research strategy, and this research aims to identify how a system works, determine what may be done better, find results, and make recommendations for further implementation or research.

1.8. Structure of research

In this section the broad structure of the thesis is given. Figure 4 below illustrates the layout of this thesis as well as the flow of the research. This thesis begins with an introduction that discusses the background and subject of the research. In the chapter about research methodology a view of how the research work will be performed, that is to say how the researcher will secure that the work is truly based on scientifically accepted methods. Next a 'state of the art review' is performed where literature and best practice is documented. Following that the documentation obtained from Landsvirkjun are reviewed. It is hoped that that chapter show how Landsvirkjun defines estimation of cost and prepares its projects. Concluding the Landsvirkjun review a comparison of current practice and best practice is made and a summary of the main differences is drawn up.

Due to the strong interest regarding the EF-project a review of small hydropower plants will be performed. This review is intended to be a short theory review of literature in connection to small hydro. After that the main conclusion regarding small hydro is summarized a summary an approach to making a cost model for small hydropower plants will be made. Finally a discussion about the research describes what was accomplished. The research ends with the conclusions.

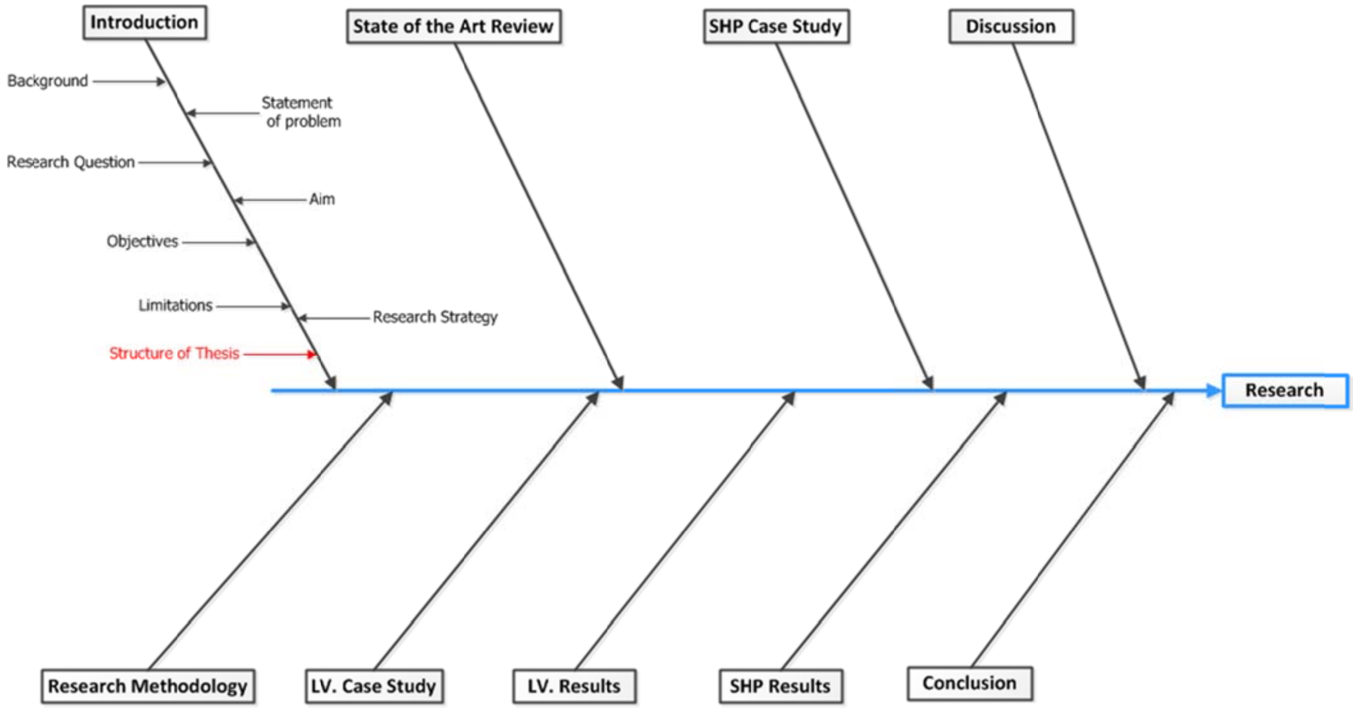


Figure 4: Fishbone structure of research

2. Research Methodology

The following sections describe the methods used in relation to the research methodology are described. They will elaborate on what has been stated in section 1.7.

2.1. Introduction

The basic principle for this research is simple; the aim is to obtain data, analyze it in a neutral manner and report the findings. In Figure 5 the methodology used to find data on Landsvirkjun is illustrated. As is shown on that figure the main source of data regarding Landsvirkjun's cost model is the company itself. The only other data or more precisely information is from the supervisor of this research, but he is a specialist on the model.

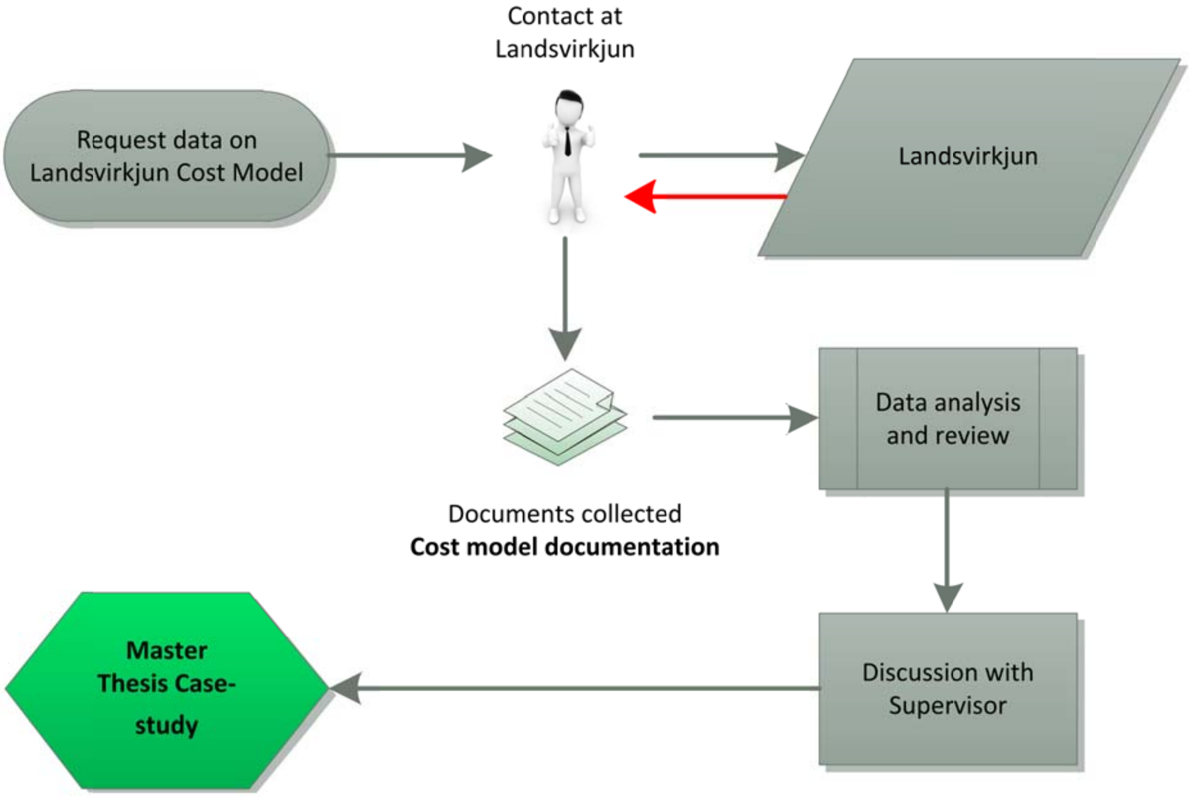


Figure 5: Process Used for Seeking Data

2.2. The Case Study

This research is largely based on findings obtained by a case study. A case study analysis is the process of detailed study of an individual group, organisation, event, or project (Fellows and Liu 2008). There are two types of case studies that can be performed:

- Case study of an organization (exploratory)
- Case study of a project (explanatory)

The case study performed in this research is defined as explanatory. The subject for review is the Landsvirkjun's Cost Model, and it cannot be considered to be a study of an organisation. However, it is not correct to state that it is a project either; the model is a tool that Landsvirkjun applies. The case study performed is intended to explain how this tool is applied and functions. Further definition of the Explanatory Case Study is given in section 2.2.1.

A case study analysis can be based on many resources such as observations, interviews, questionnaires, reports and archival records. Fellows and Liu (2008) define four main uses for case studies in construction management research. They are as follows:

- a source of insight and ideas
- to describe phenomena
- project-biography
- illustrative anecdote

The case studies performed in this research will be based on:

- Observations
- Interviews
- Reports
- Archival records

The use of case studies for this research is favourable due to limited information available on the Landsvirkjun Cost Model.

2.2.1. Explanatory Case Study

This Landsvirkjun Cost Model Case Study is defined as explanatory as its aim is to be used for hypotheses testing. The inputs for this study are based on reports and archival records obtained from Landsvirkjun. The goal is to show how Cost Estimation is handled at the company.

The objective of this exploratory case-study is to create a solid base that will support any further research, case-studies or sampling of the Landsvirkjun Company, and give a reference to processes and regulations that may be quoted later.

2.3. State of Art Review

State of the art review refers to that which is often called *theory review*. Pure and applied theory is both up for review. The objective of this review is to drawing-up the *state of the art* comparison for institutions and organisations. The state of the art review was conducted throughout the research since it was not clear at outset what material would be needed to complete this work. Keeping the review open had its drawbacks as it was difficult to limit the overwhelming amount of information obtained.

The goal of any review is to provide a critical assessment to the work visited; it is not adequate to merely summarize what the literature states without also providing a critical evaluation of the findings (Fellows and Liu 2008). According to Fellows and Liu (2008), it is never appropriate for the researcher to express personal opinions, because a state of the art review should be based on literature. Haywood and Wragg (1982) add to this by stating that the review must demonstrate that the writer has studied existing literature with insight. Therefore it not sufficient to simply list a summary of reviewed literature; critique must be also used to draw out issues and arguments.

2.4. Interviews

There are three types of interviews: structured, semi-structured, and unstructured (Fellows and Liu 2008). The interviews used in this research lie between semi-structured and unstructured. The goal of the interviews was to get input from practitioners on how Cost Estimates were prepare by the company and what data was available on this process. This kind of information is always subject to interpretation and bias from the interviewees (Fellows and Liu 2008).

2.5. Conclusions

This chapter describes the methods used for this research. These methods were based on established theory and as such ensured the quality of this research. Figure 6 depicts how the method and data collection points came together to form the basis of this thesis research.

There three main sources are depicted as main data inputs, they are an interview, case study, and theoretical review. This data will be analyzed with the main research topic in mind, creating the center of focus somewhere in between these topics. This is defined as applied research since its main objective is to improve the cost estimation, still the line is blurry since new knowledge could be obtained but that would be unexpected and therefore this is not defined as pure research.

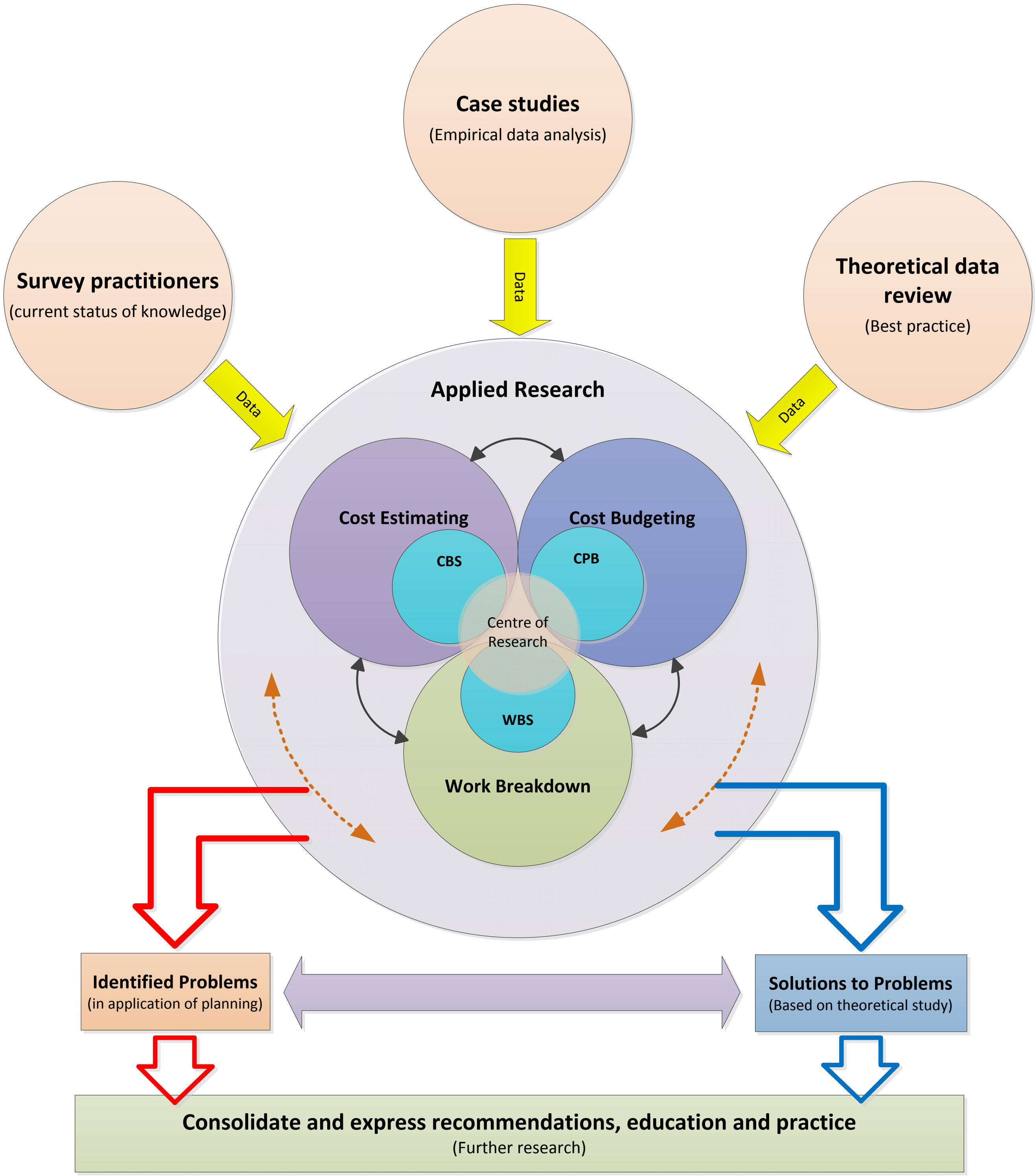


Figure 6 : Data gathering and analyses process.

3. State of the Art Review

State of the Art Review aim is to define the main literature that is relevant to Cost Estimating. The goal is to explain how established theory and new literature in the field of PM describe the methodology and approach of estimating costs.

To begin, the review will be based on the necessary processes to achieve scope as outlined by the Project Management Institute (PMI[3]). The PMI uses a detailed process that will give account of all the necessary elements needed to establish the Cost Estimate. Supporting the PMI review, other literature will be used as needed.

According to the PMI (2008), estimating cost is a part of the Project Cost Management. Estimating costs is the process used for developing an approximation of the capital needed to perform and complete a project activity. The cost estimate is a prediction based on available information at the time the estimate is made. It is important to consider cost trade-offs and risks. The Estimate Costs inputs (i.e. Basic Cost Estimate Documents) are illustrated in Figure 7.

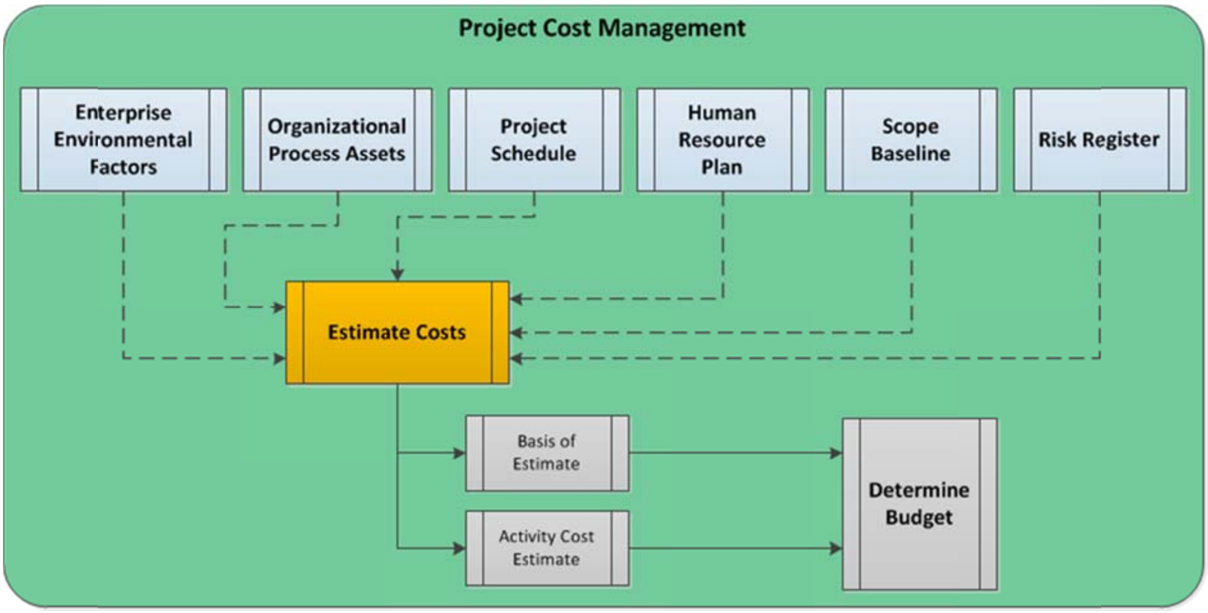


Figure 7: Estimate Costs Input & Output Data Flows, Adopted from PMI (2008)

After the cost has been estimated two outputs, the Basis of Estimate and Activity Cost Estimate, are used as inputs to the 'determine Budget Process'.

Project Management

This thesis is as study of how an agency uses aspects of Project Management (PM) to identify cost. The definition of a project and PM will be given in the section 3.1. These definitions and overviews are only the key points regarding the two concepts as both of them cover a vast quantity of theory and could each be a subject of an entire thesis. The selected definitions that follow are widely accepted and were used in this research.

[3] Home page of the PMI, URL:http://www.pmi.org/Pages/default.aspx

3.1. Project Management

PM is a structured framework around a defined project. In some sense, it is used by everyone every day. During any given day, person’s brain, with the help of his or her body, indicates, initiates, defines, plans, breaks down, executes, monitors, controls and closes multiple projects; this is the goal of a good PM. In this example, one’s brain is so good at managing these tasks that one does not know it is doing it. Thus, the challenge is to also apply this organized approach to the work we do consciously. It can be said that everyone applies this methodology; we just recently defined it as PM.

The definition of PM that is widely accepted and is used in this thesis is stated below:

Project management is the planning, organization, direction, and controlling of company resources for a relatively short-term objective that has been established to complete specific goals and objective. Furthermore, project management utilizes the systems approach to management by having functional personnel (the vertical hierarchy) assigned to specific project (the horizontal hierarchy) (Kerzner 2009).

To this can be added the following:

Project management is the application of knowledge, skills, tools and techniques to project activities to meet project requirements. Managing a project includes:

- *Identifying requirements*
- *Establishing clear and achievable objectives*
- *Balancing the competing demands for scope, quality, time and cost*
- *Adapting the specifications, plans, and approach to the different concerns and expectations of the various stakeholders. (PMI 2008)*

From these definitions it is clear that PM spans a large field and requires specific knowledge, organisation, and discipline. It can be difficult to justify the application of all the elements that have been recognized in connection to PM, especially when dealing with smaller projects. The Project Manager must evaluate what tools and method he needs for the successful completion of each project he manages.

The PM knowledge areas, as they have been depicted by PMI are listed here below.

- Project Integration Management
- Project Scope Management
- Project Time Management
- Project Cost Management
- Project Quality Management
- Project Human Resource Management
- Project Communications Management
- Project Risk Management
- Project Procurement Management

The areas that will be the focus of this literature review fall under the fields of (1) Project Cost Management and (2) Project Scope Management.

3.1.1. Project

It is important to realize when an idea can become defined as a project because there is a significant difference between these two terms. As soon as an idea moves to being a project, it is of great importance and should be treated as such. How it is treated should give indication of its size and importance. The theory of PM should be used to handle its quickly growing complexity. The definition of a project is given below:

A project can be considered any series of activities and tasks that:

- *Have a specific objective to be completed within certain specifications,*
- *Have defined start and end dates,*
- *Have funding limits (if applicable),*
- *Consume human and nonhuman resources (i.e., money, people, equipment),*
- *Are multifunctional (i.e., cut across several functional lines)(Kerzner 2009).*

This definition coincides with what the PMI, a world-leading organization in PM, accepts as appropriate (PMI 2008).

3.2. Pre-Project activities

3.2.1. Needs and Demands

At the beginning of any project needs and demands must exist. This can be represented to the organisation in the form of a business requirement, opportunity, or problem. Heldman (2009) split these demands and needs into seven groups, which are:

- Market demand
- Customer request
- Legal requirement
- Social need
- Strategic opportunity/business need
- Technological advance
- Ecological impacts

An organisation must decide how to prioritize these needs and demands, and how to determine whether or not they are worthwhile. Many of these needs and demands will often lead to the initiation of a new project.

3.2.2. Project Proposal

The Project Proposal states the highest goals of the project. It should be written before the project starts (although this is not always the case). It is the next step that follows the identification of a need or a problem, and therefore it is the fundamental reason for considering a new project (Taylor 2008).

The Project Proposal is usually developed by one or more of the following; key stakeholders with the help of marketing personnel, a project sponsor, project manager, team members or senior executive(s) (Taylor 2008, Roitha 2007).

Lock (2007) puts weight on the importance of challenging the approach taken when a proposal is made, and emphasized the value of looking at other strategic options in considerable depth.

3.2.3. Feasibility Studies

Before the decision is taken to initiate a project, it may be preferable to perform a Feasibility Study. This is should be done so that at least it is clear that the project is viable, and has the possibility of succeeding. If the outcome of the Feasibility Study is unknown, then it is recommended that the study is treated as a special project. If the Feasibility Study is positive (i.e. the project is given the go-ahead), then a new project team should be established. One should note, however that the people that work on the project should *not* be the same people that worked on the Feasibility Study. This is done to eliminate bias (Heldman 2009).

3.2.4. Summary

The scale and detail of the pre-project documents must depend on the project's size and complexity, and resources needed to complete it. All projects should go through stages where Needs and Demands, Project Proposals and Feasibility studies are performed. The information produced by this work must be documented and filed accordingly. The information created at the Pre-Project level is the foundation of all that will follow; it is the core reason for proceeding with the project.

3.3. Basic Cost Estimate Documents: Inputs

3.3.1. Enterprise Environmental Factors

The Enterprise Environmental input refers to factors that are outside the project but might still influence the success of the project. Heldman (2009) and PMI (2008) suggest some factors that should be considered when formulating a project, see Appendix I.

The factors that influence the Estimation of cost include (PMI 2008):

- **Market conditions:** Here description of products, service, and resources are available in the market. It should also describe from whom they are and what terms and condition may apply.
- **Published commercial information:** Information on resources cost rate is sometimes available from commercial databases that provide skills and human resources cost, including also standard cost for material and equipment. Published seller price is also a source of information

3.3.2. Organizational Process Assets

Organisational Process Assets refers to an organisation's policies, guidelines, procedures, plans, approaches, and standards for executing work (also project work). According to Heldman (2009) and PMI (2008), these include a wide range of elements that can affect the project, such as:

- Organisation standard processes, and definitions
    - Financial controls
    - Communication requirements
    - Issue and defect management procedure
    - Change control procedures
    - Risk control procedures
    - Procedures used for authorizing work
    - Performance measurement criteria
- Organisation standard policies
    - Project management policies
    - Safety policies
- Templates
    - Project charter templates, and etc.
- Historical information and lessons learned knowledge base.
    - Previous project risk
    - Performance measurements
    - Earned value data
    - Schedules from previous projects

Historical information has been shown to help with the project charter, project scope statement, development of project management plan, the process of defining and estimating activities, etc. (Heldman 2009). The value of historical data should not be underestimated.

3.3.3. Project Schedule

The Project Schedule is an output document that is created in the Develop Schedule Process which is a part of the Project Time Management. That process analyzes activities sequences, durations, resources requirements and schedule constrains. Scheduling tools are used for creating the schedule; it can be iterative work to produce an acceptable schedule (PMI 2008).

The Project Schedule determines the planned start and finish date for project milestones. The schedule requires constant maintaining to keep a realistic schedule throughout the project work process (PMI 2008). Scheduling requires activities of the project to be identified. These are all the activities necessary to complete the *work packages* that are defined in the WBS (see section 3.5) (APM 2006).

3.3.4. Human Resources Plan

The Human Resource Plan is a part of the Project Management Plan[4], it describes how human resources are to be defined, staffed, managed, controlled and released. It describes how human resources are to be managed and what they should do. The Human Resource Plan should at least include the following documents:

- Roles and responsibilities,
- Project organization charts, and,
- Staffing management plan (PMI 2008).

[4] The Project Management Plan is outside the scope of this research

3.3.5. Scope Definition and Baseline

3.3.5.1. Define scope

The process of defining scope is the development of a thorough description of the project and product(s). The grounding of a solid project scope statement is crucial to a project's success. It is based on the major deliverables, constrains and assumptions that should be documented during the project initiation. When the project moves on to the planning phase, the scope is fine-tuned and defined in more detail as more information has become available. All known constraints and assumptions are analysed as best as possible; if any new risks, assumptions or constraints are found to be necessary later in the project, they must also be added (PMI 2008).

3.3.5.2. Scope Baseline

The Scope Baseline is one of the main components of the Project Management Plan. It is the baseline against which all changes to the project will be measured. Once the items to be included in the scope baseline have been approved, formal change management for the project begins (Norman et al. 2008). According to PMI (2008), the scope baseline should include:

- Project scope statement,
- WBS, and
- WBS dictionary.

The Project Scope Statement is discussed further here below, but WBS and WBS dictionary are covered in Chapter 3.5.

Project Scope Statement

The purpose of the Project Scope Statement is to describe in detail the project objectives, the deliverables, and the work required to produce the deliverables. The scope statement is an agreement that states precisely what the project will produce. This provides an understanding of the project scope among the project stakeholders. It is important to list what is part of the project and what is excluded from the project, as this is key in managing stakeholder expectations. The scope statement can be used to direct the project team's work, and is a basis for future project decisions (Heldman 2009, PMI 2008). It is critical to include a high level of detail in the scope statement because this determines how well the project manager can control the project scope.

3.3.6. Risk Management and the Risk Register

Risk Management

Inherent risk is a part of all projects. No project can be undertaken without possible Risk Events materializing. In Project Management risk is defined as: an uncertain event or set of circumstances that, should it occur, will have an effect on achievement of one or more project objectives. The Risk Event, therefore, is both an opportunity and a threat; both are managed through a risk management process (APM, 2006).

The APM (2006) defines Project Risk Management as:

"Project Risk Management is a structured process that allows individual risk events and overall project risk to be understood and managed proactively, optimizing project success by minimizing threats and maximizing opportunities".

When an unforeseen event occurs it impacts one or all of the following; cost, schedule and quality of a project. Figure 8 illustrates the risk management problem. The chance of a Risk Event occurring is greatest at concept, planning and start-up phases of the project. The cost of a Risk Event is small if it materializes early, rather than late in the project. The opportunity to minimize or work around the Risk Event is therefore early in the project life cycle (Gray & Larson 2008).

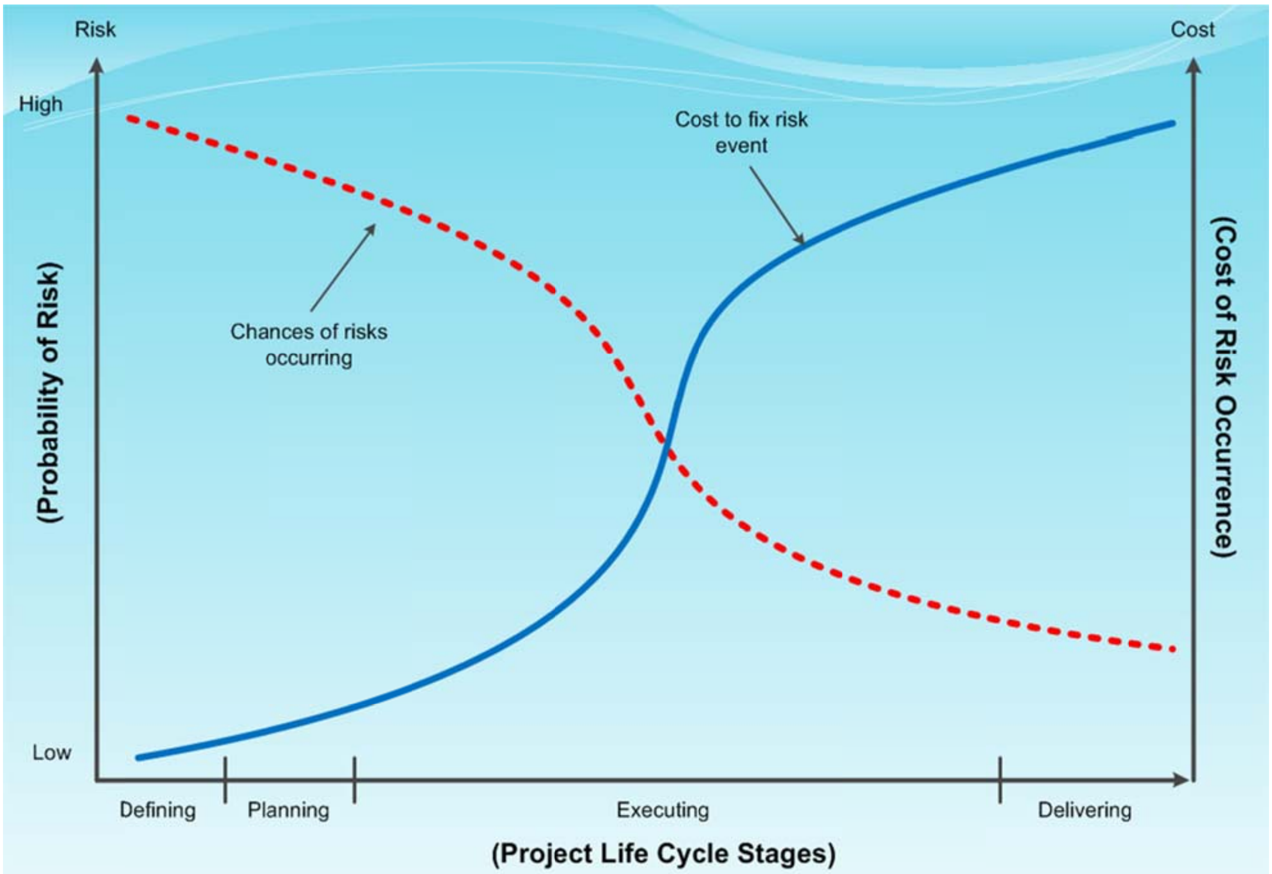


Figure 8: Risk Event Graph, adopted from Gray & Larson (2008).

When risk has been identified the Risk Response Plan (RRP) can be implemented. The RRP aims to avoid, reduce, transfer or accept threats as well as to exploit, enhance, share or accept opportunities, with contingency for risks which cannot be handled proactively (APM 2006). In Figure 9 the Risk Management Process is shown.

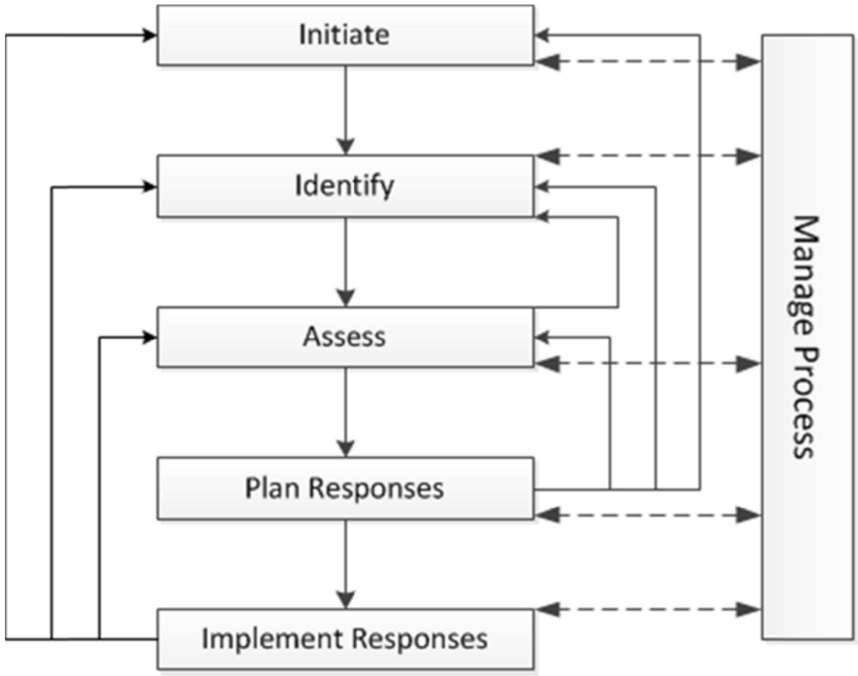


Figure 9: The Risk Management Process, adopted from APM (2004).

The main stages of Risk Management are the following: Risk Identification, Risk Assessment, Risk Response Development and Risk Response Control (Gray & Larson 2008).

Risk Register

The Risk Register is the main output from the Identify Risk process in the Risk Management Process. The Risk Register is a dynamic-document; it is created by the outputs of other risk management processes and needs to be updated as time passes and new information is created. The basis of the Riske Register, as previously stated, is from the Identify Risk process. After its creation it becomes available to the other Project Risk Management processes (PMI 2008).

The risks that are identified in the Risk Register or the *list of identified risks* as they are called within the register are described as well as possible and within reasonable limits. There description should state the risk event, what its impact is and/or if it causes another event. This description should show the root cause of the risk and its effects. In some cases potential risk responses are identified during the Identify Risk process. If this is the case then these responses may are used as inputs in the Plan Risk Responses process (PMI 2008).

3.4. Project Statement of Work (SOW)

Project Statement of Work (SOW) is a narrative description of the product or service that needs to be delivered by the project. If the project is internal to the organization, then it is generally in the hands of the project sponsor or initiator of the project to write the SOW. However, if it is external to the organization, then it is the responsibility of the buyer and can be in the form or bid, such as a request for information, a request for proposal, or a part of a contract (PMI 2008, Heldman 2009).

It is not ideal to have a contract in place before a project is fully defined, but in the case where that is the situation, it should be used as an input in the scope definition process. Also, it is important to properly document all agreements (as they are considered legally binding) that are made between parties. These should be included as input documents since they help document the scope of the project (Norman et al, 2008).

Based on Heldman (2009) and PMI (2008), the following information should be included in a SOW:

Business Need

A business need for the project might be based on governmental regulation, legal requirements, technological advances, or market demands.

Product Scope Description

The Product Scope Description describes the characteristics of the product that the project is intended to deliver. It should also include a description of the relationship between the product or service being created and the business need or demand that is driving the project.

Product descriptions contain less detail in the early phases of a project and more detail as the project progresses. Product scope descriptions, like the work of the project, are progressively elaborated. They will contain the greatest amount of detail in the project execution processes.

Strategic Plan

The Strategic Plan documents the organisation's strategic goals. Part of the responsibility of a project manager during the initiating processes is to take into consideration the company's strategic plan. The management team will refer to the strategic plan when choosing which new projects to initiate and which ones to drop, depending on their relationship to the strategic vision of the company.

3.4.1. Business Case

The Business Case (also known as Cost-Benefit Analysis) is intended to explain why the project is needed from a business standpoint, while also showing that the project is worthy of the required investment (PMI 2008). The Business Case should be directly traceable to the "Needs and Demands" (Heldman 2009), which was described in section 3.2.1. The requesting customer or organisation, in the case of internal projects, is responsible for producing the Business Case document. It is created as a result of one of the following (PMI 2008):

- Market demand
- Organizational need
- Customer request
- Technological advance
- Legal requirement
- Ecological impact
- Social need

If the project is spilt up in to multiple phases, then the Business Case should be periodically reviewed so it can deliver the intended business benefits.

An interesting point was raised by Kerzner (2009) in connection to the Business Case development. He found that companies view the Project Manager's contribution limited during the Business Case development. Kerzner pointed out that these Business Cases often turn out to be highly optimistic in their approach with little regard for the schedule and/or budget. This results in a slim likelihood of the Business Case meeting the demands that have been set forth. Instead, it is more likely that the project will fail to meet expectations, and that the blame will be placed on the Project Manager. To get a more realistic proposal, the Project Owner (PO) must value the expertise of the Project Manager in the development of the Business Case.

3.5. Work Breakdown Structure

The use of WBS goes back to the 1960's when the U.S. Department of Defence (DoD) and National Aeronautics and Space Administration (NASA) used it for aiding their planning and controlling of large projects (Cleland 1964).

WBS is defined by PMI (2008) as:

> *"A deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables, with each descending level of the WBS representing an increasingly detailed definition of the project work. The WBS organizes and defines the total scope of the project, represents the work specified in the current approved project scope statement."*

Without a well-developed and properly managed WBS, the likelihood of a project's success is severely diminished (Norman et al. 2008).

3.5.1. WBS

The WBS provides a clear vision for the project leaders, participants and stakeholders. It breaks-up the project scope into manageable, hierarchical and definable packages of work that make it possible to balance the control needs of management, with a sufficient level of detailed project data. This creates a framework for the project deliverables over the life cycle of the project. This break up of project work makes it possible to communicate with everyone involved in the project, and clearly identifies accountability within the project (PMI 2006). With respect to accountability, the WBS is connected to the OBS[5] and Responsibility Assignment Matrix[6] (RAM).

The upper levels of the WBS are intended to reflect the major deliverable work areas of the project, but they can also be used to outline the major phases of the project's life cycle. These upper levels make it possible to create logical summary points for assessing the communication of accomplishments, performance of teams and individuals, and measurement of cost and schedule performance compared to specific deliverables as well as the overall project. In order to avoid confusion, it is best to define the levels of the WBS prior to construction (PMI 2006).

The lowest level of the WBS, called the "Work Package", contains all the planned work. A work package must be cost-estimated, scheduled, controlled and monitored. Using this work breakdown relationship "work" refers to the work products or deliverables that are the result of an effort but not the effort itself (PMI 2008). The deliverable-oriented WBS provides, at the least, the following benefits to the project (PMI 2006):

- Better communication to project sponsors, stakeholders, and team members;
- More accurate estimation of tasks, risks, timelines, and costs;
- Increased confidence that 100% of the work is identified and included; and
- A foundation for the control processes within the project.

3.5.1.1. Deliverable-Based Management

The Deliverable-Based Management (DBM) takes the control concept beyond the Work Package to also include tasks and activities in the project schedule. All the tasks and activities produce individual deliverables that can be combined with other deliverables from the intended Work Package deliverables. This approach is used to manage the entire project by the creation and integration of individual and compound deliverables. By adopting this approach, the project can be managed at a detailed level. This makes it easy to sum up the deliverables based on the WBS hierarchy, which is the true power of DBM. It allows for cost, schedule, resources and quality to be understood, measured, aggregated and monitored for specific deliverables at higher WBS element levels. This enables the project manager to visualize and communicate how the project is performing. DBM is the management approach that should be used for most projects (Norman et al. 2008).

3.5.1.2. Activity/Task-Based Management

Activity-Based Management (ABM) is the opposite of DBM. It is a valid technique for supporting of on-going business operations. When ABM is used, the cost at activity level is most important factor of consideration when managing and controlling the cost of the business. Using ABM, the project manager can tie all project costs to specific operational activities, and therefore is able to control the projects connected costs. A detailed analysis of specific operational deliverables is time-consuming and costly to perform because activities often impact several deliverables simultaneously and can cross business units and functions. This inability to group work and cost against the WBS hierarchy and then show traceability is a serious problem for the manager. ABM is therefore appropriate for an on-going business operation; it is, however, inappropriate for the management of a project (Norman et al. 2008).

[5] The details of the Organization Breakdown Structure are outside the scope of this review.
[6] The details of the Responsibility Assignment Matrix are outside the scope of this review.

3.5.1.3. Importance of the WBS

There are many things that must be included in the management of a project if it is to be successful (as outlined in Chapter 3). The WBS is an important tool that can help secure project finish that is acceptable to all stakeholders. According to PMI (2006), the WBS does the following:

- *Defines all the work of the project, and only the work of the project, thereby clarifying the project scope;*
- *Reflects the input from all team members to ensure buy-in;*
- *Provides the baseline for subsequent change control;*
- *Is a primary input to other project management processes—for example, resource planning, cost estimating, schedule development, and risk identification;*
- *Provides the framework for project control, performance monitoring, and the foundation for communication with all stakeholders; and*
- *Ensures the work of the project correlates appropriately with the RAM and the OBS.*

In the field of Earned Value Management (EVM), performing a WBS of sufficient quality is vital if Earned Value (EV) is to be applied (PMI 2005)

3.5.1.4. WBS Quality

The quality of the WBS must to be considered; it is not enough just to make a WBS and then be done with it. Quality includes the ideas of harmony to requirements and fitness for use (that is to say, the project is fitting for its intended purpose) (PMI 2006). WBS should be created as early as possible in the life cycle and evolve as the project grows. It can therefore be described as a living document. The WBS must meet the project managers' requirements; it is of no use to make a WBS that overwhelms the project team. Its complexity has to be balanced so that it can both give guidance and help with decision making. Indeed, it is of little value if it is not actually used to manage the project (Norman et al. 2008).

According to PMI (2006), there are two main WBS Quality Principles that all WBS should incorporate. These principals are explained in Appendix II.

3.5.1.5. Approaches to creating WBS

There are many ways to go about creating a WBS. It can be created from scratch, recycled from existing WBS's or developed from a template or pre-defined WBS standards. All of these approaches are common in practice. The approach that is selected depends on the project manager and/or the organization's preference.

Details about WBS creation are given in Appendix III, based on PMI (2006).

3.5.2. WBS Dictionary

The WBS Dictionary adds to the level of clarity for everyone connected to the project. This is done by providing explanations, context and detail for each element within the WBS. The WBS Dictionary thus helps communication and facilitates understanding. It further elaborates on the boundaries and scope of the elements of the WBS. It answers questions about scope that cannot be explained with simple WBS element entry (Norman et al. 2008). According to PMI (2008), the WBS dictionary should include at least the following:

- Account identifier codes,
- Work description,
- Responsible organization,
- Listing of scheduled milestones,
- Associated scheduled activities,
- Required resources,
- Estimation of costs,
- Quality requirements,
- Acceptance criteria,
- Technical references, and
- Contact information.

3.5.3. Summary

The WBS transforms the boundaries and the scope into an easily understandable document that the whole project team and stakeholders can use. The creation of a WBS may seem like a challenge to people unfamiliar with the process, but it can be simple to begin with and then evolve as users become more comfortable with it. In conclusion, the outputs from this process are key in conveying and securing the scope and work of the project at hand.

In connection to Cost Estimating, the WBS is one of the fundamental tools for defining project cost elements. As such the WBS Quality Principles must be fulfilled (see Appendix II).

3.6. Cost Estimating Methods

3.6.1. Introduction

Cost estimation falls within the field of Budgeting and Cost Management. An initial cost estimate is a part of the business case, and used as part of the investment appraisal of the project. The cost estimate is updated along with the scope, schedule, and resources. As the overall cost estimate arises it will need to include allowance for risk and contingency. The cost estimate becomes the budget for the project when it has been agreed by the Project Sponsor (APM, 2006).

GAO (2009) makes a distinction between cost estimating and analysis:

Although "cost estimating" and "cost analysis" are often used interchangeably, cost estimating is a specific activity within cost analysis. Cost analysis is a powerful tool, because it requires a rigorous and systematic analysis that results in a better understanding of the program being acquired. This understanding, in turn, leads to improved program management in applying resources and mitigating program risks.

Furthermore GAO goes on to say:

Cost estimating involves collecting and analyzing historical data and applying quantitative models, techniques, tools, and databases to predict a program's future cost. More simply, cost estimating combines science and art to predict the future cost of something based on known historical data that are adjusted to reflect new materials, technology, software languages, and development teams.

Two main categories of cost estimation are defined:

- Life-cycle cost estimate (LCCE) that may include independent cost estimates, independent cost assessments, or total ownership costs, and
- Business case analysis (BCA) that may include an analysis of alternatives or economic analyses (GAO 2009).

GAO (2009) defines the cost estimation process for High-Quality Cost Estimates (i.e. estimates that are comprehensive and accurate and that can be easily and clearly traced, replicated, and updated) see Figure 10.

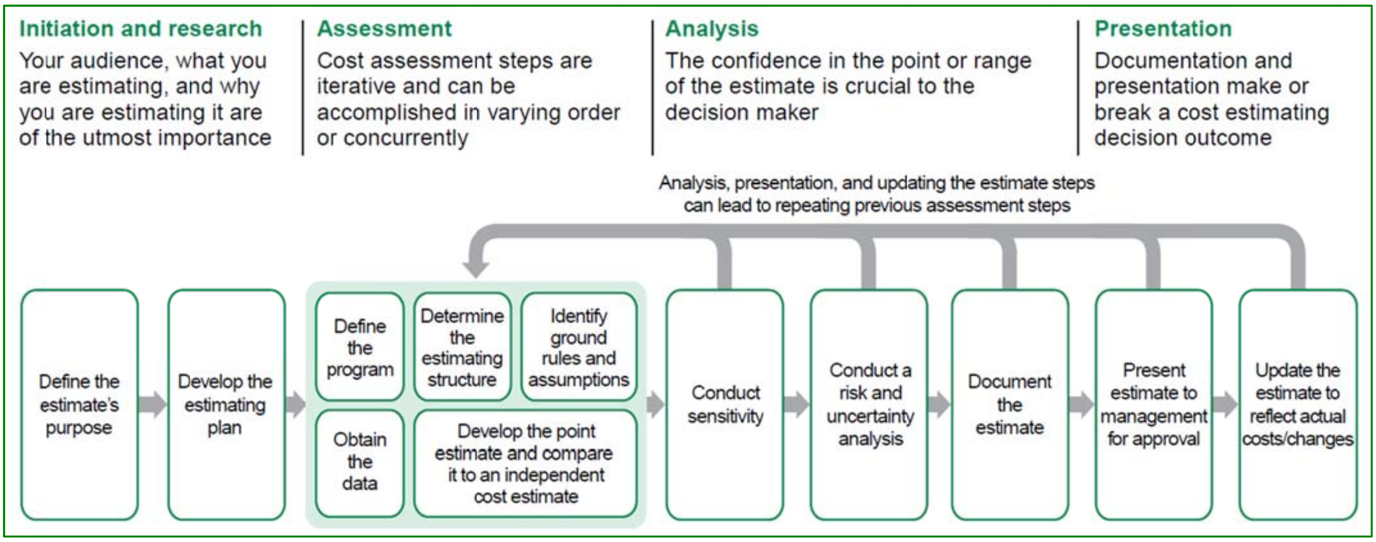


Figure 10: The Cost Estimation Process, (GAO, 2009).

To make the cost estimate a certain methodology approach needs to be adopted. The most common methodologies in use in practice are illustrated in Table 1. The focus of the Cost Estimating Methods section is the definition of methods used for estimating cost.

Table 1: Standard Project Estimating Methodologies, Adopted from Kerzner (2009)

Estimating Method	Generic Type	WBS Relationship	Accuracy	Time to Prepare
Parametric	ROM[7]	Top down	-25% to +75%	Days
Analogy	Budget	Top down	-10% to +25%	Weeks
Engineering (grass roots)	Definitive	Bottom up	-5% to +10%	Months

A company or corporation that aims to maximize its profitability must constantly improve its estimating and pricing methodologies. Estimating requires that information be collected prior to the start of the estimating process (Kerzner 2009). According to Kerzner (2009), typical information that is required for estimation includes, but is not limited to:

- Recent experience in compatible work
- Professional and reference material
- Market and industry surveys
- Knowledge of the operations and processes
- Estimation software and databases
- Interviews with subject matter experts

It can be difficult to state that it is possible to completely standardize the approach taken to projects. The reason is that projects can range from a feasibility study, modifications of existing facilities or complete design of a complex structure. Therefore the estimate type and information desired may differ (Kerzner 2009). This needs to be kept in mind when discussing cost estimation methods.

[7] Rough Order of Magnitude (ROM)

3.6.2. Analogy Method

The analogy is an approach based on historical data for service or products that have previously been procured and are similar to that for which an estimate is being made. It is important that the estimator describes his assumptions including why and how the current project or program is similar to the comparison example (they should be analogical). Factual data, estimated cost and all other relevant data used must be made available (GAO 2009).

The analogy method is based on the assumption that no new project represents a totally new undertaking. Using that assumption the analogy method, based on actual historical cost information from a similar project, estimates a new project by adjusting and compensating for any differences between the new and existing project (GAO 2009). The analogous models are usually used for early estimates that often are called:

- Order of Magnitude,
- Conceptual, and
- Ballpark Estimates (Rad 2002).

These estimates are then used to compare various options to determine the viability of a project in the screening process. Some of the analogous estimation tools are; ratio estimating, the three-quarters rule, the square root rule, and the two-thirds rule.

According to GAO (2009) this method is typically used early in the project life cycle when (1) insufficient actual cost data is available and (2) technical and project definitions are good enough so that adjustments can be made.

Advantages of the analogy method include:

- Can be used without detailed project requirements being known,
- If analogy is strong, estimate will be defensible,
- Analogy can be developed quickly at small cost, and
- The connection to historical data is readily understood due to simplicity (GAO 2009).

Disadvantages of the analogy method include:

- Analogy relies on a single data point,
- Problems finding detailed cost, technical, and project data, and
- Bias in adjustment of technical parameters factors (GAO 2009).

The nature of this method requires that the "reasonable person test" is applied (i.e. the source of the analogy and the adjustments must be logical, credible, and acceptable to a reasonable person). Also, since the analogies are one-to-one comparisons, the historical project data and the project under development should be as similar as possible. Analogies are often used to cross-check other methods, even if the analyzers are using more prestige methods.

Using analogy, expert opinion plays a large role in modifying system data. Therefore, it is recommended that adjustment should be quantitative rather than qualitative, avoiding subjective judgment as much as possible (GAO 2009). When analogy uses WBS as a base reference, the key is, each time the WBS is updated the estimate is simply enhanced (i.e. it is not necessary to create a new estimate). The information used in the analogy should be extrapolative and adjustable in light of:

- Time – the year in which the project was completed,
- Location – the location of the current/proposed project, and
- Capacity – size or capacity comparison between the current and proposed project (Rad 2002).

3.6.3. Parametric Analysis Method

According to Rad (2002) the terms *modular estimating* and *parametric estimating* have been used to describe models that are essentially very similar in usage, principle and underlying structure. The difference between them is that they are used in different industries. This section will describe their differences' and which term should be used to describe which model type.

3.6.3.1. Parametric Estimating

The Parametric Estimating, referrers to a top-down approach. This method uses parametric models based on key cost factors to derive cost data. The cost estimator cites a model and factors that are used along with any assumptions. The method is based on creating a statistical relationship between historical cost and project, physical, and performance characteristics such as speed, accuracy, tolerance, reliability, friendliness, error rates, and complexity. Unlike an analogy method, the parametric estimating is based on data from many projects and covers a broad range (GAO 2009, Rad 2002).

The goal of using Parametric Estimation is the creation of a statistically valid Cost Estimation Relationship (CER) by use of historical data. Using the CER, a model can be built that computes a project based on its new parameter inputs (GAO, 2009). The model calculates dependent variables of cost and duration based on independent variables. The independent variables are quantitative indices of performance and/or physical attributes. The accuracy of the estimate is based on the size of the project array data available (Rad 2002).

Documentation of the inputs is important when using such models, it can show if serious errors have been made in the estimate. In future application, such documentation helps improve the models. The adequate number of data points and a normalized data sets are important for parametric estimation. The parametric models are limited by the data sets they are made from. Limits such as project cost, size, and complexity must be considered.

For the CER the cost estimator must consider the main cost drivers; this should be done by studying the technical baseline and analyzing of data with tools such as scatter charts. When cost drivers have been identified the CER can be developed with mathematical expressions. CERs should be developed by use of regression techniques for the identification of statistical inferences. CER applies rates, factors, and ratios as they are defined in Appendix II.

Advantages of parametric cost estimation include:

- When data is available, parametric relationships can be derived at any level. As the design is updated, the CERs can quickly be modified and give results;
- Testing different input parameters and recording the resulting changes in cost can be used to produce sensitivity analysis;
- Parametric relationships derived from statistical analysis, often, contain objective measure of validity and calculated standard error. This can be used in risk analysis, and provide confidence levels for the estimate; and
- CERs rely upon historical data that provides acceptable objectivity. This makes the model more defendable (GAO 2009).

Disadvantages of parametric estimates include:

- Data base requirements in respect to effort of gathering, consistent and reliable data;
- Normalization can be time consuming and must be done correctly;
- Understanding how normalization was performed is necessary otherwise the estimator must accept the database on faith. Not understanding the CER increases risk of mistakes;
- CERs must be updated and capture the most current cost, technical, and project data;
- If data outside the CER range is used it may cause problems, the CER loses its predictive capability outside the development range; and
- It can be difficult for others to understand the CER, if it is based on nonlinear, or other, complicated relationships between cost and independent variables (GAO 2009).

A parametric model used in connection to construction projects is based on specific characteristics or inputs. From such models the output variables including cost of design processes are computed. Example of input and output data for construction projects is given in Table 2.

Table 2: Construction and Industrial Project: inputs & outputs, based on (Rad, 2002)

• **Input**	• **Output**
– Project Type	– Design Cost
– Frame Material	– Structure Cost
– Exterior Material	– Equipment Cost
– Roof Type	– Crew Size
– Ground Conditions	– Labor Cost
– Desired Floor Space	– Phase Duration
– Equipment Type	– Project Duration

Parametric models are refined and tuned for specific project within specific industries. These models should be regularly evaluated, validated, calibrated, and customized for accuracy and appropriateness. The estimates of cost and duration are usually used to establish preliminary budget that will be compared to financial desirability with other projects. It is extremely dangerous to use the parametric model to develop definite budgets unless its organization allows for major modifications, as the estimate matures throughout the projects life cycle (Rad 2002).

3.6.3.2. Modular Estimating

The Modular Estimate is used for projects that have a physical deliverable e.g. refineries, power stations, office buildings, or manufacturing plants (Rad 2002). This approach characterizes the facility by indices describing quantity and size of key components such as (Rad 2002):

- Power rating
- Number of pumps
- Physical size of pumps and turbines
- Size of plant floor
- Capacity
- Number of cranes

The model bases it calculation on historical data and predictive formulas developed for the models characteristics to estimate the project's cost, duration, and resources. Modular Estimating is manly used in construction, process, and manufacturing projects (Rad 2002). An example of characteristics and attributes used in a modular estimate are shown in Table 3.

Table 3 : Modular and Parametric models, based on (Rad, 2002)

• **Physical Characteristics**	• **Performance Attributes**
– Flow Capacity	– Speed
– Storage Capacity	– Accuracy
– Number of Equipment	– Error Tolerance
– Size of Equipment	– Reliability
	– Friendliness

3.6.4. Weighted Average Method

In the Weighted Average Method at least three or more projects are compared so that a weighted average can be derived. The estimator uses historical data suitable for the project and then produces the weighted average calculation; this includes weighted criteria and rationale showing how the current project is similar to the comparison examples. The main advantage of this method is that it is simple to use, but its disadvantage is the accuracy which is solely based on the quality of the historical data and the weightings assigned (Garrett, 2008).

3.6.5. Engineering Build-up Method

The Engineering Built-up Method uses a bottom-up approach to summarize cost estimates performed at low levels of the WBS. An Engineer Build-up Estimate is used at the lowest level of detail and consists of labor and materials cost, in addition to overhead and fees.

This estimate method is based on the assumption that historical cost is a good predictor of future cost. The premise is that data gathered at development phase can be used to estimate the cost of the production.

Advantages of build-up technique include:

- The ability to see exactly what the estimate includes and what may have been overlooked;
- Its unique application to the project and manufacturer;
- Good insight into major cost contributors; and
- Easy transfer of result to other projects (GAO 2009).

Disadvantages of build-up technique include:

- It can be expensive and time consuming.
- It is not flexible, and cannot answer what-if questions.
- A new estimate is always needed for each alternative.
- The product specification must be stable and well known.
- All changes to project and processes must be reflected in the estimate.
- Small errors can multiply quickly into large errors in the summation.
- Element can be omitted by accident (GAO, 2009).

3.6.6. Expert Opinion/Judgment

Expert opinion can be used in the absence of data; this is however considered too subjective. Therefore, much data gathering is needed to validate the experts' opinion. This method relies on the interviewing skills of the estimator as he must capture the experts' knowledge. Experts should only be used to estimate cost if it is with in their expertise, and their credentials should be validate beforehand (GAO, 2009). It is more common that Expert Judgment is used to validate estimates. The expert must consider the details of the project complexities and characteristics. The expert may modify the estimate or concur with the conclusion (Rad 2002).

Advantages of the expert opinion are:

- It can be used when no historical data is available,
- It is quickly performed when experts have been assembled,
- Different perspectives and unknowns can be realized,
- It can help cross-checking for CERs that require data beyond the data range,
- It can be blended with other estimation techniques within the same WBS element, and
- It can be applied in all acquisition phases (GAO 2009).

Disadvantages of the expert opinion are:

- Lack of objectivity;
- Risk of expert groups will, under influence of one expert, be swayed to bias decision making (see discussion on Technical Consensus Method below); and
- Not very accurate or valid as a primary estimation method (GAO 2009).

When data is not available expert opinion can be used, however is should be used sparingly and only as a check off. Relying on expert opinion as a main source for cost estimation is unwise (GAO, 2009). However, expert judgment can be considered a reliable source for checking how realistic an estimate is (Rad, 2002).

3.6.7. Technical Consensus Method

Technical Consensus Method is based on group consensus, where experienced, qualified personnel are asked to prepare resource estimates and considerations/assumptions. The cost estimator cites specific specialists involved, their qualifications, estimation assumptions, data, and the average response to support the estimate. This method is used when no structured estimating model can be applied (Garrett 2008).

3.6.8. Range Estimating Method

The Range Estimate increases the reliability of earlier estimates, by providing a cost range for a specific project element. This concept is founded in the PERT technique, where probabilistic project duration is obtained with the use of multiple durations defined for individual activity durations and then, in addition to the probabilistic project durations, a range of likely duration values is computed (Rad 2002).

Because the range estimate uses probabilistic elemental cost, it provides not only the statistically most likely WBS elemental cost but two others; the most pessimistic and most optimistic estimate. Using these three costs the most likely cost for the element or project can be determined.

Another approach based on the same information (i.e. the three values must be available for all elements of a fully developed WBS) is the addition of a random number generation tool to estimate project cost (Rad 2002).

This method has been shown to limit over-optimistic estimates, as it steers away from selecting "in the middle" values. The basis for the method is described by Equation 1.

Equation 1: Range Estimating, based on (Rad 2002)

1. **Elements**
   - Optimistic Cost, CO
   - Most Likely Cost, CM
   - Pessimistic Cost, CP
2. **Calculated Expected Cost of Each Activity**

   CE = (CO+4CM+CP)/6

   Standard Deviation = (CP-CO)/6

Note the distribution that is assumed is; Burt Pert, λ=4

Range Estimation can be used for fully developed WBSs, however the range estimating is more valuable when the WBS elements have not been fully developed (i.e. early in the project life and when cost of the elements is at the order-of-magnitude accuracy) (Rad 2002).

3.6.9. Summary

There are many Cost Estimating Methods recognised by theory, and some methods go by multiple names. In some cases the description and used depends on the cost estimate application and the industry it is being used in. The literature is clear on the basics methods that make up these methodologies.

The review has shown each Cost Estimating Method strength and weakness, as well as its appropriate application. The estimator must be familiar with these methods and able be to assess at what stage in the cost estimation process each method should be used.

The importance of having a WBS in place early in a projects development has been observed. Throughout the review of estimating methods, the reference to the WBS as a fundamental cost estimation tool was supported. It is clear that if a quality cost estimate is to be produce, then the WBS must be in place so that the project can be sufficiently documented.

3.7. Types of Cost

3.7.1. Direct Cost

Direct costs or prime costs, is in construction, cost of installed equipment, material and labor directly involved in the physical construction of the permanent facility (AACE 2005b).

Labor

This cost element is made from different categories of labor. Labor cost is typically defined as direct cost; it can be identified and allocated to a specific cost objective. Direct labor cost categories include engineering, manufacturing and service labor (Garrett 2008).

Material

Material cost is cost that is included in the contracted effort. Material cost generally includes raw material, parts, subassemblies, components and manufacturing supplies that become part of the product. Collateral cost (i.e. freight and insurance) can also be considered to be material cost. Material cost can be either direct or indirect; the difference is that direct material cost can be identified to the final cost objective. Indirect material cost can be identified to two or more final objectives or an intermediate cost objective (Garrett 2008).

Subcontractors

Subcontracted cost includes costs derived from major subcontracted work that is a part of the overall project. These costs are usually large, unusual or one-time costs that will benefit the proposed contract and cost objective (Garrett 2008).

Other Direct Cost ODCs can be cost such as *travel and living, construction equipment, overhead* and other *miscellaneous Cost.*

3.7.2. Indirect Cost

In construction, all cost that do not become a final part of the installation, but are required for the orderly completion of the installation and may include, but are not limited to, field administration, direct supervision, capital cost, startup cost, contractor's fees, insurance taxes and etc. (AACE 2005b).

Expense Salaries

Expense Salaries includes indirect employee salaries associated with the time spent performing expenses-related activities that are not specifically required for performance on contract (Garrett 2008).

General and Administrative (G&A) Cost

G&A are management, financial and other expenses related to the general management and administration of the business unit as a whole. G&A cost include salaries, staff services and, selling and marketing expenses (Garrett 2008).

Other costs of importance are *Fringe Expenses* and *Contract-Related Cost*.

3.8. Cost Estimate Classification

Due to the fact that Cost Estimates need to evolve with projects, one version of a cost estimate is usually not enough. A Cost Estimate needs to be created for each stage of the projects lifecycle up-to the point when the tender or execution stage is reached. However, it varies how theses project stages are defined and how many they are. Each firm and organization can have its own classification. Examples of common guidelines and standards are shown in Table 5, where the standards have been benchmarked to the classification given by AACE (2005a).

The classification system that AACE (2005a) proposes is only valid for cost estimates that are used for Engineering, Procurement, and Construction (EPC) work. The details of the AACE-Classification system are given in Table 4. The cost estimation stages that are used by AACE are defined further in Appendix V.

Table 4: Cost Estimation Classification Matrix, (AACE, 2005a).

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

Table 5: Comparison of Classification Practices, (AACE, 2005a).

AACE Classification Standard	ANSI Standard Z94.0	AACE Pre-1972	Association of Cost Engineers (UK) ACostE	Norwegian Project Management Association (NFP)	American Society of Professional Estimators (ASPE)
Class 5	Order of Magnitude Estimate -30/+50	Order of Magnitude Estimate	Order of Magnitude Estimate Class IV -30/+30	Concession Estimate Exploration Estimate Feasibility Estimate	Level 1
Class 4	Budget Estimate -15/+30	Study Estimate	Study Estimate Class III -20/+20	Authorization Estimate	Level 2
Class 3		Preliminary Estimate	Budget Estimate Class II -10/+10	Master Control Estimate	Level 3
Class 2	Definitive Estimate -5/+15	Definitive Estimate	Definitive Estimate Class I -5/+5	Current Control Estimate	Level 4
Class 1		Detailed Estimate			Level 5 Level 6

INCREASING PROJECT DEFINITION

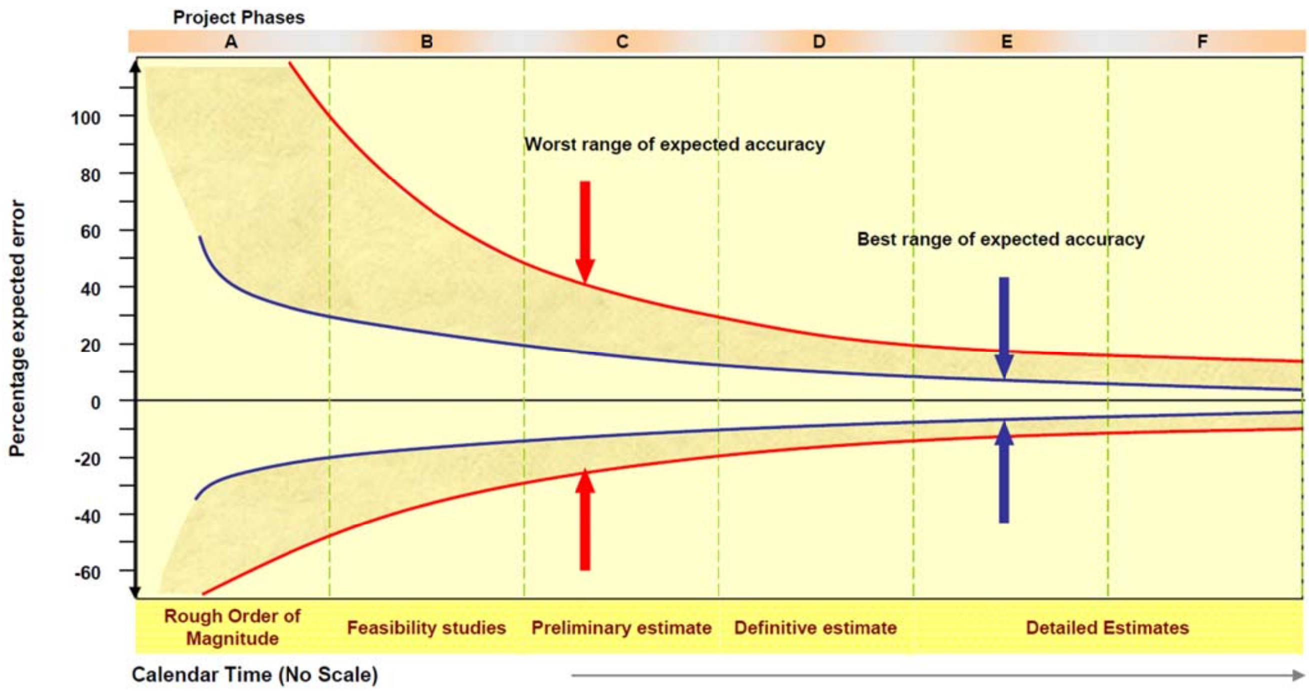


Figure 11: Types of Cost Estimates vs. Product Realisation (Roy 2005)

In respects to the AACE guidance, if they are to be applied, the quality and detail of data must be compatible to what is expected by AACE. Illustration of the project data and engineering deliverables for each of the five estimate classification levels is given in Table 6. The deliverables shown are common practice in the Process Industries (AACE, 2005a). Finally, the expected accuracy of estimation classes is illustrated as a function of time in Figure 11.

Table 6: Estimate Input Checklist and Maturity Matrix, (AACE, 2005a).

	ESTIMATE CLASSIFICATION				
General Project Data:	CLASS 5	CLASS 4	CLASS 3	CLASS 2	CLASS 1
Project Scope Description	General	Preliminary	Defined	Defined	Defined
Plant Production/Facility Capacity	Assumed	Preliminary	Defined	Defined	Defined
Plant Location	General	Approximate	Specific	Specific	Specific
Soils & Hydrology	None	Preliminary	Defined	Defined	Defined
Integrated Project Plan	None	Preliminary	Defined	Defined	Defined
Project Master Schedule	None	Preliminary	Defined	Defined	Defined
Escalation Strategy	None	Preliminary	Defined	Defined	Defined
Work Breakdown Structure	None	Preliminary	Defined	Defined	Defined
Project Code of Accounts	None	Preliminary	Defined	Defined	Defined
Contracting Strategy	Assumed	Assumed	Preliminary	Defined	Defined
Engineering Deliverables:					
Block Flow Diagrams	S/P	P/C	C	C	C
Plot Plans		S	P/C	C	C
Process Flow Diagrams (PFDs)		S/P	P/C	C	C
Utility Flow Diagrams (UFDs)		S/P	P/C	C	C
Piping & Instrument Diagrams (P&IDs)		S	P/C	C	C
Heat & Material Balances		S	P/C	C	C
Process Equipment List		S/P	P/C	C	C
Utility Equipment List		S/P	P/C	C	C
Electrical One-Line Drawings		S/P	P/C	C	C
Specifications & Datasheets		S	P/C	C	C
General Equipment Arrangement Drawings		S	P/C	C	C
Spare Parts Listings			S/P	P	C
Mechanical Discipline Drawings			S	P	P/C
Electrical Discipline Drawings			S	P	P/C
Instrumentation/Control System Discipline Drawings			S	P	P/C
Civil/Structural/Site Discipline Drawings			S	P	P/C

- Note (blank): development of the deliverable has not begun.
- Started (S): work on the deliverable has begun. Development is typically limited to sketches, rough outlines, or similar levels of early completion.
- Preliminary (P): work on the deliverable is advanced. Interim, cross-functional reviews usually been conducted. Development may be near completion except for final reviews approvals.
- Complete (C): the deliverable has been reviewed and approved as appropriate.

3.9. Cost Contingency

Contingency is added to the estimates to counter risk and uncertainty, it is one method of dealing with the unknown factors that are a part of any project. AACE (2005b) defines it as:

"An amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, and/or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs".

A cost that cannot be accounted for when the estimate is made is met by the contingency. Approaches using a "static" contingency value are not recommended. The contingency needed should be a function of the desired probability that the final project cost will not overrun the estimate. If it is likely that cost will exceed the estimate, then the contingency should be high. Arbitrarily assuming a constant value of 10% contingency, is not logical (AACE, 2005b).

In engineering project two types of contingencies are used to compensate for different types of uncertainties; they are Project Contingency and Process Contingency (Parsons, 1999).

Project Contingency *is based on the degree of project definition available at the time of making the estimate. This type of contingency covers expected omissions and unforeseen cost caused by lack of complete engineering. Project contingency compensates for the inherent estimate inaccuracy associated with each stage of a project.*

Process Contingency *is based on the degree of uncertainty caused by use of new technology. It is an effort to quantify the uncertainty in performance because of limited technical data. For those technical areas with greater risk, the process contingency is designed to compensate for the inherently greater inaccuracy associated with the cost elements. Examples of Process Contingencies are illustrated in Table 7.*

Table 7. Process Contingency: Comparison of Estimate Classes for Various Situations, (Parsons, 1999).

State of Development	AACE	NASA	EPRI
New Design beyond SOTA	40% +	50%	40% +
New Design within SOTA	n/a	35%	n/a
New Design Hardware through PDR	30 - 70%	25%	30-70%
New Design Hardware through CDR	20-35%	20%	20-35%
Modifications Required to Existing Hardware	5-20%	15%	5-20%
No Modifications Required	0-10%	10%	0-10%

Note: State of the Art (SOTA), Conceptual Design Report (CDR), and Preliminary Design Report (PDR).

It is important to point out that usually cost contingency excludes (AACE, 2005b):

- Major scope change
- Extraordinary events
- Management reserves
- Escalations and currency effects

The terms *contingency* and *client-reserve* are often confused and used to describe the same buffer fund. The term contingency is used for funds that are added to estimates to compensate for cost estimate inaccuracies resulting from lack of project details. The client-reserve refers to those funds that are set aside to subsidize the cost change caused by change in client objectives (Rad 2002).

Contingency funds are not intended to cover cost of errors in design, implementation, omission, and miscalculation in estimating. Costs that arise out of such issues should be address as part of renegotiation for new budget or new contract, and etc. The client-reserve refers to funds that the client set asides as part of the organizational budget, but is apart from the contract budget, and is intended to accommodate project cost variations caused by change in project environment or objectives (Rad 2002).

3.9.1. Cost Contingencies Recommended Practice

According to Parsons (1999) research on AACE-guidelines, it is favorable to apply contingency analysis on each element of the WBS. By using this method it is possible to account for uncertainties associated with different phases of the project and use compensation of project and process contingencies. The application of the method is simple, the cost estimator decides the Total Estimated Cost (TEC) for each element as follows:

TEC = Estimated Cost + Total Contingency Allowance

Total Contingency Allowance = Project Contingency + Process Contingency

The TEC for the total project is determined by summing the TECs for all WBS elements.

Therefore, if a new design with a PDR is under consideration, the Recommended Contingency Allowance (RCA) for that project at Construction-stage (i.e. Class I, see Table 4 and Table 7 in connection to example) is:

- Design Complete: 50-100% (percentage of project definition)
  - Project Contingency: ± 5% *(based on P50[8])*
  - Process Contingency: ± 30-70%
  - Total RCA: ± 35-75%

It is important to stress that this would only be the RCA for one WBS element. The wide range reflects the uncertainty that follows the use of new technologies.

[8] 50% level of confidence

3.9.2. Standard Deviation as Contingency

Rothwell (2004) proposes the use of standard deviation to estimate the contingency for a project. Two distributions are defined for governing the needed contingency, (1) normally distributed cost estimate and (2) non-symmetric distributed. The normal distribution is shown in Figure 12, and an example of a non-symmetric distribution is shown in Figure 13.

Based on this method the standard deviation can be determined either by considering the accuracy and confidence in the cost estimate based on expert judgment, or using statistical or Monte-Carlo techniques. It is also possible to use software like @Risk (an EXCEL add-in). The standard deviation technique gives the estimator a method for comparing values for contingency with expectation regarding accuracy and confidence of the cost estimate. This method allows for easy comparison of cost contingency percentages with the probability distribution of the cost estimate (Rothwell 2004).

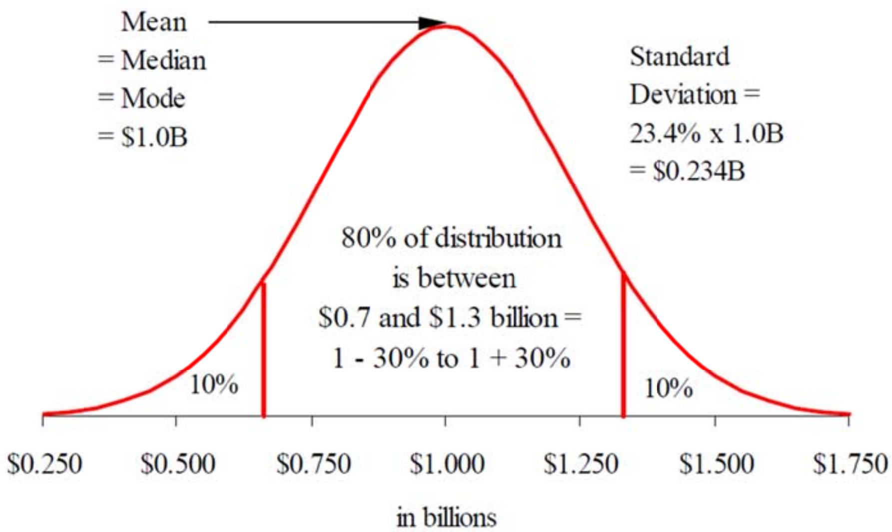


Figure 12: Cost estimate with a normal distribution, (Rothwell 2004).

For example if cost estimate is normally distributed the contingency level can be found as:

X : level of accuracy

Z : Z-value, depends on confidence level — And we have: $\sigma = \frac{X}{Z}$

σ : Standard deviation

Using normal distribution for *Finalized Estimate* with X= ±10% and 80% confidence. The contingency is calculated as:

$$\sigma = \frac{X}{Z} = \frac{10\%}{1.28} = 7.8\%$$

This formula can be used for all the cost estimate stages since normal distribution is assumed.

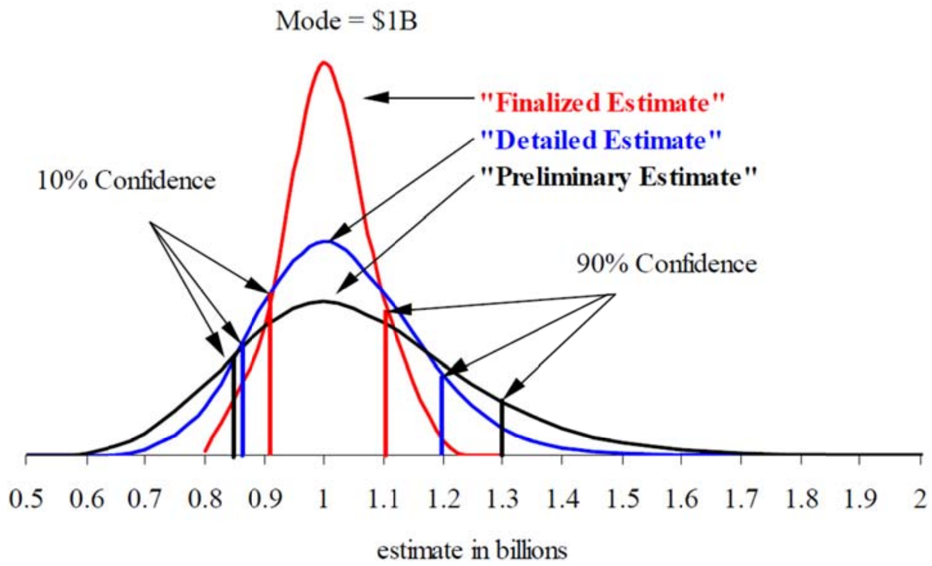


Figure 13: Lognormal densities for three project stage estimates, (Rothwell 2004).

The non-symmetric cost estimation is favourable because the low range is less, in absolute value, than the high range. The reason for this is that final cost is often higher than the estimates indicates, and there is no possibility that the final cost will ever be less than zero (which is a possibility when using the normal distribution). Based on this the non-symmetric distribution is more realistic for many cost estimates (Rothwell 2004).

Using the example given by Rothwell (2004), the lognormal cumulative distribution for the project stage estimates is found, see Figure 14. Then, the mode is set equal to 1.0 by dividing the cost distribution by the mode. The standard deviation and range can be found for confidence level of 80%, as is illustrated in Table 3.

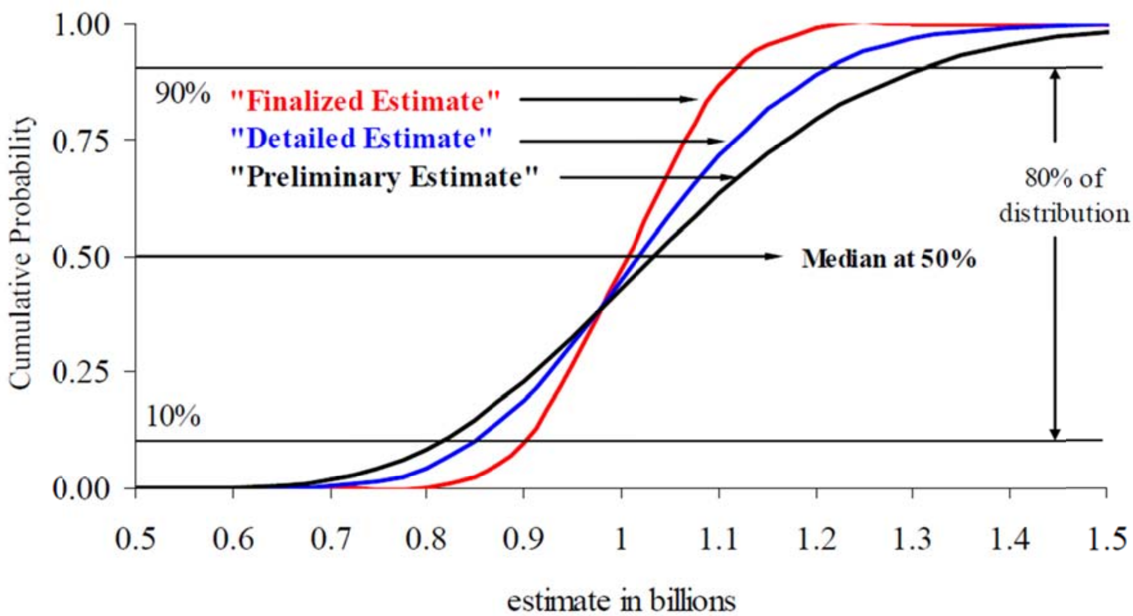


Figure 14: Lognormal Cumulative Distributions for Three Project Stage Estimates, (Rothwell 2004).

Table 8: Medians, Means, and Standard Deviations for Lognormal Estimates, (Rothwell, 2004).

	Mode	Median	Mean	Variance	Standard Deviation	80% Confidence
Preliminary Estimate	1.000	1.033	1.049	3.4%	18.3%	-18% to +31%
Detailed Estimate	1.000	1.017	1.025	1.7%	13.1%	-14% to +20%
Finalized Estimate	1.000	1.005	1.008	0.5%	7.0%	-8% to +10%

Table 8 shows that by setting the contingency level equal to the standard deviation, the contingency for a Finalized Estimate with an 80% confidence interval -8% and +10% would be 7%.

3.9.3. EIA Approach to Cost Contingency

The EIA in its report *Assumptions to the Annual Energy Outlook 2010*, recommends a division of the cost contingency. EIA (2010) uses two Contingency Factors the Project Contingency Factor (PCF) and Technological Optimism Factor (TOF). For the PCF, The EIA (2010) indicates, that contingency allowance is defined by the AACE as:

"specific provision for unforeseeable elements if costs within a defined project scope; particularly important where previous experience has shown that unforeseeable events which will increase costs are likely to occur".

However, the TOF is defined as:

"The technological optimism factor is applied to the first four units of a new, unproven design. It reflects the demonstrated tendency to underestimate actual costs for a first-of-a-kind unit". EIA (2010).

Thus, based on the EIA approach the contingency multiplier is the sum of these two factors. This is a similar to what the AACE-guide described in section 3.9.1.

3.9.4. Summary

Based on the literature reviewed it can be stated that the preferred method of applying contingency is element based, and then splitting contingency into two factors (e.g. project and process factor) to depict the uncertainty of cost and required material. How the contingency percentage is then selected is more difficult to state, the literature points to standards and guidelines.

However, more prestige practitioners recommend statistical and mathematical analysis for selecting the contingency level, namely; Monte Carlo Simulation (Al-Bahar, 1988), Artificial Neural Network (ANN) (Chen and Hartman 2000), Belief Network (Khalafallh et.al. 2002) and Linear Regression (Sonmez et.al. 2007). Other views point to the practitioner's limited knowledge of statistical analysis and suggest a form of Fuzzy Expert System (Idrus et.al. 2010). This approach is based on expert judgment, but uses a structured approach for managing and estimating qualitative factors.

Ultimately, the approach selected for contingency must take into account the available information that is to be used for the estimate. Therefore, each Cost Estimator needs to consider the environment he is working in and what data he is using (i.e. qualitative or quantitative). Also, contingency should be considered for each element of the WBS.

3.10. Conclusion

The review of literature was mainly based on solid well established knowledge, which has been tuned and developed over the decades. All the resources that were used are new and up to date in respects to theory and publications. Estimation of cost is a process that requires much of documentation. These inputs are in most cases outputs from other process that must have been started or finished prior to the estimation of cost.

This review has documented what can be considered to be current best practice regarding the methodological approach for performing a cost estimate. As has been shown it requires much preparation and work. If a company or an agency wants to be able to meet the requirements of best practice it is likely that it needs a state-of-the-art project management framework, along with capable project management professionals.

It is clear that there are many approaches available when it comes to choosing a methodology for estimating cost. The route taken depends on the focus of the organization and its projects. In some cases the methods used can vary between projects as not all projects require the same accuracy, and more importantly, available information regarding a project differs much from one project to another.

The importance of the WBS as a management tool was illustrated, in fact all the literature reviewed recognized it as a fundamental part of the project management process. The WBS provides a unified view of project data, in addition to integrating cost and schedule control.

Cost estimates created by Cost Engineers applying the appropriate cost estimating methods and documentation described in this chapter will produce quality estimates. The use of Risk Analysis and contingency, based on the WBS gives the project stakeholders the best possible view of the likely cost of a project.

4. Landsvirkjun Cost Model Case Study

4.1. Data Gathering

It was clear at the outset that any research into cost estimation practices at Landsvirkjun would be dependent upon data made available by the company itself. Landsvirkjun provided a descriptive document for their cost model; in this document all formulas and cost relationships are given (Landsvirkjun 2006). However, this document does not give account of how the model that is describes is applied. Therefore the guidance of Mannvit Engineering, a company that works regularly with the model was sought (Júlíusson 2010).

4.2. Basis of Landsvirkjun Cost Model

The Landsvirkjun Cost Model is based on informal Public–Private Partnership (PPP) of the governmental company Landsvirkjun and the private businesses Almenna Verkfræðistofan, Mannvit and VERKÍS. The first edition of the model was published in 1990 and it has been updated five times since then (twice in 1991 and once in the years 1993, 1996 and 2007).

The WBS that is proposed forms the basis of the cost breakup of the project. Therefore, the project WBS must be unambiguous, provide sufficient amount of detail and traceability. According to Landsvirkjun (2006), the breakup of projects and project elements is divided up into four stages, see Figure 15.

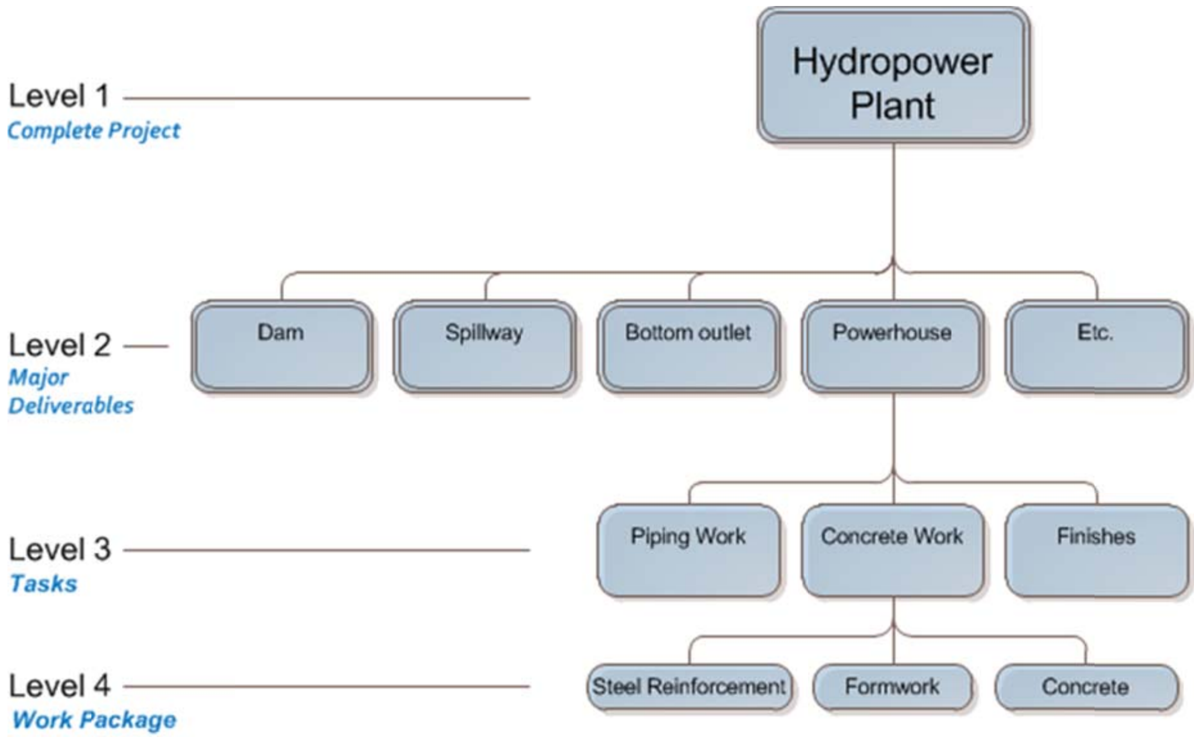


Figure 15: Landsvirkjun Example WBS (Landsvirkjun 2006).

4.3. Cost Estimation Methodology

The Landsvirkjun Cost Estimation Model is made from two parts, the first part *Kolla 5.0a* (i.e. the unit price part of the model) is a parametric model. *Kolla 5.0a* uses CER to create formulas to estimate cost. *Kolla 5.0a* hold a large registry of task, and each task is composed of independent elements. The fundamental independent elements are labor, material and machinery costs (Landsvirkjun 2006).

Six project phases are defined in the Landvirkjun Cost Model:

- Feasibility (8)
- Preliminary design (7)
- Project design (6)
- Tender design (5)
- Contracting (4)
- Project closure (0)

Each phase is given a number ranging from zero up-to eight. To add to the otherwise clear definition of the project phases, a project can be between phases (i.e. having a number like 7.6).

In the task registry, efficiency of labor and machinery is estimated, along with the material cost (if appropriate). The task registry uses this information to estimate the cost of using e.g. dynamite for rock blasting and pushing the rock with a bulldozer, this would include:

a) Cost of work = Operator (bulldozer) [ISK/m^3] + Specialists (dynamite) [ISK /m^3]
b) Cost of machinery = bulldozer (O&M) [ISK /m^3] + drill (O&M) [ISK /m^3]
c) Cost of material = Rock (free) + dynamite and charge [ISK /m^3]

The summary of factors a, b and c multiplied by the estimated amount of rock (m^3) gives the total cost of this task. *Kolla 5.0a* holds the unit costs of the independent elements; the only input necessary is the quantity estimate. *Kolla 5.0a* unit costs information is based on historical and supplier data (Landsvirkjun 2006).

The second part, making-up the Landsvirkjun Cost Estimation Model is the quantity estimate. The methodology applied in estimating quantities depends on the firm performing the estimate; each firm uses its own preferred quantity estimate method. Early quantity estimates when limited design data is available can be based on model outputs or Expert Judgment.

However, as design progresses and more information becomes available the quantity estimates become progressively more dominated by the application of the Engineering Build-up Method. At the later stages some minor aspects of the projects may have to be estimated by use of Expert Judgment since project data is rarely exhaustive, still the focus is many on quantity take-offs from drawings (Júlíusson 2010).

The unit pricing model is well defined and clearly set-up. Precondition regarding the CERs are described in detail in Landsvirkjun's Cost Estimation manuals. The quantity model(s) are not coordinated by Landvirkjun therefore each firm applies its own methodology (e.g. Parametric, Analogy or Expert Judgment method). Research into the details of the quantity models and how the methodologies are applied are outside the scope of this research. In Figure 16 the general structure of the Landsvirkjun Cost Estimation Model is illustrated.

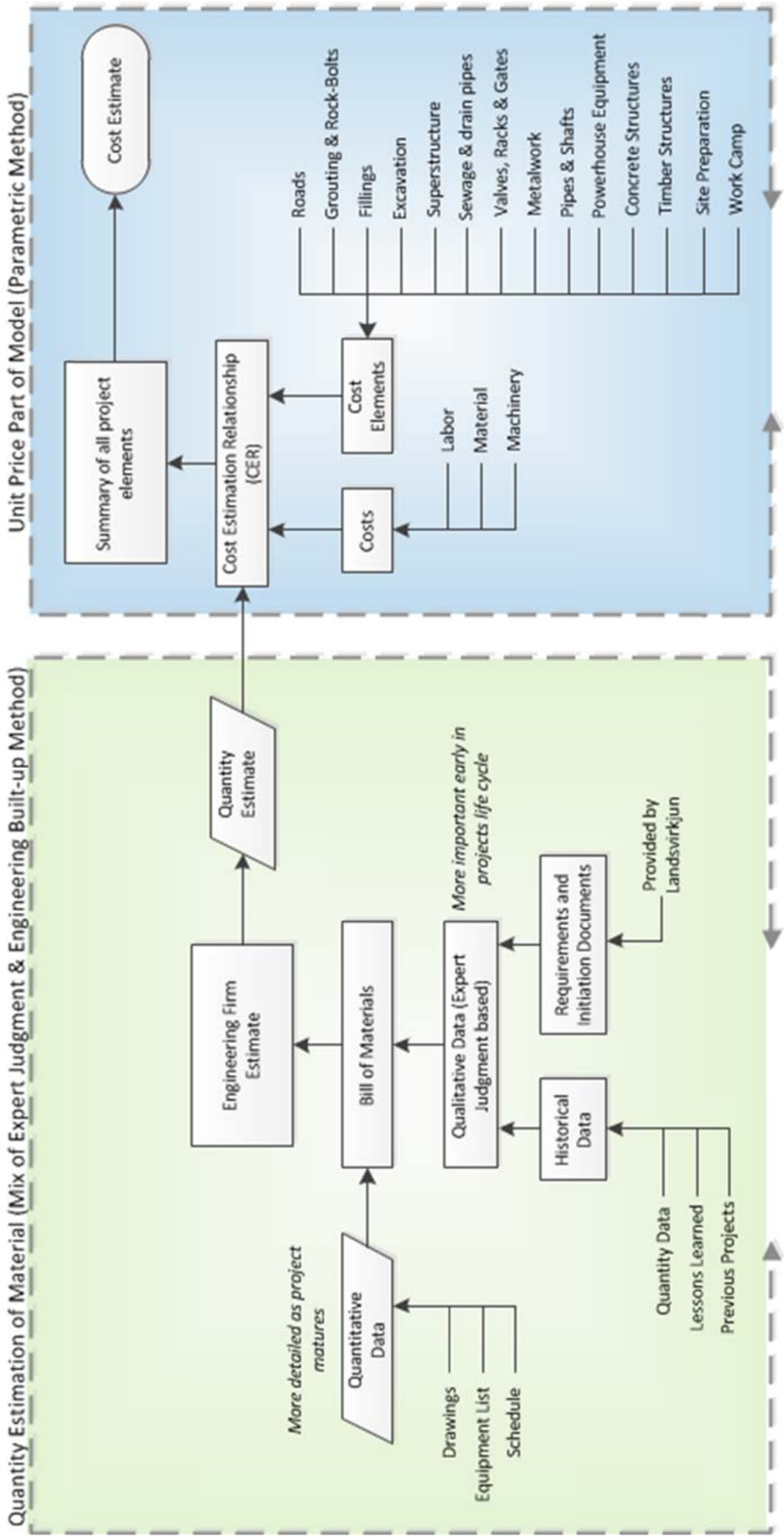


Figure 16: Structure of Landsvirkjun's Cost Model (Landsvirkjun 2006, Júlíusson 2010)

4.4. Contingency

The contingency, as described by literature does not stand for the same thing as is discussed in the guidance for the cost estimator. There it is called unforeseen *cost* and defined as:

The unforeseen cost is intended to cover bias in estimation. Also, the unforeseen cost covers additional work and unknown site conditions (Landsvirkjun 2006).

This statement indicated a blurry line between contingency and unforeseen cost. According to Júlíusson (2010), contingency is not covered in Landsvirkjun's Cost Model itself. The model calculates the total cost of the project without contingency, but includes unforeseen cost that it limited to the contractors work. This unforeseen contractors cost can be estimated by the use of a predefined formula that is based on the previously mentioned project design level. This unforeseen cost formula, therefore, gives a "static" value (i.e. does not consider probability or risk) (Landsvirkjun 2006).

Though the model does not include the contingency by default, it can be added to the cost models estimate manually (i.e. the output calculations would be manipulated). Such procedures are not described in Landsvirkjun's guidance. However the guide leaves room for interpretation, this is therefore left up to the estimator.

4.5. What is Being Estimated

It is important to clarify what type of cost is estimated by the Landsvirkjun Cost Model. The previous chapters have defined two types of cost; direct and indirect cost. The Model takes both types into consideration (Landsvirkjun 2006).

The indirect cost is split up into preparation cost of contractor, Site cost of contractor, unforeseen cost i.e. additional work not directly connected to project and other contractor costs. The indirect costs is estimated based on CERs, where the location of the project is connected to start-up, traveling & living, management, financial and other expenses related to the general management and administration (Landsvirkjun 2006).

The direct cost is also described by CERs that have been defined in the parametric model. Figure 16 illustrates that the direct cost is based on labor, machinery and material. The summary of the direct and indirect cost represents the total estimated cost. In addition to cost the model can estimate time durations and resource requirements (material, equipment and labor) (Júlíusson 2010).

4.6. Conclusion

Based on the information available it is clear that the cost model itself is well defined (i.e. CERs). Guidance regarding other aspects of the model, such estimating risk and adding contingency were not discussed. A classification system for estimates does not seem to be in place similar as was discussed in section 3.8. It was concluded that the model is in fact consisting of two parts. One covering the CERs and calculations of cost, the other focused on providing quantity estimates. Finally, the WBS used by Landsvirkjun to define its projects was described and illustrated in a figure.

5. Landsvirkjun Case Study: Analysis and results

5.1. Introduction

Landsvirkjun: Analysis and Results is intended to draw together and conclude the main subjects that where identified in the research and need further attention. This is, as previously stated based on the comparison of best practice and current practice.

5.2. Presentations of results

5.2.1. New Proposal for the WBS

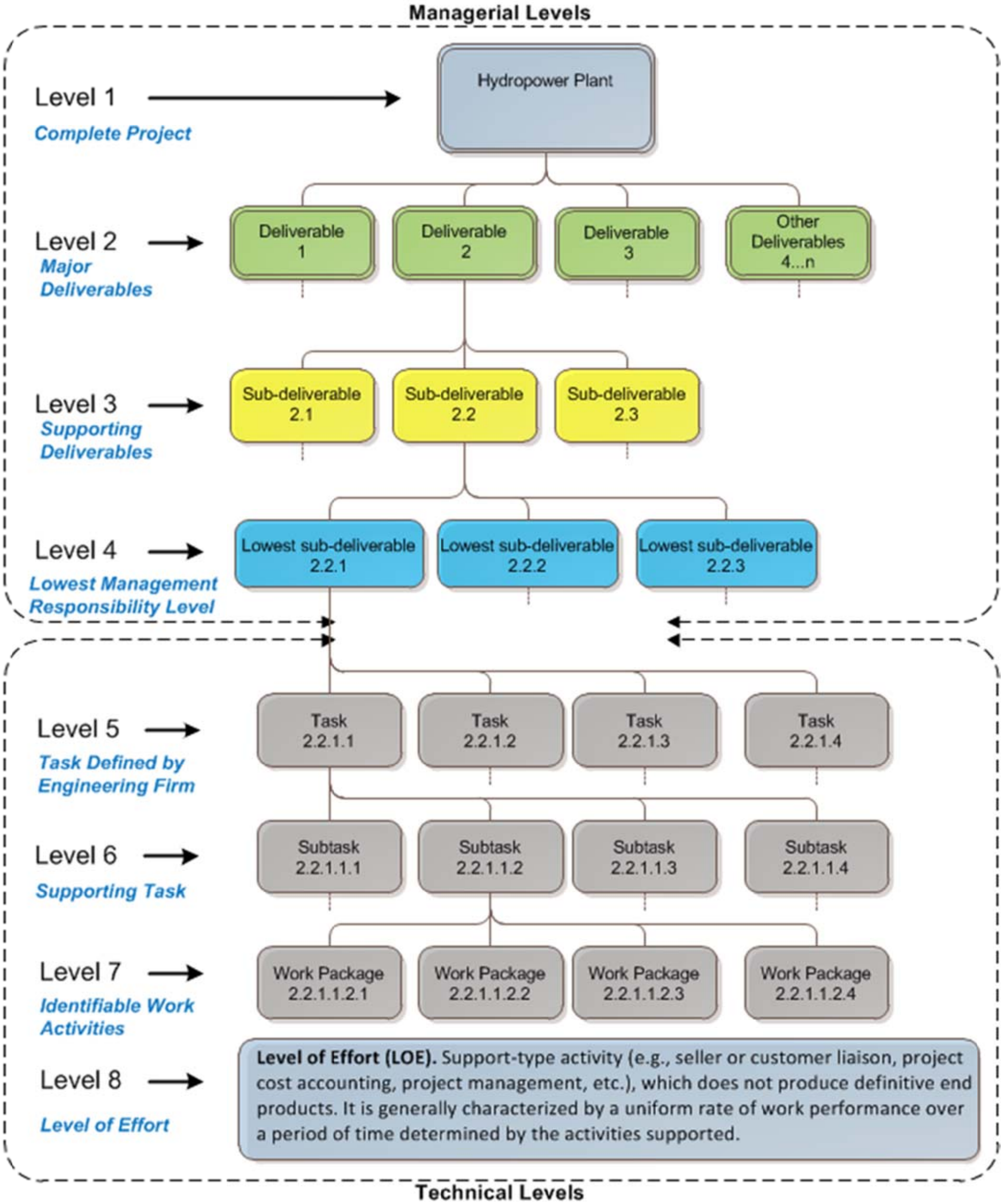
The State of the Art Review shows that the WBS is a fundamental tool for defining scope and breaking-up a project so that 100% of the required project work is documented. The application of the WBS leads to the creation of the time schedule, resource and labor requirements. Cost Accounting and Estimating are also directly connected to the WBS.

It is clear that for a large project (e.g. a hydropower project), it is necessary to have a complete and detailed WBS in place that secures the high precision for defining the project scope. Therefore, a more detailed WBS is proposed for the Landsvirkjun Cost Model, see Figure 17.

As is illustrated in Figure 17, the proposed WBS includes eight levels (i.e. seven main WBS-levels in addition to one level reserved for Level of Effort (LOE)). Levels one to four are Managerial Levels, that is, they are defined by Landsvirkjun's project team, and illustrate the project and its deliverables. The Managerial Levels can also be used to map Project Management related work and milestones. The remaining levels are Technical Levels and are developed by the engineering firm (i.e. the designers). The 100% rule applies for both the Managerial and Technical Levels.

Cost Accounts need to be assigned to the WBS to secure the connection to the Cost Management and the assignment of organizational responsibility for project sections. The Cost Accounts should be reviewed in connection to the OBS and CBS. The review of theses factor are outside the scope of this research.

Landsvirkjun's hydropower projects include similar deliverables; therefore, a standardized WBS is applicable for Landsvirkjun hydropower projects. Standardization of the WBS secures repeatability of procedures, benchmarking of project and clear documentation of project processes. This, along with the creation of historical data, will allow future project managers to learn from projects and hopefully improve upon them in the future.



Note: The WBS is illustrative only. It is not intended to represent the full project scope of any specific project, nor to imply that this is the only way to organize a WBS.

Figure 17: WBS Framework, adopted from (PMI 2006, Kerzner 2009, Gray & Larson 2008)

5.2.2. Risk Management

Risk Management is a fundamental part in the management of projects, and pinnacle in relation to estimation of cost. The correct application of Risk Management gives the project stakeholders an overview of likely risks and otherwise hidden costs. For the cost estimator, information outputs from Project Risk Management enables him to asses with more detail the project's cost.

The review of Landsvirkjun's Cost Model guide did not reveal a structured approach to Risk Management (Landsvirkjun 2006). This is a major concern in respects to the accuracy of the model. Unclear management of risk further increases the possibility of risk materializing in the Execution Stage of the project. Such risks cost projects substantially more than if the risk had been identified early in the Defining/Planning Stage.

Risk is likely estimated by some means for Landsvirkjun's projects (probably by the engineering firms). Landsvirkjun must define how it wants the Risk Management to be performed. This definition, however, should be concerned with what Landsvirkjun's requires to be analyzed and to what extent (i.e. what quality is expected and what documents should be produced). The technicalities and selections of risk analysis tools should be left to the engineering firms.

5.2.3. Cost Estimate Classifications

It has been shown that Landsvirkjun uses six phases for locating project in the construction life-cycle, as previously discussed. Theses phases are not suitable for using in connection to cost estimations. Landsvirkjun should make the effort to define such a cost estimate classification system. Also, requirements of the estimate classes should be clearly documented. A suggestion of such a classification system, based on the literature review is illustrated in Table 9.

Table 9: Suggestion of New Cost Estimate Classification for Landsvirkjun.

Estimate Class	Level of Project Definition [a]	End Usage [b]	Methodology [c]	Expected Accuracy Range[d]
Order of Magnitude	0% to 2%	Concept Screening	Analogy or Expert Judgment	L: -20% to -50% H: +30% to +100%
Feasibility	1% to 15%	Study of Feasibility	Parametric Model or Expert Judgment	L: -15% to -30% H: +20% to +50%
Preliminary design	10% to 40%	Budget	Parametric Model, Expert Judgment or Engineer Built-up	L: -10% to -20% H: +10% to +30%
Tender design	30% to 70%	Control	Parametric Model or Engineer Built-up	L: -5% to -15% H: +5% to +20%
Contracting	50% to 100%	Bid/Tender	Parametric Model or Engineer Built-up	L: -3% to -10% H: +3% to +15%

Notes: **[a]** Expressed as % of completed definition. **[b]** Typical purpose of estimate. **[c]** Typical estimation method. **[d]** Typical variation in low and high ranges (contingency typically at 50% level of confidence).

5.2.4. Clarifying the Contingency

Based on the Landsvirkjun Cost Model Case Study it is clear that the application of cost contingencies need to be defined. The contingency allowance with respects to estimation classes must be selected.

It is common to use standards or guidelines to estimate the cost contingency. In these cases a specific amount of cost contingency is recommended for specific classes of cost estimates. The organizations that make these standards base these ranges on accumulated knowledge that has been obtained over time; their guidance should not be adopted blindly. All guidance and standards should be weighed and adjusted with the help of Expert Judgment. Landsvirkjun can also make its own guidelines or (as has been implied) simply adopt an international standard.

The application of the contingency, based on the State of the Art Review suggests that the contingency should be applied in connection to the WBS. Standards or guidelines should be used along with Expert Judgment where quantitative data cannot be applied. However, when quantitative data exist statistical and mathematical analysis should be used.

Finally, contingency and its connection to risk in the Landsvirkjun Cost Model is poorly defined and need more attention. The division of project and process contingency need to be addressed as well as the distinction between contingency, client reserve and new/additional work.

5.3. Conclusion

Landvirkjun needs to implement as standard WBS for it hydropower projects. Such a tool gives the company a much better overview of it projects and deliverables. The WBS also puts pressure on the engineering firms to document with clarity what work they need to have performed. Cost and scheduling of project becomes easier, and the basis for Earned Value Management automatically becomes an integrated part of all projects. And most importantly the WBS improves the flow of information between project stakeholders.

A company like Landvirkjun should have a cost estimation classification system in place. It should be clear what each estimate represented and how accurate they are expected to be. Also the information used to prepare the estimates should be standardized, to secure the quality of estimates. Having compatible cost estimates makes benchmarking simple and increases the possibility for identifying areas of improvements.

Risk Management needs to be reviewed, but as with the other analysis, Landsvirkjun should state how detailed such an analysis should be. It should be possible to compare risk analysis and see what factors are constantly causing the most problems. The same can be said about the contingency; however it is clear that it should be based on the WBS elements.

Finally the question must be raised, is it acceptable to Landsvirkjun that it only requires the calculations of unit cost estimates to be compatible?

6. Small Hydropower Plants Case Study

This case study is intended to review and document up-to-date theory available about Small Hydropower plants. It is necessary to study the definition that exist regarding small hydro and not simply adopt local practice. Accepting local standard and practice can be considered sufficient in connection to local studies, but for a masters-research a scientific approach must be applied.

Also, cost estimation approaches need to be intended specifically for a certain type of projects. The projects that are considered for the EF-Project, which this case study is intended to support, are of that nature (i.e. small hydropower plants).

As has been stated previously this research is aimed at defining the correct methodology that should be used for estimating cost, and therefore not the specifics and details of calculations. Still for the purposes of this case study the major components of cost need to be identified. The detailed analysis of formulas and how they are built up is outside the scope of this research. Also, any formulas and assumptions would need to be based on historical data that had been gather and analyzed, (no such data was found for this research).

6.1. Definition of Small Hydropower Plants

It is important to get a clear view of what the phrase Small Hydropower Plant (SHP) means. The definition of a SHP varies much between countries. Hydropower plants are commonly classified based on:

- Design Capacity (kW installed capacity)
- Design Head
- Design Type (layout)
- Type of Supply (grid type or destination of supply)

The following sub-sections focus on providing a clear picture of what is meant by SHP. It is fundamental that the classification of small hydropower plants is clear, since any data gathering and processing will take this into consideration. This directly affects the creation of historical data, which is the foundation of any cost estimate. Regarding the *type of supply*, this subject will not be discussed in detail, as it is self-explanatory.

6.1.1. Design Capacity

In Table 10, examples of station capacity for SHP are given (The full listing of the various definitions of Small hydropower Plants found is given in Appendix VI).

Table 10: Small Hydropower Plants Definitions (Varun 2008, Kumar 2008, AGMHP2008, ESHA 2004)

Country	Power (MW)
Sweden	< 1.5
Italy	< 3
UK(NFFO[9])	< 5
UNIDO[10]	< 10
UNIPEDE[11]	< 10
ESHA[12]	< 10
Portugal	< 10
Ireland	< 10
Spain	< 10
AGMHP[13]	< 10
Belgium	< 10
Greece	< 10
France	< 12

Table 10, indicates a tendency towards 10 MW being set as the upper limit for installed capacity of SHP in the European Union (ESHA 2004).

The definitions in Table 10 are not compatible with what is commonly considered to be SHP in Iceland. In Table 11, an example of an Icelandic definition of a SHP is given as well as a comparison to India and Germany.

Table 11: Classification of Small Hydropower (Varun 2008, AGMHP 2008, Mannvit 2010)

Country	Pico-Hydropower	Micro-Hydropower	Mini-Hydropower (MHP)	Small-Hydropower (SHP)	Full scale (large) Hydropower
Iceland	X	<100 kW	100 – 300 kW	**300 – 1000 kW**	> 1 MW
Germany	<500W	0.5 – 100 kW	**100 – 1000 kW**	1 – 10 MW	> 10 MW
India	X	<100 kW	**101 – 2000 kW**	2.1 – 25 MW	> 25 MW

[9] The Non-Fossil Fuel Obligation
[10] United Nations Industrial Development Organization
[11] International Union of Producers and Distributors of Electricity
[12] European Small Hydro Association
[13] ASEAN-German Mini Hydro Project

Based on the review performed in this section it is clear that what is generally considered to be a SHP in Iceland is regarded as MHP in other countries. Also, the commonly used definition if a SHP in Iceland is 1/10 of what is commonly being considered to be SHP in many EU-countries. For the purposes of this research any scheme with an installed capacity of 1 MW or less will be considered as SHP.

6.1.2. Design Head

In Table 12, three classifications for SHP head[14] are illustrated. In connection to head it has been concluded by Aggidis et al. (2010) and Jones (1988) that a head lower than two meter is usually not economical and therefore not considered as a suitable hydropower project.

Table 12: Head Classifications (Mannvit 2010, AGMHP 2008, BHA 2005, ESHA 2004)

Classification	ESHA	Mannvit Engineering	AGMHP	BHA[15]
High head	>100 m	> 250 m	> 50 m	> 50 m
Medium head	30 – 100 m	50 – 250 m	15 – 50 m	10 – 50 m
Low head	2 – 30 m	< 50 m	< 15 m	<10 m

Based on the review in this section it is clear that it is difficult to state how head should be classified in connection to SHP. Since the EF-Project is concerned only with SHP-Projects in Iceland the definition given by Mannvit Engineering is adopted. However it is pointed out that German and UK literature suggest that these values be much lower (AGMHP 2008, BHA 2005).

6.1.3. Design Type & Site Layouts

For clarification purposes this section will be split into two sections, first the design type and then the site layouts of hydropower plants.

6.1.3.1. Design Type

The design type refers to the main two classifications of hydropower plants. Schematics along with the main components of a hydro system are illustrated in Figure 18 and Figure 19. The definitions of these two design types are given here below:

Storage plants—these plants have enough storage capacity to off-set seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year. Large dams can store several years' worth of water (Green 2010).

Run-of-river plants—these plants use little, if any, stored water to provide water flow through the turbines. Although some plants store a day or weeks' worth of water, weather changes—especially seasonal changes—cause run-of-river plants to experience significant fluctuations in power output (Green 2010).

[14] **Net Head**: Normally used in context of head availability to turbine. It is equal to the *gross head* minus hydraulic losses in the waterways as the water passes from headwater to tailwater (ASCE 1989)

[15] British Hydropower Association

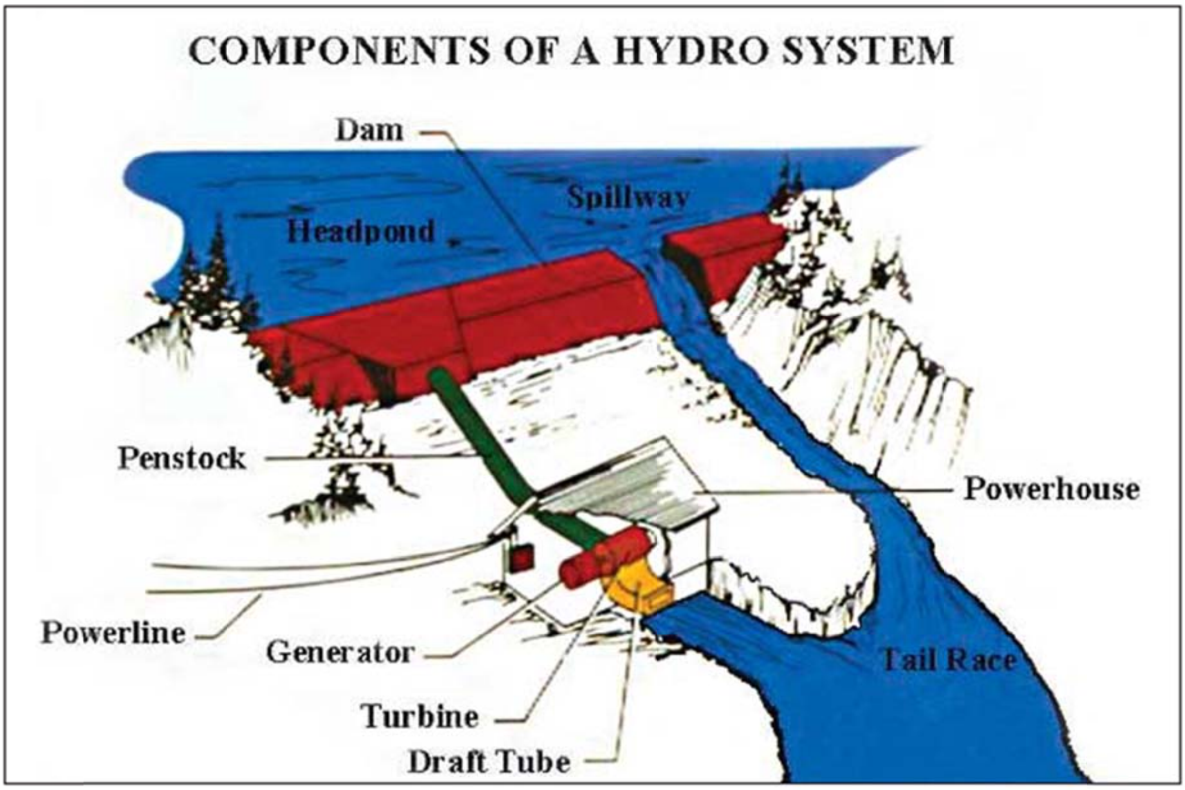


Figure 18: Storage Plant (RETScreen 2004)

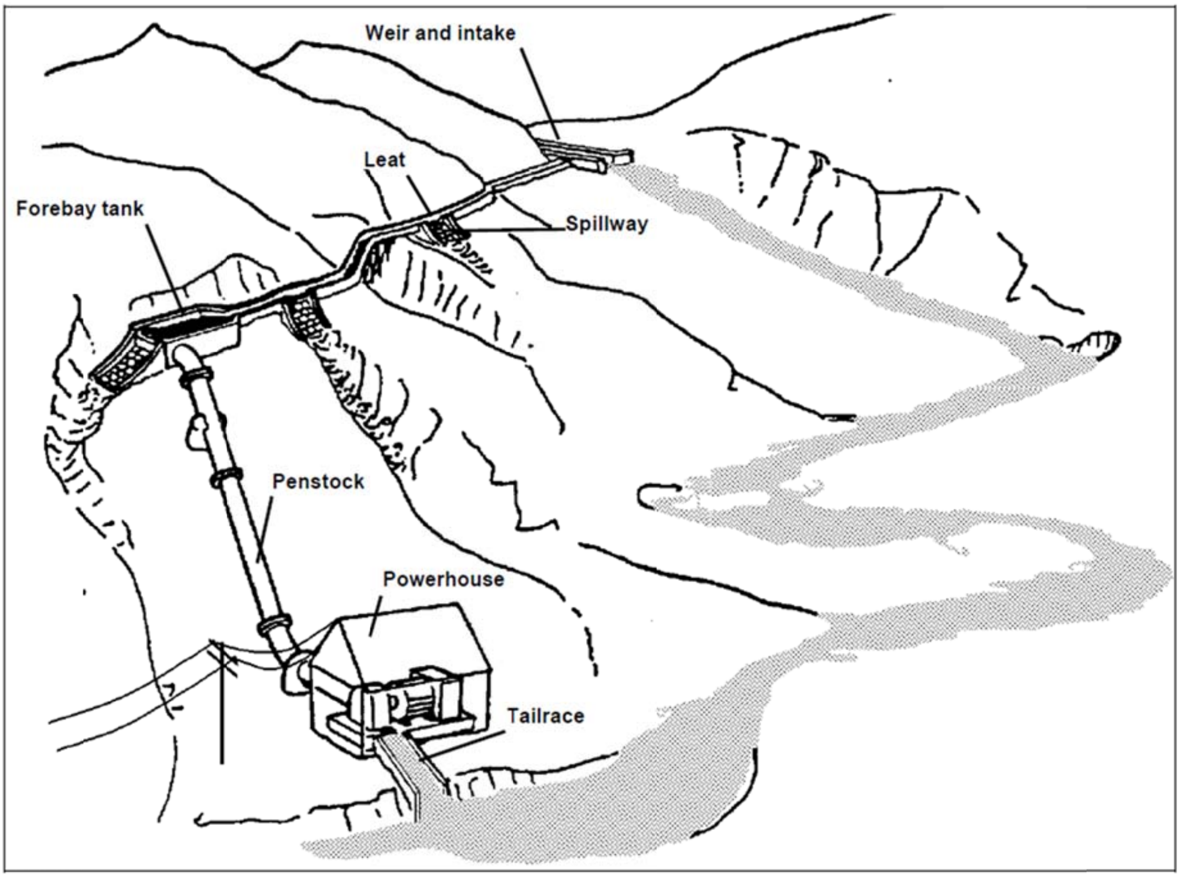
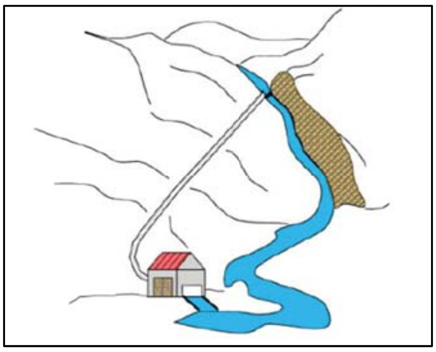


Figure 19: Run-of-River Plant (BHA 2005)

6.1.3.2. Site Layout

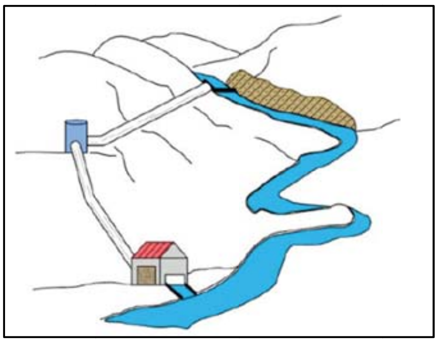
In the previous section the two design types were defined, however the site layout must be considered as well. For the purpose of defining the appropriate approach to site layout, three sources the Mannvit (2010), The Jones Report and BHA will be compared. This comparison is general in nature as the detail descriptions of the site layouts can be extensive.

Mannvit Engineering Site Layouts (Mannvit 2010)



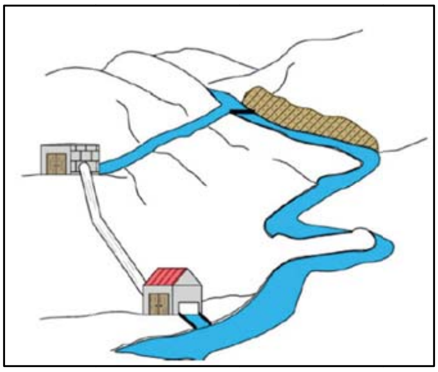
Penstock Only

Water is taken from the river by diverting it through an intake at a weir. A penstock directs the water from the intake directly to the powerhouse. After leaving the turbine, the water discharges down a ‘tailrace’ canal back into the river. [medium/high head]



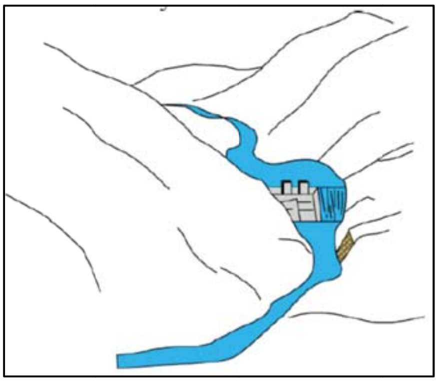
Pipe and Penstock

Water is taken from the river by diverting it through an intake at a weir. In medium or high-head installations water may first be carried horizontally to the forebay tank by a low-pressure pipe. Before descending to the turbine, a pressure pipe, or ‘penstock’, conveys the water from the forebay to the powerhouse. After leaving the turbine, the water discharges down a ‘tailrace’ canal back into the river. [medium/high head]



Canal and Penstock

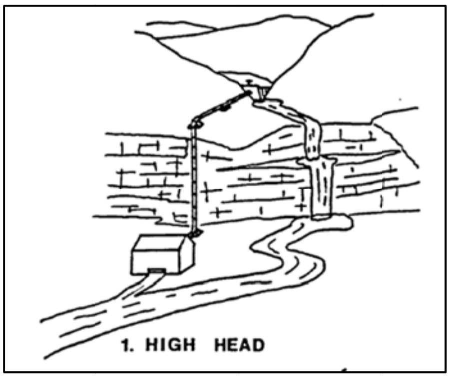
Water is taken from the river by diverting to a canal. In medium or high-head installations water is first carried horizontally to the intake. Before descending to the turbine, a pressure pipe, or ‘penstock’, conveys the water from the intake to the powerhouse. After leaving the turbine, the water discharges down a ‘tailrace’ canal back into the river. [medium/high head]



Barrage

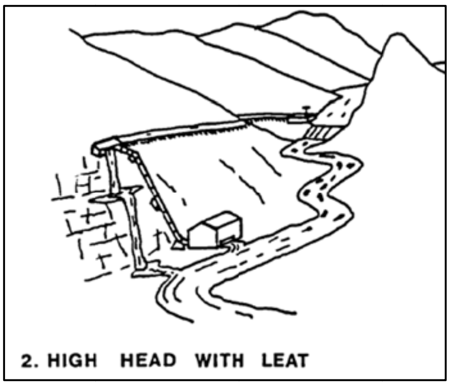
The power plant is made up of a weir or a dam, intake, and powerhouse all in the same construction. In this case the penstock is very short and directs water from the intake to the turbine. [low head]

Jones Report Site Layouts (Jones 1988)



Penstock Only

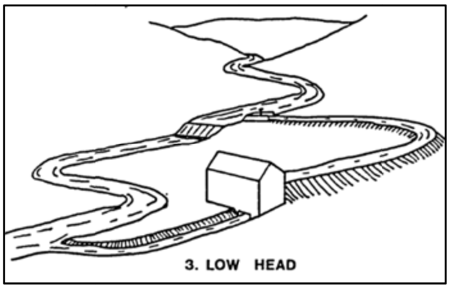
Water is taken from the river by diverting it through an intake at a weir. A penstock directs the water from the intake directly to the powerhouse. After leaving the turbine, the water discharges down a ‘tailrace’ canal back into the river. [medium/high head]



Canal and Penstock

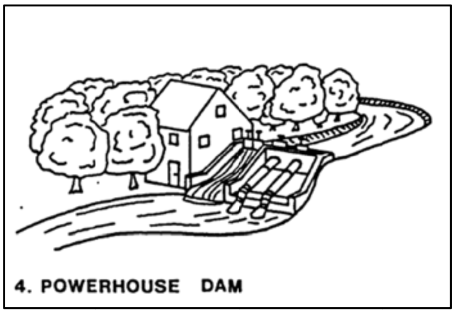
The scheme can be summarized as follows:

Water is taken from the river by diverting it through an intake at a weir. In medium or high-head installations water may first be carried horizontally to the forebay tank by a small canal or ‘leat’. A pressure pipe, or ‘penstock’, conveys the water from the forebay to the turbine, which is enclosed in the powerhouse. After leaving the turbine, the water discharges down a ‘tailrace’ canal back into the river. [medium/high head]



Mill Leat

Where the project is a redevelopment of an old scheme, there will often be a canal still in existence drawing water to an old powerhouse or watermill. It may make sense to re-use this canal, although in some cases this may have been sized for a lower flow than would be cost-effective for a new scheme. [low head]

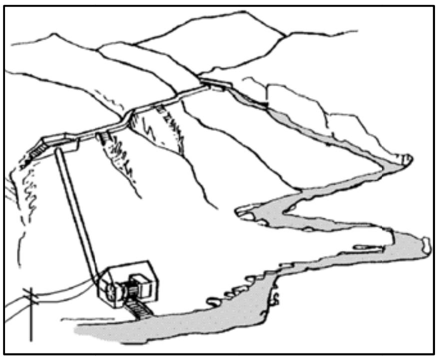


Barrage (powerhouse dam)

The power plant is made up of a weir or a dam, intake that is connected to a powerhouse. In this case the penstock is very short and directs water from the intake to the turbine. [low head]

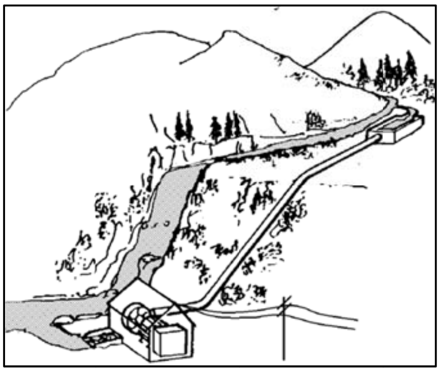
(Old scheme application)

BHA Site Layouts (BHA 2005)



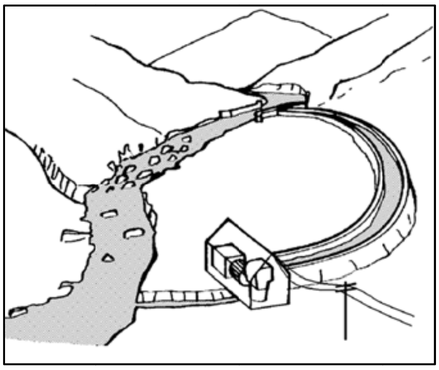
Canal and Penstock

Water is taken from the river by diverting it through an intake at a weir. In medium or high-head installations water may first be carried horizontally to the forebay tank by a small canal or 'leat'. Before descending to the turbine, the water passes through a settling tank or 'forebay' in which the water is slowed down sufficiently for suspended particles to settle out. A pressure pipe, or 'penstock', conveys the water from the forebay to the powerhouse. After leaving the turbine, the water discharges down a 'tailrace' canal back into the river. [medium/high head]



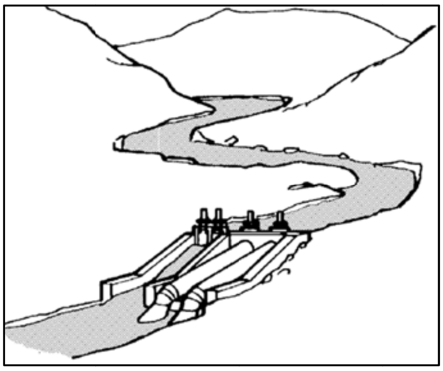
Penstock Only

A variation on the Canal-and-Penstock layout for medium and high-head schemes is to use only a penstock, and omit the use of a canal. This would be applicable where the terrain would make canal construction difficult, or in an environmentally-sensitive location where the scheme needs to be hidden and a buried penstock is the only acceptable solution. [medium/high head]



Mill Leat

Where the project is a redevelopment of an old scheme, there will often be a canal still in existence drawing water to an old powerhouse or watermill. It may make sense to re-use this canal, although in some cases this may have been sized for a lower flow than would be cost-effective for a new scheme. [low head]



Barrage

Similar as to the Mill Leat, is may be possible to have a barrage development on the same site. Otherwise, the power plant is made up of a weir or a dam, intake, and powerhouse all in the same construction. In this case the penstock is very short and directs water from the intake to the turbine. [low head]

6.1.4. Considering the Build-up of Cost

Having established what is meant by a SHP it is necessary to find out how the cost of such projects is defined. To be able to describe the approaches to estimate cost of such project the main cost elements need to be outlined. According to RETScreen (2004) and BHA (2005), the costs of a *small hydro generating station*[16] can be described under these headings:

- Civil Works
- The Cost of grid-connection
- Electrical & Mechanical Equipment
- Engineering and project management fees

The focus of this review will be on (1) civil works and (2) electrical & mechanical equipment; these topics will be discussed in the following sections. The grid-connection and engineering and management fees are minor compared to other cost. This does not mean that those cost can be neglected, however, they can be added as lump-sums or percentile of other costs.

6.1.4.1. Civil Work

To begin with a weir or dam directs the water into a canal, tunnel, penstock or turbine inlet. After the water has passed through the powerhouse it goes to the tailrace and then back to the river. Weirs or dams usually are the largest cost of SHP. The water passages of a SHP are the following: an intake and a trashrack, a gate and an entrance to a canal, penstock or directly to the turbine. The entrance and exit of the turbine include valves and gates (RETScreen 2004).

This is the general description of the main components of a standard SHP. Civil work will be split-up into categories based on the main components of the SHP. These categories work as umbrellas. Each category has many smaller components of the SHP within.

According to Singal (2010), the main civil work of a SHP can be divided into:

a. Diversion dam or weir and intake
b. Desilting chamber
c. Power Channel including head race tunnel
d. Forebay and spillway
e. Penstock
f. Powerhouse building
g. Tailrace channel

[16] RETScreen defines small hydro as: 1-50 MW

6.1.4.2. Electrical-Mechanical Equipment

The Electrical-Mechanical equipment is the equipment and systems required to develop the energy available in the flowing water and then to convert it into electrical energy, to control it and transmit it to the power grid. Regarding cost and space the major items are the turbines and generators (Singal 2007). Similar as before these are the main cost components of the SHP and are umbrellas for other components of the SHP.

According to Singal (2010, 2007), RETScreen (2004), the main electrical and mechanical components of SHP are:

a. Inlet Valve
b. Turbines with governing system
c. Draft tube
d. Gates
e. Generator with excitation system,
f. Electrical protection and control system
g. Transformers for station service and power transmission;
h. Electrical switchgear
i. Water shut-off valve(s) for the turbine(s);
j. Hydraulic control system for the turbine(s) and valve(s);
k. Utility interconnection or transmission and distribution system.

6.1.5. Summary

This section has reviewed the main aspects that need to be considered when defining SHP-Projects. It was found that of the three topics (design capacity, design head and design type) the design type (i.e. layout) was generally compatible within literature. However, the Icelandic approach is, in the opinion of the author, much clearer than the other two definitions of site layouts. This is based on the following:

- The Icelandic (Mannvit) approach defines four versions of the site layout; between these version all possible layout versions are covered. The BHA and Jones site layouts also cover most of the same layouts as Mannvit, however they introduce two other types (Mill Lear and Powerhouse) of layouts which are not specific layout types but repurposing of existing structures and therefore not appropriate (more relevant in connection to new project, repurposing or refurbishing of old sites).
- This is understandable since there is likely a large marker in these countries for converting existing structures into SHP. However the classification of it as a specific layout type is not in accordance with the other definition. The fact that the hydropower plant is built in a ‘green field’ or ‘brown field’ does not affect the layout type, only the complexity and cost of the project.

The other two topics (design capacity and design head) varied much between sources; likely due to the fact each country uses its own norms and market size to define them. Indications of standardizing of these factors within the EU were identified and that is something that needs to be considered in the future.

6.2. Considerations for EF-Project Cost Estimation

In section 6.1 the definitions of a SHP and its main cost elements have been identified. This section and its sub-sections aim to summarize the findings of what has been concluded previously in this case study. The goal is that from this a foundation for the classification and sorting of projects can been established, eliminating any confusion about what is meant by a SHP-Project specifically in connection to the EF-Project.

6.2.1. SHP-Projects Classification system

Based on this case study it is possible to draw together what has been established regarding the classification of SHP-Projects. The classification system in Table 13 can be used to sort the various project that need to be studied to compile a historical databank of small hydropower projects in Iceland (further discussed in Chapter 7).

Table 13: Classification of SHP in Iceland, Adopted from Mannvit (2010)

	Design Type		Design Capacity			Design Head		
	Storage	Run-of-River	Micro	Mini	Small	Low	Medium	High
Classification	Plant	Plant	< 100 kW	100-300 kW	300-1000 kW	< 50m	50-250 m	> 250 m
Penstock Only[1)]								
Pipe and Penstock[1)]								
Canal and Penstock[1)]								
Barrage[1)]								

1) Based on definition given by Mannvit

Having such a classification system is the first step of defining the SHP-Projects. The next step is to create a standard WBS for each of the classification depicted in Table 13. These four WBSs would be similar, but not identical, they allow for a standardized breakdown of these classifications, and provide a numbering system for each component based on the layout type. Also, the clarification and tractability of cost relationships provides a strong bases for further analysis and buildup of a cost estimation system (see further discussion in Chapter 7). The WBSs also provides a basis for planning and scheduling such projects.

6.2.2. SHP-Projects Cost Breakdown Structure (CBS)

The CBS is similar to the WBS, but with the difference that is shows only the cost elements. The creation of a CSB is favorable, in this case, for purposes of defining the main cost elements of SHP. Also it is reasonable to have a CBS in place so that all cost elements are defined even though they may not be a part of a specific project. In Figure 20 a CBS based on the previous sections of this case study is illustrated.

The detail of the CBS can be developed further, but it is sufficient for the purposes of this research. However, if used, then this CBS should be fully developed in connection to the WBSs that need to be created for the site layouts, briefly mentioned in the previous section.

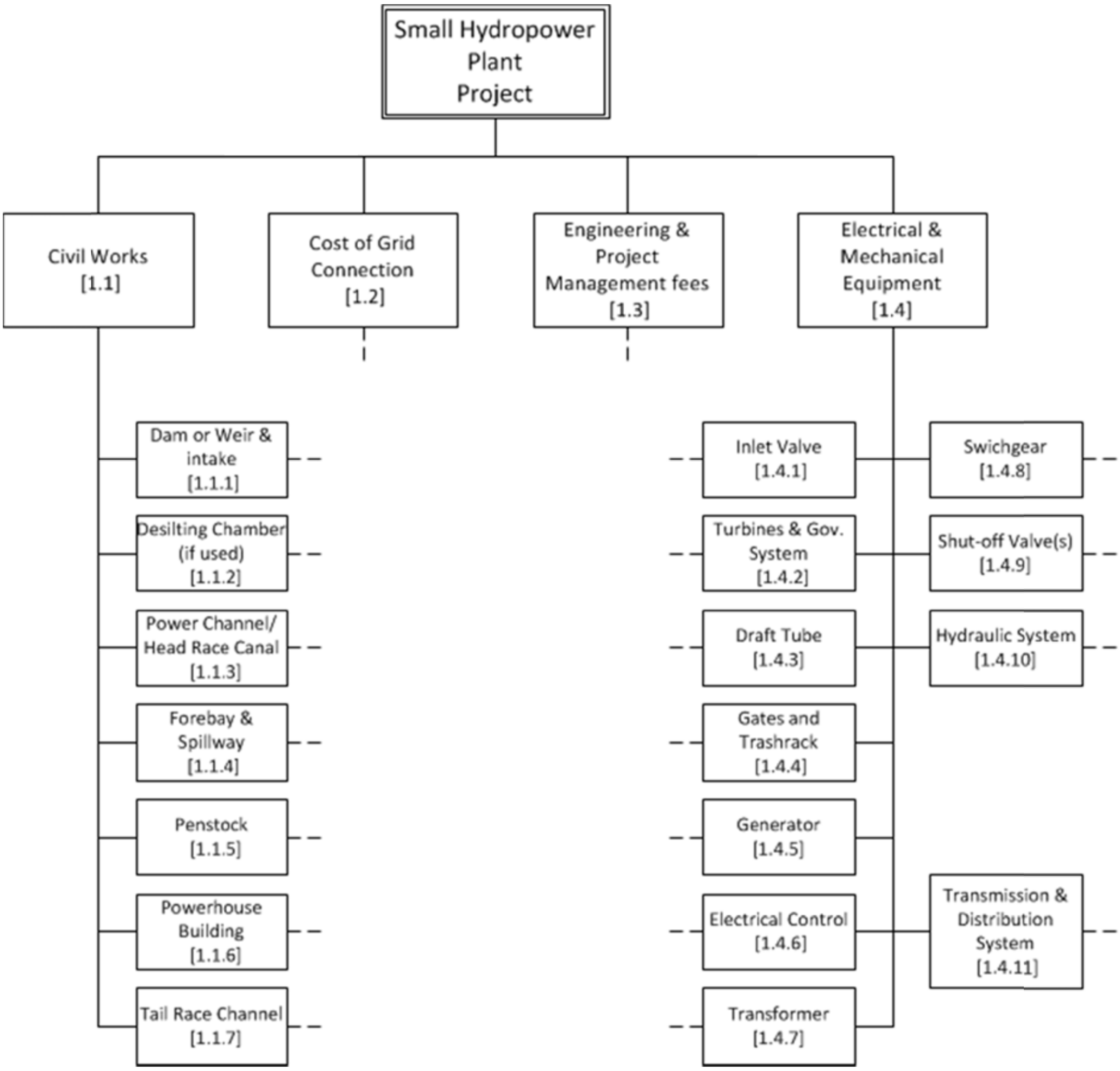


Figure 20: Small Hydropower Plant Cost Breakdown Structure (CBS)

7. SHP Analysis and Results: EF-Project

In this chapter a proposal of a methodology approach to be used for the EF-Project is set forth based on the research findings. This is intended to be used as guidance for the approach taken, if it is decided to create a cost estimation model.

7.1. Method Selection

The Modular Estimate method is proposed for the EF-Project. This method is used for projects that have physical deliverables as described in section 3.6.3.2. The use of this method provides a means to select the deliverables needed for each specific project based on the SHP-project classification. Then the cost could be estimated for each deliverable based on historical information.

7.2. Historical Data

In recent years much interest has risen into the potential of SHP in Iceland. There is also a long history of such plants being used by frames all over the country. However, currently there is no historical database available that describes the costs of building a SHP in Iceland.

Collection of data to be used for the EF-Project needs to start as soon as possible. Two approaches are possible in respect to collecting data, first only new project that are developed in connection to the EF-Project will be collected and compiled in a database. The other possibility adds previous (old) project to the database as well.

Such data would give indication to how best to formulate the formulas, and regression and scatter chart analysis would further draw forth the appropriate cost drivers.

7.3. Cost Estimation Class and Accuracy

The accuracy of the model is unclear since no historical data is available. The accuracy of any model is based on the amount of historical data available. However, it can be concluded that a model of this type will only serve as an *estimate of feasibility*, therefore the cost estimates will be in the range (L: -15% to -30% and H: +20% to +50%).

If the estimated cost from a model was within acceptable limits to the owner, and the decision is taken to continue with the project. Then the next step is to start creating a more specific design suitable for the location in question, that is to say the owner would have to make the decision to move the project into ‘Preliminary Design’. At that time design data would start to formulate that should make a parametric or modular estimate unnecessary. The logical step is to input quantity data into an Engineer Build-up estimate. The Engineer Built-up estimate could also be based on the cost data obtained from the same historical data as the modular estimate. Based on the findings of this research, it is concluded that that three estimates need to be performed. The first one is the one which is described in this chapter; a feasibility estimate based on the Modular method. Second is the preliminary design estimate that is undertaken after the owner has accepted the results of the feasibility estimate and decided to continue. Finally if the owner still decides to continue the design is finalized and the third and final estimate is performed which is the contracting estimate (see Table 9 for details of estimates).

7.4. EF-Project Cost Estimation Process

The cost estimation process can be split up into two; first it is the process of creating the CERs that can represent the likely cost for a given component based on unit rates (e.g. dollars per kW). The other process is performed by the project owner, he must have sufficiently defined his project based on the main classification (i.e. capacity, head and type). The user puts his information into the model and the model looks-up the cost data and inputs the information into the appropriate CERs. The result is a feasibility class estimate that should give the owner an idea of what his project will cost.

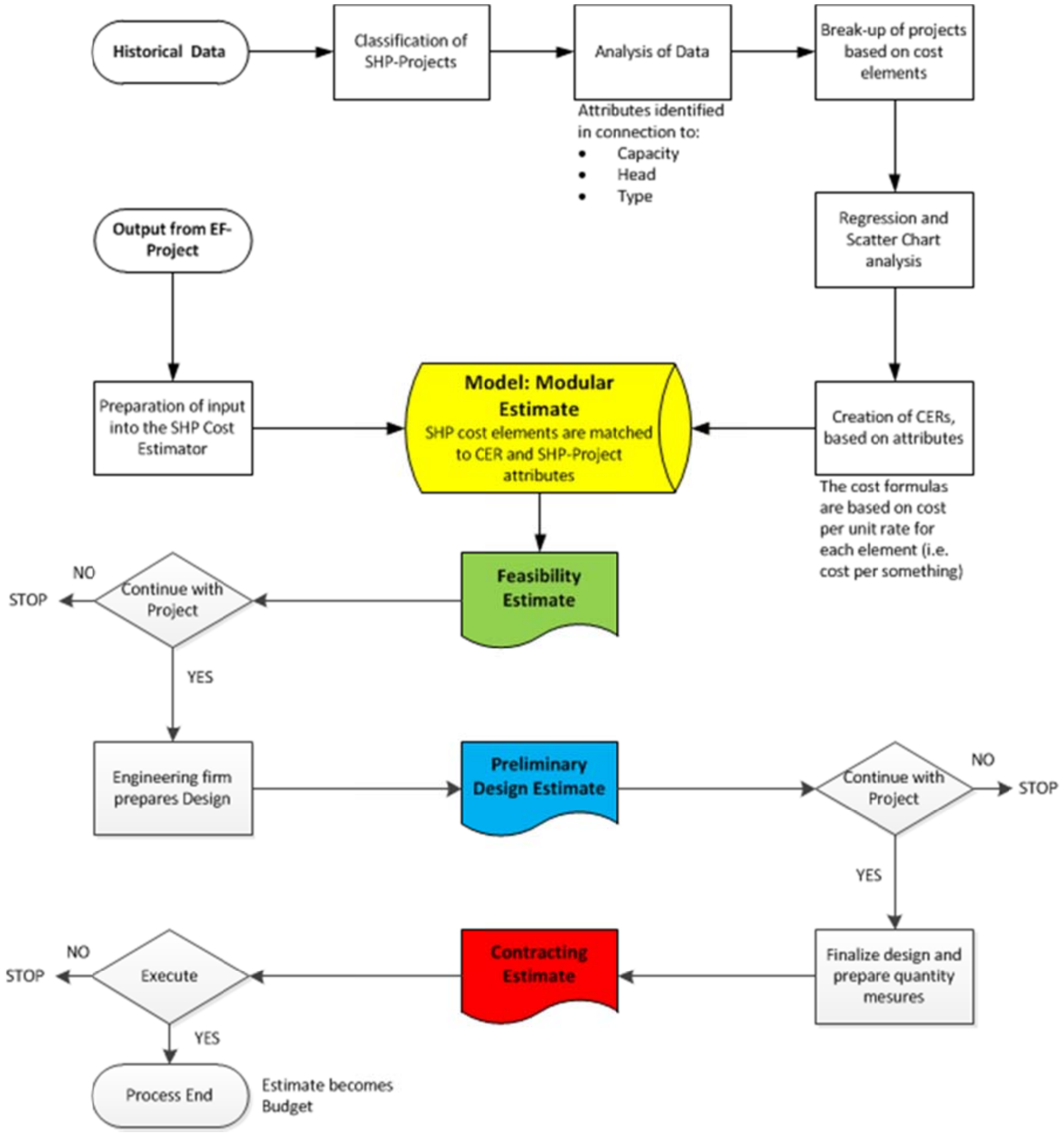


Figure 21: Cost Estimation Processes

An example of a cost estimating formula based on scatter chart and regression analysis is given here (Aggidis et al. 2010):

$$C_{EM} = 12000 \cdot \left(kW / H^{0.2}\right)^{-0.56} \quad (£, 2008)$$

C_{EM}: electro-mechanical equip., kW:kiolwatt, H:Head

8. Discussion

8.1. Relevance of Research

8.1.1. Landsvirkjun Research

The main focus of this this study is on the Landsvirkjun cost estimation methodology. A research like this has not been performed before therefore the documentation of how Landsvirkjun performs its cost estimates is interesting. Also, this research made it possible to compile a best practice comparison that can be used to benchmark current practice at Landsvirkjun.

Researches of similar nature (i.e. document current practice) to this one are fitting for the atmosphere that exists in Iceland today. This is due to the fact that much of what was considered to be examples of state-of-the-art practice in Iceland before the financial crash have turned out to be not so good. Landsvirkjun is a company owned by the government, it has been able to conduct its business without much outside influence. Other Icelandic agencies, like the Road Administration, have not been allowed to freely mature and have been limited by the political environment. In light of this difference a study of how project management has evolved at Landsvirkjun is an interesting area. Benchmarking of Landsvirkjun's practice and success compared to governmental agencies can reveal weaknesses and strength, which is beneficial for the state.

8.1.2. Small Hydropower Research

Small hydro has, in all likelihood, the most potential for growth in Iceland. Lobbying and the political environment, seems to be aimed at bring the development of large hydropower projects to a standstill.

This has invoked much interest in small hydro and as a result the EF-project was born. However the biggest question regarding small hydro is its feasibility and that brings us to the topic of cost. Simple cost estimating tools need to be developed to filter out the projects that are economically viable. For such tools to be developed, definitions of what is meant by and what is a part of SHP must be clarified.

As a result of shortage of local projects engineering firms have been force to increasingly marketing them self abroad. SHP is popular all over the world, and if Icelandic engineering firms want to get into that market they need to adapt. Therefore a comparison of what is considered to be a SHP in Iceland compared to other countries needs to be addressed.

8.2. Project Management at Landsvirkjun

Estimation of cost is part of Project Management. This study was not focused on how projects were managed in general by the company, only how it managed the estimation of cost. Nonetheless insight into the management of projects was gained thorough this research. And as a result a noticeable void in guidance regarding how projects should be prepared was noticed (i.e. what documents Landsvirkjun requires its partners to produce).

The main focus of the cost estimates at Landsvirkjun is on the performance of calculations, and all cost estimates are to be performed through Kolla 5.0a. The processes for creating inputs for Kolla 5.0a are not standardized and guidance on the subject is limited. Based on the information available it seems that Landsvirkjun needs to clarify its guidance regarding cost estimation, especially regarding estimation of quantities. Having three engineering firms all using their own approach for estimating of quantities makes it difficult to compare their work. As a result opportunities for improvements are lost and the danger of over and under estimation quantities persists. It can be concluded that synchronization of practices between engineering firms will improve the compatibility of cost estimates as it well as provides a basis for improving quantity estimates.

It seems that many aspects regarding cost estimation at the company are based on undocumented traditions and trades that project managers at Landsvirkjun enforce. Not clearly defining what is required to be performed and delivered affects the repeatability of project delivery. Lessons learned are missed and the same mistakes are likely to happen again. It is crucial to clearly define the management of a project from start to finish. Improvements can then be identified and implemented and best practice captured.

8.3. Reconcile empirical findings with theory

8.3.1. Landsvirkjun Research

All the literature assumes that there is a clearly defined project management framework in place. This framework secures that all necessary documents are created, updated and made available to all the project stakeholders. Regarding the estimation of cost for Landsvirkjun's projects it is not clear what inputs are required to be available to the cost estimators and how estimates are compatible since they themselves are not classified specially. Theory review illustrated that a classification of estimates as well as document requirements should be clearly stated.

The methodology used for estimating cost by Kolla 5.0a is compatible to best practice. On the other hand the quantity estimation part of Kolla 5.0a should be clarified and practices made compatible between estimators. Everything should be aimed at clarifying documentation, so that benchmarking of information can be performed and excellence can be achieved. As the literature reviewed shows that it is all about the quality of historical data.

8.3.2. Small Hydropower Research

Though this topic was not a formal part of the main research topic and therefore the 'State of the Art Review', a study of literature was performed in Chapter 6. The definition of SHP, proposed by literature varied depending on sources, still it was concluded that for Europe a trend was being created and perhaps a standardized definition will be put forth for EU-counties in the near future.

Differences in definitions of head and capacity (discussed in Chapters 6.1.1 and 6.1.2) between Iceland and other counties literature was significant. The reasons to why these differences exist are in some part contributed to market size in regards as to capacity, and local norms in respects to head. Due to these factors, Iceland has set itself apart from other countries. Clearly the Icelandic definition of SHP does not coincide with what is generally considered to be SHP in other counties. Based on the literature reviewed in connection to SHP, it was possible to describe differences between definitions and put forth a classification system for the EF-project.

8.4. Research Related Difficulties

8.4.1. Landsvirkjun Research

This research is based on an analysis of data made available from Landsvirkjun, in the form of a report. The main problem that was encountered regarding the research was the lack of documentation available for study. This was not realized until late in the study when it became apparent that the data that had been received was too focused on describing CERs used by Kolla 5.0a. This posed a significant problem, as the process under investigation is not transparent. It was therefore difficult to perform an exhaustive research on the Landsvirkjun. The author believes that a sufficient amount of data was not obtained for this research so that a full view of the methodology applied at Landsvirkjun for managing projects and there cost could be identified.

It is clear that much in-house data exists at Landsvirkjun; the problem is that this data is not freely available, and much of it is regarded as confidential. It is the author's opinion that research into the methods used for managing project need to be conducted at Landsvirkjun or at least in circumstances where all existing data can be quickly obtained.

Finally, the issues regarding "distance" from supervisor and Landsvirkjun's, had noticeable disadvantage as the availability of these resources could not be used to their best abilities. For a research of this nature, close proximity to resources is essential.

8.4.2. Small Hydropower Research

Having a secondary topic proved to be difficult. Much work was put into preparing for the Landsvirkjun Case study and when it came to reviewing literature regarding small hydropower it came evident that the topic was not as straight forward as had been assumed. In hindsight it is the researcher's conclusion that it was mistake to include this topic in the research as it took focus and time away from the Landsvirkjun research. However, documentation on this subject was freely available and with the time left it was possible to clarify many of the basic issues that must be well-defined for any future work.

8.4.3. General Issues

Issues regarding language must also be mentioned. It should be clear to the reader at this stage that much of the information used in this research is in a language other than English. This required the author to translate some information; this can influence the final result as the authors' views and understanding of text can influence the translation. This is something that the author is aware of and consciously attempted to minimize.

8.5. Conclusions

Cost estimates are based on assumptions, it is unlikely that an estimate will ever be 100% correct, errors are always made. The quality of this work is mostly based on the details of information available at the time the estimate is made. This information can be both qualitative and quantitative; therefore it is not simply the task of computing based on formulas that have been derived from historical data. The insight of the estimator is in many cases the deciding factor. His assumptions cannot be described by formulas, that is why it is imperative they the also be documented. When dealing purely with quantitative data it is more appropriate to use statistical analysis than Expert Judgment. The key is to make sure that those who use the estimate understand how it came about and what assumptions lie behind its conclusion.

9. Conclusions

9.1. Final Conclusions

9.1.1. Summary of Research

Landsvirkjun

The research set out to study how cost estimation was approached by Landsvirkjun. To begin with the documents available from Landsvirkjun were analyzed and the methodology applied extracted. It became evident that it would only be possible to describe Landsvirkjun's general approach to cost estimation, based on the available information. Factors such as risk analysis and contingency were not described in any detail, and specialist guidance had to be sought to describe those subjects. It was concluded that risk and contingency needed to be clarified.

Landsvirkjun guidance for Kolla 5.0a poorly describes how estimates should be performed. A tendency for loosely documenting definitions and stating requirement is believed to be a problem regarding management of project. That can be traced back to the company's long tradition of performing cost estimation and therefore certain habits have been established. The work of documenting and creating standards based on these traditions has likely not been done.

Most potential for improvement for Landsvirkjun is in connection with how it standardizes it project definitions and deliverables. The current WBS used at Landsvirkjun is not compatible to best practice, and an outline for a new WBS was introduced. Having a quality WBS increases the probability of project success and secures repeatability as well as contributing to a better cost and time management. The WBS is a fundamental tool in modern project management.

A classification system for cost estimates at Landsvirkjun was proposed. Implementation of such a system is in accordance with what is considered to be best practice. Also it should be stated how accurate these estimate are expected to be, and what data is required to have been created when they are performed.

Energy Farmer

Study of small hydropower plants was performed to support the goal of preparing the ground for the creation of a cost model for such projects. A detailed review of reports and papers was undertaken for this purpose. It quickly became apparent that this study would need to be more basic than was originally anticipated. The definition of SHP was not as straight forward as was assumed. Clarification of the definition of SHP was required, since it is the premise for all other work that will be performed later.

Different definitions of capacity, head and type were examined, and a global value ranges for SHP definitions was compiled. Following this the Icelandic informal definition of SHP was reviewed. However since the Energy Framer is local project and specific only to Iceland, it was concluded that it was favorable to keep to the Icelandic values. Nonetheless it is pointed out that this does limit the models application as well as any comparison to other non-local models is problematic. Finally the main cost factors were identified and a preliminary CBS proposed.

9.1.2. Consolidation to Research Objectives

The first objective of this research was to identify what methodology was applied at Landsvirkjun for cost estimation. This was accomplished in the case study of Landsvirkjun (Chapter 4). Based on what had been defined in the theory review it was possible to conclude that Landsvirkjun used the Parametric, Expert Judgment and Engineer Build-up methods to estimate costs. Other factors such as the WBS, risk and contingency were analyzed and discussed. The methodology applied by Landsvirkjun is in some respect compatible to best practice (i.e. the cost calculator of Kolla 5.0a), but definitions of other aspect of the cost estimation process need to be clarified.

The second objective was to create a best practice comparison by review of theory. This was done in the State of the Art Review (Chapter 3).

The third objective was to recommend an approach to creating a cost model for the EF-project. This was done, and a general approach based on what has been covered in this research was put forth in section 7.4.

The fourth objective was to establish what the main cost estimation attributes are for Small hydropower plants. This was done by reviewing the literature connected to the SHP case study. The main cost factors where then illustrated in section 6.2.2.

Finally the hypothesis (*i.e. tools used to estimate costs of Landsvirkjun's projects are, for all practicable purposes, consistent with best practice*) was not confirmed as the available documentation did not cover all aspects that were outlined in the theory review. Also clarifications and definition of those factors that were covered was not adequate.

9.2. Contribution

In connection to Landsvirkjun the fundamental methodology applied by the company was documented. Insight into how the company uses the cost calculations and quantity estimates as two different segments of one model has been covered, giving other researchers a basis to work from. It has been indicated that Landvirkjun, as an owner, is not describing the quality of performance for the management of projects sufficiently. Points in connection to the WBS, Risk Management and Contingency have been raised and improvements suggested.

The study into the field of small hydropower has made it possible to position the, commonly used, definition for SHP in Iceland in comparison to what other countries use. The problems connected to the Icelandic SHP definition were raised and it pointed out that in global context it is only compatible with a MHP.

Basis for classifying hydropower projects in Iceland was introduced and the main cost factors/classes where identified. Based on this work it should be possible to start compiling a database for further analysis.

9.3. Further research

The review of Landsvirkjun's cost estimation methodology raised many question regarding the general management of projects. The most interesting area, in the author's opinion, for further study is the Project Management Framework and if processes used at Landsvirkjun are standardized between projects. This is mainly due to the fact that if an up-to-date Project Management Framework is in place it secures constant improvement in management of projects. In respects to cost estimation, further study is required of existing guidance within Landsvirkjun. Performance of risk analysis should be looked at closely as well as what traditions exist for applying contingencies to projects.

The preparation for creating a cost-model for the EF-project needs to be taken to the next phase, which is the creation of a projects-databank. Therefore a study of well documented SHP-projects is needed. The creation of a databank makes it possible to analysis and create CERs by the used of scatter-chats and regression analysis.

References and Bibliography

AACE (2005a). AACE International Recommended Practice No. 18R-97. AACE International

AACE (2005b). Project And Cost Engineers´ Handbook 4th. Marcel Dekker, Cirmarron Road, NY, ISBN 0-8247-5746-7

Anderson, S.D., and R.L. Tucker. (1990) Improving industry cost effectiveness. Potential for Construction Industry Improvement—Assessment Methodology. Vol. 1, pp. 25-31.

Atkin, B. (2010) interview by Viðar Helgason. Discussion on the value process (9 FEB 2010).

Aggidis, G.A., Luchinskaya, E., Rothschild, R., Howard, D.C. (2010). The costs of small-scale hydro power production: Impact on the development of existing potential. Renewable Energy. Volume 35, Issue 12, December 2010, Pages 2632-2638.

AGMHP (2008). Introduction on: ASEAN-German Mini Hydro Project: Classification of Hydropower Plants. Webpage: agmhp.aseanenergy.org . From: http://agmhp.aseanenergy.org/media/documents/2010/10/07/m/i/microsoft_powerpoint_-_a.02_classification_en.pdf . (Retrieved: Jan 14, 2011).

Al-Bahar, J. F. (1988). Risk management in construction project: A systematic analytical approach for contractors. Civil Engineering Department, Doctor of Philosophy: University of California at Berkeley.

ASCE (1989). Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments, Volume 2, Waterways. American Society of Civil Engineers, 245 East 47th street. New York.

Association For Project Management (APM) (2004). Project Risk Analysis & Management (PRAM) guide 2thedn. APM Publishing, Princes Risborough, ISBN 1-903494-13-3

Association For Project Management (APM) (2006). APM Body of Knowledge 5thedn. APM Publishing, Princes Risborough, ISBN 1-903494-13-3

BHA (2005). A Guide to UK Mini-Hydro Developments: version 1.2. From: http://www.british-hydro.org/mini-hydro/download.pdf. (Retrieved: Jan 16, 2011).

Bryman, A., and Cremer, D. (1994) Quantitative Data analysis for Social Scientists. Ed.revised. London: Routledge.

Büschken, Joachim, and Huth, T. (2009) Stage-Specific Effects of Organizational Structure and Boundary-Spanning on the Performance of New Product Development Teams. Working Paper Series (Catholic University of Eichstätt-Ingolstadt Germany), April 2009.

Chen, D., and Hartman, F. T. (2000). A neural network approach to risk assessment and contingency allocation. AACE International Transactions.

Cleland, and David, I. (1964) *Project Management: An innovation of thought and theory*. Air University Review 16, (Nov-Dec 1964).

EIA (Energy Information Administration) (2010). Assumptions to the Annual Energy Outlook 2010. DOE/EIA-0554(2010). Washington DC, EIA.

Eisenhardt, K. M., and Tabrizi, B.N. (1995) Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry. Administrative Science Quarterly. Vol. 40, no. 1, pp. 84-110.

ESHA (2004). Guide on How to Develop a Small Hydropower Plant (Part 1). European Small Hydropower Association.

Fellows, R., and Liu, A. (2008) Research Methods for Construction. 3rd. Oxford: Blackwell publishing.

GAO (2009). GAO Cost Estimating And Assessment Guide: Best Practices for Developing and Managing Capital Program Costs. U.S. GAO, Washington DC, GAO-09-3SP

Garrett, G.A. (2008). Cost Estimating And Contract Pricing: Tools, Techniques And Best Practices. CCH, Riverwoods, ISBN 978-0-8080-1819-3

Gray, C.F. & Larson ,E.W. (2008). Project Management: the managerial process 4thedn. McGraw-Hill, New York, ISBN 978-0-07-128751-7.

Green (2010). “Hydroelectric Power - Water power - micro hydro systems.” www.green-trust.org. July 31, 2010. From: http://www.green-trust.org/hydro.htm (Retrieved: Jan 16, 2011).

Haywood, P., and Wragg E.C. (1982) Evaluating the Literature. Nottingham: University of Nottingham.

Heldman, Kim. (2009) *Project Management Professional Exam Study Guide*. Ed. 5th. Indiana: Wiley Publishing.

Idrus, A., Nuruddin, M.F., & Rohman, M.A. (2010). Development of project cost Contingency estimation model using risk analysis and fuzzy expert system. Civil Engineering Department, University Technology PETRONAS, Bandar Seri Iskandar, Tronoh 31750, Perak Darul Ridzuan, Malaysia

Jones, I.D. (1988). Assessment and Design of Small-Scale Hydro-Electric Power Plants. University of Salford, Department of Civil Engineering.

Júlíusson, Einar M. (2010), interviews by Viðar Helgason. Discussion on Landsvirkjun Cost model.

Kerzner, Harold (2009). Project Managemetn, a systems approach to planning, scheduling, and controlling. 10th. New Jersey: John Wiley & sons, Inc.

Kumar A. (2008). Current Technology Scenario and Expectations: Small Hydro Projects. Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee.

Landvirkjun (2006). Kostnaðarlíkan Landsvirkjunar: Endurskoðun 2006, Hefti 3 af 3, Kolla 5.0a – Kostnaðarforsendur. Landsvirkjun, LV-2007/3.

Lock, D. (2007) *Project Management*. 9th. Hampshire: Gower Publishing Limited.

Mannvit (2010). Litlar Vatnsaflvirkjanir: Kynning og leiðbeiningar um undirbúning. 2nd. Iðnaðar- og viðskiptaráðuneytið, Mannvit Engineering (April 2010).

Norman, E. S., Shelly A. B., and Robert T. F. (2008) *Work Breakdown Structures: The foundation for project management excellence*. New Jersey: John Wiley & sons.

Parsons, E.L. (1999). Waste Management Project Contingency Analysis. FETC, Pennsylvania, DOE/FETC-99/1100

PMI. (2005) *Practice Standard for Earned Value Management*. Newtown Square: Project Management Institute.

—. (2006). *Practical Standard for Work Breakdown Structures. 2nd*. Newtown Square, Pennsylvania: Project Management Institute.

—. (2008) *A Guide to the Project Management Body of Knowledge.* 4th. Project Management Institute.

Rad, P.F. (2002). Project Estimating And Cost Management. Management Concepts, Vienna VA, ISBN 1-56726-144-2

RETScreen (2004). Clean energy Project Analysis: RETscreen® Engineering & Cases Textbook. Minister of Natural Resources Canada. ISBN: 0-662-35671-3

Roitha, D. (2007) *project proposal*. Webpage: e-articles.info. (05 May 2007). From: http://e-articles.info/e/a/title/Project-Proposal/ (Retrieved: Desember18, 2010).

Rothwell, G. (2004). Cost Contingency as the Standard Deviation of the Cost Estimate for Cost Engineering. Stanford University, Stanford CA, SIEPR Discussion Paper No.04-05

Roy Rajkumar (2005). ACostE Learning Event, 2nd . Cranfield University UK.

Singal, S.K., Saini, R.P., and Raghuvanshi, C.S. (2010). Analysis for cost estimation of low head run-of-river small hydropower schemes. Alternate Hydro Energy Centre, India Institute of Technology, Roorkee, India.

Singal, S.K., Saini, R.P. (2007). Analytical Approach for Cost Estimation of Low Head small Hydro Power Schemes. Alternate Hydro Energy Centre, India Institute of Technology, Roorkee, India.

Sonmez, R., Ergin, A., & Birgonul, M. T. (2007). Quantitative methodology for determining of cost contingency in international project. Journal of Management in Engineering, 23, 35–39.

Taylor, M.D. (2008) *Articles.* Webpage: PMhut. (16 July 2008). From: http://www.pmhut.com/how-to-write-a-project-proposal (Retrieved: August 18, 2010).

Varun, I.K. Bhat & Ravi Prakash (2008). Life Cycle Analysis of Run-of River Small Hydro Power Plants in India. The Open Renewable Energy Journal, Vol. 1, 11-16.

Appendix

I. Appendix: Enterprise Environmental Factors

Governmental or industry standards: These include elements such as;

- regulatory standards and regulations,
- quality standards,
- product standards,
- and workmanship standards.

Infrastructure: This refers to the organization's facilities and capital equipment.

Human resources: This refers to the existing staff's skills and knowledge.

Personnel administration: These are guidelines for hiring and firing, training, and employee performance reviews.

Organization's work authorization system: This defines how the work of the project is authorized.

Marketplace conditions: Supply-and-demand theory applies here along with economic and financial factors.

Stakeholder risk tolerances: This is the level of risk stakeholders are willing to take on.

Political climate: This concerns both the internal and external political climate and influences on the project or organization.

Organization's established communications channels: These are the mechanisms the organization uses to communicate both internally and externally Commercial databases these refer to industry-specific information, risk databases, and etc.

II. Appendix: WBS Quality

WBS Quality Principle 1

The first principal is "A quality WBS is a WBS constructed in such a way that it satisfies all of the requirements for its use in a project" (PMI 2006). This principal has two sub-principals that apply to satisfying requirements for use of a WBS.

Sub-Principal 1 – Core Characteristics

The core characteristics make it possible for the WBS to satisfy the needs of every project. It is very clear that a WBS either has these core characteristics or not. These characteristics represent the minimum set of specific attributes that the WBS must contain (PMI 2006), (Norman, Brotherton and Fried 2008). If the WBS is missing any of the core characteristics, then it is not a quality WBS. According to PMI (2006) the core quality characteristics that a WBS needs to have to full fill the core quality are:

- Deliverable-oriented grouping of project elements.
- Defines the scope of the project.
- Clarifies the work and communicates project scope to all stakeholders.
- Contains 100% of the work defined by the scope.
- Captures internal, external, and interim deliverables in terms of work to be completed, including project management.
- Is constructed so that each level of decomposition contains 100% of the work in the parent level; This applies at all levels within the hierarchy: the sum of the work at the ‘‘child’’ level must equal 100% of the work represented by the ‘‘parent’’ and the WBS should not include any work outside the actual scope of the project i.e. cannot include more than 100% of the work. This also applies at activity level (PMI 2006), (Haugan 2002).
- Contains work packages that clearly support the identification of the tasks that must be performed in order to deliver the work package.
- Provides a graphical, textual, or tabular breakdown of the project scope.
- Contains elements that are defined using nouns and adjectives—not verbs.
- Arranges all major and minor deliverables in a hierarchical structure.
- Employs a coding scheme for each element that clearly identifies its hierarchical nature when viewed in any format such as a chart or outline.
- At least two levels with at least one level of decomposition.
- Is created by those who will be performing the work.
- Is constructed with technical input from knowledgeable subject matter experts (SMEs) and other project stakeholders, such as financial and business managers.
- Iteratively evolves along with the progressive elaboration of project scope, up to the point the scope has been base-lined.
- Is updated in accordance with project change control, thereby allowing for continual improvement, after the project scope has been base-lined.

Sub-Principal 2 – User-Related Characteristics

The user-related characteristics make it possible for the WBS to be used for purposes that are special to a specific project, industry, environment, or are applied in a particular way to individual project. By using these characteristics it is possible to get a high-quality WBS, which can meet all the project needs and requirements (PMI 2006).

According to PMI (2006) the user-related characteristics include but are not limited to:

- *Achieves a sufficient level of decomposition.*
- *Provides sufficient detail for communicating all work.*
- *Is appropriate for tracking, as required by the specific project or organization.*
- *Is appropriate for control activities.*
- *Can contain specific kinds of WBS elements, as needed for each project.*
- *Enables assignment of accountability at the appropriate level.*
- *Has a succinct, clear, and logically organized structure to meet project management and oversight requirements.*

WBS Quality Principle 2

The second principal is "WBS quality characteristics apply at all levels of scope definition" (PMI 2006). No conceptual difference is between a program, project, or portfolio WBS. It does not matter at what level a high-quality WBS is developed, it contains exactly the same characteristics and attributes as a high-quality WBS developed at an individual project level (PMI 2006).

III. Appendix: Approaches to Creating WBS

Many methods and tools are used in making WBSs, they include but are not limited to (PMI 2006):

- Outlines
- Organisational Charts
- Brainstorming techniques
- Fishbone diagrams
- Top-down and bottom-up development strategies

It is recommended that such tools are used since they promote consistency and repeatability in development of WBS. They can also promote the guidelines, standards, or organizational principles, they have been shown to significantly reduce the development effort, simplifying of the WBS process, and promotion of reuse of WBS elements (PMI 2006). In Table 14 some of the WBS creation methods are shown, including their advantages and challenges.

Table 14: WBS Creation Methods, based on (PMI 2006).

WBS Creation Method	Advantages	Challenges
Top-Down	●Structures project conveniently for status reporting. ●Helps ensure project are logically structured. ●Is Valuable when brainstorming/ discovering project deliverables. ●Can accommodate additional deliverables as they are uncovered.	●Requires constant attention that no work packages are overlooked. ●WBS needs to be elaborated to sufficient detailed level permit management oversight and control.
Bottom-up	●Starts with all deliverables and work backwards into a project. ●Confirms that all work packages are included.	●Identifying all deliverables before producing the WBS. ●Making sure work packages are logically grouped. ●Can lose focus on big picture.
WBS Standards	●Formats are predefined. ●Enhances cross-project WBS consistency.	●Making a project fit the standard ●Can lead to inclusion of unnecessary deliverables or failure to include project-specific deliverables. ●Not all projects fit into highly structured set of WBS standards.
WBS Templates	●Provides a starting point for WBS creation. ●May help determine appropriate level of detail required. ●Enhances cross-project WBS consistency.	●Requires a project fit the standard. ●Can lead to inclusion of unnecessary deliverables or failure to include project-specific deliverables. ●Not all projects fit into highly structured set of WBS standards.

IV. Appendix: Rates, Factors, and Ratios

The GAO (2009) defines rates, factors, and ratios as:

- *A rate uses a parameter to predict cost, using a multiplicative relationship. Since rate is defined to be cost as a function of a parameter, the units for rate are always dollars per something. The rate most commonly used in cost estimating is the labor rate, expressed in dollars per hour.*
- *A factor uses the cost of another element to estimate a new cost using a multiplier. Since a factor is defined to be cost as a function of another cost, it is often expressed as a percentage. For example, travel costs may be estimated as 5 percent of program management costs.*
- *A ratio is a function of another parameter and is often used to estimate effort. For example, the cost to build a component could be based on the industry standard of 20 hours per subcomponent.*

V. Appendix: Class definitions, based on (AACE 2005a)

CLASS 5 ESTIMATE	
Description: Class 5 estimates are generally prepared based on very limited information, and subsequently have wide accuracy ranges. As such, some companies and organizations have elected to determine that due to the inherent inaccuracies, such estimates cannot be classified in a conventional and systemic manner. Class 5 estimates, due to the requirements of end use, may be prepared within a very limited amount of time and with little effort expended—sometimes requiring less than an hour to prepare. Often, little more than proposed plant type, location, and capacity are known at the time of estimate preparation. **Level of Project Definition Required:** 0% to 2% of full project definition. **End Usage:** Class 5 estimates are prepared for any number of strategic business planning purposes, such as but not limited to market studies, assessment of initial viability, evaluation of alternate schemes, project screening, project location studies, evaluation of resource needs and budgeting, long-range capital planning, etc.	**Estimating Methods Used:** Class 5 estimates virtually always use stochastic estimating methods such as cost/capacity curves and factors, scale of operations factors, Lang factors, Hand factors, Chilton factors, Peters-Timmerhaus factors, Guthrie factors, and other parametric and modeling techniques. **Expected Accuracy Range:** Typical accuracy ranges for Class 5 estimates are - 20% to -50% on the low side, and +30% to +100% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. **Effort to Prepare (for US$20MM project):** As little as 1 hour or less to perhaps more than 200 hours, depending on the project and the estimating methodology used. **ANSI Standard Reference Z94.2-1989 Name:** Order of magnitude estimate (typically -30% to +50%). **Alternate Estimate Names, Terms, Expressions, Synonyms:** Ratio, ballpark, blue sky, seat-of-pants, ROM, idea study, prospect estimate, concession license estimate, guesstimate, rule-of-thumb.

CLASS 4 ESTIMATE	
Description: Class 4 estimates are generally prepared based on limited information and subsequently have fairly wide accuracy ranges. They are typically used for project screening, determination of feasibility, concept evaluation, and preliminary budget approval. Typically, engineering is from 1% to 15% complete, and would comprise at a minimum the following: plant capacity, block schematics, indicated layout, process flow diagrams (PFDs) for main process systems, and preliminary engineered process and utility equipment lists. **Level of Project Definition Required:** 1% to 15% of full project definition. **End Usage:** Class 4 estimates are prepared for a number of purposes, such as but not limited to, detailed strategic planning, business development, project screening at more developed stages, alternative scheme analysis, confirmation of economic and/or technical feasibility, and preliminary budget approval or approval to proceed to next stage.	**Estimating Methods Used:** Class 4 estimates virtually always use stochastic estimating methods such as equipment factors, Lang factors, Hand factors, Chilton factors, Peters-Timmerhaus factors, Guthrie factors, the Miller method, gross unit costs/ratios, and other parametric and modeling techniques. **Expected Accuracy Range:** Typical accuracy ranges for Class 4 estimates are -15% to -30% on the low side, and +20% to +50% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. **Effort to Prepare (for US$20MM project):** Typically, as little as 20 hours or less to perhaps more than 300 hours, depending on the project and the estimating methodology used. **ANSI Standard Reference Z94.2-1989 Name:** Budget estimate (typically -15% to + 30%). **Alternate Estimate Names, Terms, Expressions, Synonyms:** Screening, top-down, feasibility, authorization, factored, pre-design, pre-study.

CLASS 3 ESTIMATE	
Description: Class 3 estimates are generally prepared to form the basis for budget authorization, appropriation, and/or funding. As such, they typically form the initial control estimate against which all actual costs and resources will be monitored. Typically, engineering is from 10% to 40% complete, and would comprise at a minimum the following: process flow diagrams, utility flow diagrams, preliminary piping and instrument diagrams, plot plan, developed layout drawings, and essentially complete engineered process and utility equipment lists. **Level of Project Definition Required:** 10% to 40% of full project definition. **End Usage:** Class 3 estimates are typically prepared to support full project funding requests, and become the first of the project phase "control estimates" against which all actual costs and resources will be monitored for variations to the budget. They are used as the project budget until replaced by more detailed estimates. In many owner organizations, a Class 3 estimate may be the last estimate required and could well form the only basis for cost/schedule control.	**Estimating Methods Used:** Class 3 estimates usually involve more deterministic estimating methods than stochastic methods. They usually involve a high degree of unit cost line items, although these may be at an assembly level of detail rather than individual components. Factoring and other stochastic methods may be used to estimate less-significant areas of the project. **Expected Accuracy Range:** Typical accuracy ranges for Class 3 estimates are -10% to -20% on the low side, and +10% to +30% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. **Effort to Prepare (for US$20MM project):** Typically, as little as 150 hours or less to perhaps more than 1,500 hours, depending on the project and the estimating methodology used. **ANSI Standard Reference Z94.2-1989 Name:** Budget estimate (typically -15% to + 30%). **Alternate Estimate Names, Terms, Expressions, Synonyms:** Budget, scope, sanction, semi-detailed, authorization, preliminary control, concept study, development, basic engineering phase estimate, target estimate.

CLASS 2 ESTIMATE	
Description: Class 2 estimates are generally prepared to form a detailed control baseline against which all project work is monitored in terms of cost and progress control. For contractors, this class of estimate is often used as the "bid" estimate to establish contract value. Typically, engineering is from 30% to 70% complete, and would comprise at a minimum the following: process flow diagrams, utility flow diagrams, piping and instrument diagrams, heat and material balances, final plot plan, final layout drawings, complete engineered process and utility equipment lists, single line diagrams for electrical, electrical equipment and motor schedules, vendor quotations, detailed project execution plans, resourcing and work force plans, etc. **Level of Project Definition Required:** 30% to 70% of full project definition. **End Usage:** Class 2 estimates are typically prepared as the detailed control baseline against which all actual costs and resources will now be monitored for variations to the budget, and form a part of the change/variation control program.	**Estimating Methods Used:** Class 2 estimates always involve a high degree of deterministic estimating methods. Class 2 estimates are prepared in great detail, and often involve tens of thousands of unit cost line items. For those areas of the project still undefined, an assumed level of detail takeoff (forced detail) may be developed to use as line items in the estimate instead of relying on factoring methods. **Expected Accuracy Range:** Typical accuracy ranges for Class 2 estimates are -5% to -15% on the low side, and +5% to +20% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. **Effort to Prepare (for US$20MM project):** Typically, as little as 300 hours or less to perhaps more than 3,000 hours, depending on the project and the estimating methodology used. Bid estimates typically require more effort than estimates used for funding or control purposes. **ANSI Standard Reference Z94.2-1989 Name:** Definitive estimate (typically -5% to + 15%). **Alternate Estimate Names, Terms, Expressions, Synonyms:** Detailed control, forced detail, execution phase, master control, engineering, bid, tender, change order estimate.

CLASS 1 ESTIMATE	
Description: Class 1 estimates are generally prepared for discrete parts or sections of the total project rather than generating this level of detail for the entire project. The parts of the project estimated at this level of detail will typically be used by subcontractors for bids, or by owners for check estimates. The updated estimate is often referred to as the current control estimate and becomes the new baseline for cost/schedule control of the project. Class 1 estimates may be prepared for parts of the project to comprise a fair price estimate or bid check estimate to compare against a contractor's bid estimate, or to evaluate/dispute claims. Typically, engineering is from 50% to 100% complete, and would comprise virtually all engineering and design documentation of the project, and complete project execution and commissioning plans. **Level of Project Definition Required:** 50% to 100% of full project definition. **End Usage:** Class 1 estimates are typically prepared to form a current control estimate to be used as the final control baseline against which all actual costs and resources will now be monitored for variations to the budget, and form a part of the change/variation control program. They may be used to evaluate bid checking, to support vendor/contractor negotiations, or for claim evaluations and dispute resolution.	**Estimating Methods Used:** Class 1 estimates involve the highest degree of deterministic estimating methods, and require a great amount of effort. Class 1 estimates are prepared in great detail, and thus are usually performed on only the most important or critical areas of the project. All items in the estimate are usually unit cost line items based on actual design quantities. **Expected Accuracy Range:** Typical accuracy ranges for Class 1 estimates are -3% to -10% on the low side, and +3% to +15% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. **Effort to Prepare (for US$20MM project):** Class 1 estimates require the most effort to create, and as such are generally developed for only selected areas of the project, or for bidding purposes. A complete Class 1 estimate may involve as little as 600 hours or less, to perhaps more than 6,000 hours, depending on the project and the estimating methodology used. Bid estimates typically require more effort than estimates used for funding or control purposes. **ANSI Standard Reference Z94.2 Name:** Definitive estimate (typically -5% to + 15%). **Alternate Estimate Names, Terms, Expressions, Synonyms:** Full detail, release, fall-out, tender, firm price, bottoms-up, final, detailed control, forced detail, execution phase, master control, fair price, definitive, change order estimate.

VI. Small Hydropower Plants Definitions

Country	Power (MW)
Sweden	< 1.5
Italy	< 3
UK(NFFO[17])	< 5
UNIDO[18]	< 10
UNIPEDE[19]	< 10
ESHA[20]	< 10
Portugal	< 10
Ireland	< 10
Spain	< 10
AGMHP[21]	< 10
Belgium	< 10
Greece	< 10
Iran	< 10
France	< 12
Australia	< 20
Colombia	< 20
India	< 25
China	< 25
USA	< 30
Brazil	< 30
Philippines	< 50
New Zealand	< 50

(Varun 2008, Kumar 2008, AGMHP2008, ESHA 2004)

[17] The Non-Fossil Fuel Obligation
[18] United Nations Industrial Development Organization
[19] International Union of Producers and Distributors of Electricity
[20] European Small Hydro Association
[21] ASEAN-German Mini Hydro Project