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Time management challenges of major refurbishment projects

An analysis of 20 hydropower outages at Fortum

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Abstract

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While most western hydropower sites are already developed or protected by legislation, the aging hydropower park requires refurbishment actions. Especially to tackle the challenges of an increased fluctuation at the grid coming from the expansion of other renewable energy sources such as wind power. The company Fortum is carrying out a number of major refurbishment projects every year and want to enhance their time performance during the outage. Delayed projects are resulting in unexpected costs and production losses. By investigating 20 historical refurbishment outages from a project manager perspective, the delays are related to different sections of the outage time. These sections are referred to as work packages, meaning a set of activities related to a functional part of the plant. The material is based on interviews and project documentation. The outages are divided into three groups depending on the amount of delay and some additional set of factors are used in a comparison. The results are discussed from a time management and a multi-project perspective. The study can be viewed as an initial study to address time management challenges in a company. The methodology proves to be an efficient way to get time management challenges at a company to the surface. The results displays late manufacturing deliveries and overruns of assembly and erection durations as the most common reasons of delay. A number of potential success/failure factors are suggested. It is also pointed out that small projects are at risk being more delayed compared to larger ones.

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Preface

This thesis is written as a part of the Sociotechnical Systems Engineering programme for the degree of Master of Science in Engineering at Uppsala University. During the writing of this paper I have talked to lot of people. For many of you it might not have been the most inspiring topic: "what went wrong in your project" is perhaps not the first thing that comes to mind in the choice of interesting discussions about your job. But for me it has been very inspiring to get the chance to listen to the wide range of challenges that you are facing in your daily work. Thanks to all you project managers, project supervisors, generator experts, turbine experts, production optimizers, lawyers, dam experts and managers for teaching me about the hydropower business. Special thanks to Markus Johnsson for initiating this thesis, Hans Bjerhag for supervising me, reviewing my many drafts and teaching me about technical issues regarding the generator that unfortunately did not fit this paper. Also thanks to Marcus Lindahl that has kept me on the academic tracks and to Elísabet Andrésdóttir who has made this work go smoothly.

Thank you!

Daniel Nyqvist

Sammanfattning

Vattenkraft har flera fördelar gentemot andra energislag när det gäller elproduktion. Den kan stängas på och av på kort varsel och möjligheten att förvara vatten i dammar gör att man kan planera produktionen till när den behövs som bäst. Detta är särskilt viktigt med tanke på den ökade andelen förnyelsebara energislag då dessa mest genererar energi vid blåsiga och soliga väderleksförhållanden. Men utbyggnaden av vattenkraft har stagnerat i de nordiska länderna. Antingen är de flesta älvar utbyggda eller så har älvarna blivit skyddade av lagar som miljölagstiftningen. Samtidigt börjar de befintliga verken att åldras då flertalet byggdes från 40- till 60-talet. Behovet att renovera kraftverken är därför stort och viktigt för att bibehålla balansen i elsystemet.

För ägarna är det en konkurrensfördel att vara effektiva i hanteringen och styrningen av sina tillgångar. Bland annat är det viktigt att hålla nere de så kallade avställningstiderna, dvs den tiden då kraftverken måste vara avstängda för renovering. Avställningen kan innebära stora produktionsförluster. På Fortum Renewable Energy görs årligen flera stora renoveringsprojekt för att öka produktionssäkerheten och minska miljöpåverkan. Avställningstiderna för dessa projekt har dock ofta blivit längre än förväntat och Fortum önskar att bli effektivare i tidsplaneringen av projekten. Den här studien syftar till att förstå vilka orsaker som ligger bakom förseningarna. Genom intervjuer av projektledare och analyserande av projektdokumentation har avställningstiden undersökts. Särskild vikt har ägnats åt förståelsen av de avvikelser som har varit förklaringen till förseningarna. Undersökningen har gjorts utifrån ett projektledar-perspektiv där problemformuleringen har utgått ifrån projektledarnas åsikter. På samma sätt har potentiella lösningar formulerats utifrån detta perspektiv. Projekten går till så att kunden, som i det här fallet är Fortum, planerar de tekniska specifikationerna och utförandet som sedan upphandlas av olika entreprenörer som utför beställningen. Genom en granskning av den kritiska linjen i 20 avställningar, har olika arbetspaket blivit kopplade till utmaningar i projektstyrningen. Dessutom har avvikelser relaterats till arbetspaketen för en jämförelse av avställningarna.

Den kritiska linjen i större renoveringsarbeten följer i huvudsak av generator- och turbinarbeten vilket, bland annat, har legat till grund för kategoriseringen av avvikelserna. Resultatet visar på frekventa förseningar i arbetspaketet leverans av tyngre utrustning från både turbin- och generatorleverantörer. Monteringen och uppriktningen av den renoverade och/eller nya utrustningen var ett annat arbetspaket som ofta var försenat. Här bör företaget se över huruvida tidsuppskattningen kan vara för optimistisk med tanke på den svårighetsgrad som momenten i detta arbetspaket innebär. Det framgick även att tidsåtgången för detta arbetspaket är förhållandevis starkt förknippat med kompetensen och erfarenheten hos utförarna, vilket bör tas hänsyn till för att kunna göra en bra skattning i schemaläggningen. En mindre jämförelse av andra variabler för avställningarna gjordes där projekten delades upp i tre grupper beroende på storleken av förseningarna. Trots ett litet urval pekar resultaten på ett samband mellan projektets

prioritet och längden av förseningen. Särskilt tydligt var det för de mest försenade projekten.

Förslag på ytterligare studier har slutligen pekats ut. Bland annat kan en undersökning av effektiva metoder för styrning av leverantörskedjan, vara en intressant förlängning av detta arbete för att tackla utmaningarna i tidsplaneringen.

List of abbreviations

AD - (Fortum) Asset Development (Long term investment planning department)

AM - (Fortum) Asset Management (Operation & Maintenance department)

CPM - Critical Path Method

CCPM - Critical Chain Project Management

EPC - Engineering, Procurement, Construction

FAT - Factory Acceptance Test: *A test made in factory to ensure the quality of delivery of major equipment*

HPP - Hydropower plant

PM - Project manager

PS - Project supervisor

PMP - (Fortum) Project Management and Purchasing (Project management department)

PERT – Programme and Evaluation and Review

POT - (Fortum) Product Optimization and Trading (Business Area)

RE - (Fortum) Renewable Energy (Business Area)

SAT - Site Acceptance Test: *Similar to FAT but made on site*

SCM - Supply Chain Management

SPM - Sub project manager

WBS - Work Breakdown Structure

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1. Introduction

Hydropower has been utilized for electric energy production for over a century. Today, almost half of the electricity production in Sweden comes from hydropower plants located in the abundant river systems of the country. Though the vast majority of all Swedish rivers are already developed or protected by legislation, the hydropower plant park of Sweden and many other western countries is ageing and require devotion to refurbishment and maintenance (see Nilsson et al 2004; Perers et al 2005). As a clean and efficient alternative of electricity production, hydropower is a pivotal instrument in tackling the challenges of carbon dioxide emissions (see IEA 2002; Swedish Energy Agency 2013; Bartle 2002). Besides, hydropower has many positive features to damp the increasing supply fluctuations in the electricity system coming from expanding variable renewable energy, such as wind and solar (photovoltaic) power production. Therefore, to meet the future challenges of electricity utilization, it is of high importance that the hydropower plants available today are in the best possible condition regarding availability, reliability, safety and efficiency.

Every year the energy company Fortum's business area Renewable Energy (RE) is carrying out a number of refurbishment projects at its hydropower plants. This is done in order secure the long term production, increase the efficiency, to decrease the environmental impact and to secure the plant against unexpected and undesirable outages. For the outage to be short and the refurbishment work to be safe, the projects are planned very carefully. Despite this it happens that projects are delayed, leading to unexpected costs and production losses for the company. The duration of the outage is the most economically sensitive part of the project primarily because of the loss of production. In a hydropower refurbishment project, Forum are planning and engineering the job whereas suppliers carry out the majority of the construction. This kind of projects is often referred to as Engineering, Procurement, Construction (EPC) projects. The organization is planning many projects, from small to large, every year, which in the project management literature is referred to as a multi-project setting (Fricke and Shenhar 2000). To analyse this time management challenge, a study of 14 refurbishment projects, including 20 outages, has been made in order to find similarities amongst the projects that affects the outage time-target outcome.

1.1 Scope and aim

The study incudes: a literature review of project management with focus on time management (Chapter 2); a discussion about the choice of study and the empirical material (Chapter 3); a background description (Chapter 4) including a discussion about hydropower refurbishment projects in a wider perspective (Section 4.1) and an investigation of the parts and functions of a hydropower plant in relation to refurbishment (Section 4.2); a description of the project organization of Fortum (Chapter 5); a discussion about the outage period and a proper classification scheme (Chapter 6); two analyses of the time challenges including

- an analysis of the critical chain of the outages where deviations have been related to typical work packages of the outage (Chapter 7), and
- a investigation of potential time target success/failure variables based on a categorization of the outages to mark directions for further studies (Chapter 8);

a concluding discussion of the results and suggestions for further research (Chapter 9).

The purpose is to investigate the reasons for time management success or failure in a multi-project organization dealing with EPC refurbishment projects. More specifically, it is to find similarities amongst the projects during the project implementation period that, from a project management perspective, can be explanatory for the frequent delays of this period. Finally, the purpose is to a discuss strategies toward an enhanced time target performance.

1.1.1 Research questions

Based on the aim, two research questions have been identified.

- What are the time management challenges of an EPC refurbishment project in a multi-project setting?
- What are the scheduling potentials of a hydropower outage in an EPC project?

These questions are addressed by answering the following questions.

- What are the main explanations of the outage delays?
- What recommendations to enhance time management performance can be made?

1.1.2 Limitations

The study is limited to the outage period of the projects. It does not concern the entire project process and delays in other parts of the project other than in relation to the outage time. Moreover, the study neither concerns budgetary nor technological issues specifically. Similarly, these aspects are only in concern in relation to the outage time.

The study is limited to the outage period of the projects. It does not concern the entire project process and delays in other parts of the project other than in relation to the outage time. Moreover, the study neither concerns budgetary nor technological issues specifically. Similarly, these aspects are only in concern in relation to the outage time.

Factors that would be interesting to compare to the outage time should of course be related to the pre-conditions of the outage period and point out differences between the projects. From a strategic point of view, it could be interesting to look at production losses during the outage to see if the right strategic priorities have been made. Another investigation could look at supplier performance to estimate the uncertainty of different actors in a project. However, this report is focusing on the outage time from a project manager perspective. The strategic issues of the company are therefore only of minor importance. Total outage optimization would be an interesting extension of this study.

Last, it should be noted that different planned outage times are related to different project costs. The differences have not been considered when comparing the budgets but have, on the other hand, not been extremely varying. This would also put the focus on strategic issues but could also give a more accurate comparison between the outages.

2. Literature review

What insights has previous research attained in the understanding of time management success or failure in a multi-project organization dealing with EPC projects? To answer this question, a literature review has been made.

2.1 Success/failure factors and the multi-project

In the 80s and 90s many authors investigated the issue of project success and failure and suggested a variety of so-called critical success/failure factors (Atkinson 1999; Pinto et al 1987; Winch et al. 1996; see Söderlund et al. 2015). This literature names: top management support (Pinto and Slevin 1987); set-up of control mechanisms; monitoring and feed-back; clear targets to avoid "scope creeps" (i.e. an increase of the planned scope) and schedule duration urgency among many others as keys to project success. However, these success factors are usually listed as either very general or very specific factors affecting only a particular project (see Belassi and Tukel 1996; Engwall 2003). Belassi and Tukel (1996) found that when time is a measure of success, the project manager's (PM's) skill and communication between team members become critical. Engwall and Jerbrant (2003) discusses the importance for the PM to create prestige and legitimacy of his project in order to construct the project as technically interesting and strategically important. Belassi and Tukel (1996) also found that critical success factors in matrix organizations are more likely to be connected to project size and value. To avoid the dilemma of either a too narrow or to specific view, other researchers have addressed the need of a categorization of different project types, for example by "technological uncertainty" and "system scope" (Shenhar, 1998). Some studies have studied success factors in more specific project settings such as multi-project organizations (Fricke and Shenhar, 2000), in different organizational structures (Hobday, 2000) or in relation to different phases of the project (Pinto and Prescott 1988). Three studies of multi-project organizations have noticed that delays in small projects are generally higher than in larger ones which can be attributed mainly to higher priorities of the larger projects (see Fricke and Shenhar, 2000). Engwall (2003) names, among other things, the struggle to find available personnel the "resource allocation syndrome" as a common tendency in multi-project settings. He explains it as an effect of failing project scheduling and over commitment from the portfolio managers.

Ben Zvi and Lechler (2011) take a portfolio manager perspective and suggest that the scheduling less than 100% of the resources might increase the overall value for the organization. Kaulio (2008) studies the project leadership in an multi-project environment by a critical incident technique (CIT). He identifies common "critical incidents" for the project manager and leads the way toward a project leader perspective on the research field. Kaulio (2007) names *the stable definition versus flexible projects dilemma* of project leadership in multi project settings.

"On one hand, a well-known truth is that a sharp and stable project definition is crucial for project success, and that this definition should marshal work throughout the project. On the other hand, there is the need for flexibility and room to manoeuvre with an ability to adjust to the project to changing circumstances. The argument for the first position is found in the idea of doing things right-from-the-beginning. In contrast, the argument for the latter position is that a project cannot be planned completely, and that stakeholders: such as clients and steering committees, want to alter functionalities and/or available resources, and that learning takes place during project execution."

Laslo and Goldberg (2007) simulate conflicts between different resource allocation policies in matrix organizations and argue that budget and time target objectives are closely related.

"The dual objectives of meeting both a time schedule and of preventing a project from exceeding its budget are considered jointly in a high-tech environment with the interaction of these objectives under conditions of uncertainty requiring a consideration of ***feedbacks loops*** *during the scheduling process."* (Laslo and Goldberg 2007, pp.785; my bolding)

Furthermore, they argue that matrix organizations are unable to unite around one resource allocation policy due to divergent managerial interests between functional managers, PMs with high priority projects and PMs with low priority projects.

2.2 Time management

There are many project time management techniques. The most elementary is perhaps the Work Breakdown Structure (WBS) where all of the work necessary for reaching the project targets is broken down into different levels such as: *the organization, the plant, the functional units, work packages* and *activities.*

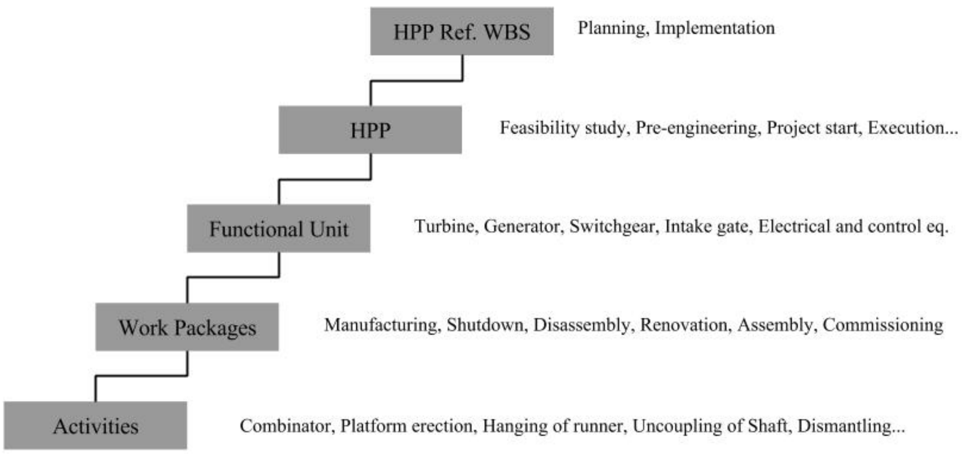

Figure 1: A work breakdown structure of a refurbishment project

To estimate project duration, a top-down or bottom-up approach can be used. Top-down means estimating the durations in the project by experience and references from earlier projects. Milestones are often the starting points of the top-down scheduling. Bottom-up means estimating activity durations and then arranging these in an order that enables the project to meet their goals. Statistical scheduling approaches like Project Evaluation and Review Technique (PERT) or deterministic ones like Critical Path Method (CPM) are common in project management that also are using resource dependencies between activities (see for example MacCrimmon and Ryavec, 1964; Kelley, 1961). These methods are today widely used in various scheduling software such as Primavera and MS Project. In the 90s, Goldratt (1997) developed a theory of time management often referred to as the Critical Chain Project Management (CCPM). It builds on the previous techniques. The theory claims to take into account typical human behaviour that can be expected during project planning and control. After the introduction of various scheduling techniques several approaches have been made in the field of time management: instrumental ones, where developed scheduling methods have been tested in projects (Bevilacqua et. al 2009); by comparative studies of different scheduling techniques (Steyn, 2001); by conceptual development of strategic frameworks (Mahmoud-Jouini et. al, 2004); and empirical approaches to investigate the management of activity duration uncertainty (Yeo and Ning, 2006). Ying and Ning (2006) make an observation of major equipment procurement delivery times. A common way to manage uncertainty of deliveries is to put in a buffer: the difference between the promised delivery date and the required-on-site date. This buffer is inserted in each level of the supply chain. Also, the longer the delivery time, the bigger the buffer between promised delivery date and required on site date. Thus a long supply chain and a long delivery time correlates with increased time waste.

2.2.1 Critical Chain Project Management

In Critical Chain Project Management (CCPM), one assumption about human behaviour is that while estimating activity duration, people make considerable provision for contingencies. Instead of increasing the certainty of meeting time targets, the extended project schedule becomes a self-fulfilled prophecy during project implementation. Normally, there are no incentives for a worker to be early to a milestone in a project. There are however incentives for the worker to improve the quality of the work when he is more likely accountable for the quality than for the schedule. Another problem recognized by the CCPM is multi-tasking. When jumping between jobs, the downtime of activities increases which affects the project duration negatively (Steyn, 2001)

The solution to these behaviours in time scheduling and project implementation is according to CCPM as follows. The chain of critical events is determined by taking into consideration resource dependencies and precedence. The critical chain is the series of activities that determines the earliest completion of the project. Each activity should be scheduled as the shortest time in which the activity could be performed in order to remove the "hidden" activity buffers for each activity. Activities not on the critical chain are put as late as possible in order to create urgency. In order to protect the critical chain, these activities are provided by a feeding buffer. A project buffer is created in the end of the project. The total time schedule of the project is shorter if the contingency buffers can be removed from each activity and only one buffer is made for the entire project. There are many suggestions about how to determine the length of the project buffer in the literature. Some are precise as "50% of the project completion time" (Bevilacqua et al, 2009) and others more vague like "should reflect the level of confidence of concerned parties in the project" (Herroelen and Leus 2011). In order to control the process the manager is keeping track of how much of the project buffer that is consumed in relation to how much of the project that is executed, and prioritizes resources to secure the critical chain.

2.3 Definitions in the text: delay, overrun and deviation

There are some frequently used terms that need to be defined to avoid confusion. A *delay* one might answer is something that is taking more time than expected. In this paper, "the expected" in the most strict and general meaning is the proposed duration of the outage settled in the project plan often two years in prior to the outage. It is represented by dates and time schedules with milestones. The duration is of high importance. This duration is (in almost all of the cases) the same duration that has been suggested in the investment proposal and has thus been a pillar in the decision-making of the project's proceedings. "The expected" in a more specific sense will be the activities in the more detailed time schedule produced by the PM closer to the outage, and followed-up during the site work. To avoid confusion, delays in activities or work packages will be called overrun. An overrun can be either be "consumed" by other overruns, handled by cutting succeeding activity durations or cause an outage delay.

The next clarification will be the word *deviation* which is used as the explanation to the overrun or delay. The explanation can be very different depending on the interpreter. Consider for example the following event.

Just before the commissioning of the unit, it was noticed that the rotor poles had been wrongly adjusted. When the unit was built, the workers had adapted the rotor to the slant stator. No documentation could be found about this action neither in prior of the project nor during investigations in the aftermath of the project. Now, instead of adapting the rotor to the stator, the rotor was aligned straight, which made it slant in relation to the stator. This caused four weeks of delay.

Here, the cause of the delay (the deviation) might be: insufficient work by the first supplier; insufficient work by the current supplier; insufficient planning by the client; insufficient documentation of the work performed by the first supplier or; bad luck. In this study, the interpretation of the cause is in the hands of the PM. But the interviews have also been focusing on constructive explanations, that is: explanations that can help the organization to learn and mitigate similar events. Thus the emphasis of the explanation in this case would be on the documentation and planning rather than on the work of the supplier.

3. Methodology

This chapter has four sections. The first section motivates the study from the stakeholders point of view and aligns it the research field. The second section discuss the selection of data. The third presents the methods briefly and the last section discusses the relation between the method and the empirical material.

3.1 The choice of study

3.1.1 Stakeholders

At the beginning of this thesis there were two starting points. Fortum could gain further insights of their refurbishment business by using their project documentation and experience from their employees. The same material could also be beneficial in the area of project management research. The methodology was shaped in the work of conforming these two starting points. In the role as owner of hydropower plants and client of major refurbishment projects, a very important aspect of Fortum's business is to be successful in managing their assets. As hydropower refurbishments are similar to their implementation, there is an opportunity to learn from earlier projects. At the same time, the project management research has given little attention to success/failure factors related to time management in EPC projects.

3.1.2 Scientific relevance

Statistical testing is a common approach to study a frequent misfit between planned expectations and realized results. It is often carried out with hypothesis testing based on surveys (Chan and Kummaraswamy 1998; Fricke and Shenhar 2000; Belassi and Tukel 1996). These "black box" methods, however, seem to lack connection to the understanding of the results: how different factors are related to each other and how they can be manipulated. They also tend to be biased depending on which stakeholder that is questioned (see Chan and Kummaraswamy 1998). For the results to be meaningful requires a good framework of comparability among the projects. In a single multi-project organization, the organizational structure, processes, hierarchy, technology and culture, are going to be more similar than across companies and businesses. These similarities shift the attention to more business specific explanations.

The *resource allocation syndrome* has been tackled from several perspectives such as the portfolio manager's (Ben Zvi and Lechler 2011), the project leader´s (Kaulio 2007) and the conflictual (Laslo and Goldberg 2007). With some exceptions (For example: Engwall 2003; Kaulio 2007) multi-project research has given most attention to the resource allocation from a portfolio manager´s or organizational perspective. Furthermore, most of the literature on time management of multi-project settings has been related to the scheduling of resources between different projects and has not been concerned with the time management of the single project in the multi-project environment.

Why is it interesting to study deviations? An obvious answer is that they are the closest explanation to the delay. They are therefore a good starting point for discussions. If an explanation is found to be frequent it can be interpreted as systematic. To study unexpected events has another major advantage, namely the abundance of information. When things are going as expected no actions are required and an evaluation seems unnecessary: "there was nothing to report, everything when well" is the common notion. When unexpected events occur a problem has to be solved, requiring analyse of the situation and decisions to be made. If it happens within a work site with several stakeholders, blame has to be addressed: the delay will be costly for at least one party. In a controversy, the contrasts between different stakeholders will be clearer: How aware was the supplier about the client's requirements? What did the PM really thought about the choice of suppliers? Or the choice of scope? Within these questions, there might be opportunities to lift the view from the single project perspective to the organizational perspective. The main disadvantage is that the study will give emphasise to the failure aspects and not on the things that can be regarded as strength within the company.

In time management and CCPM, the importance of the planning and monitoring of the critical chain is emphasized as an important factor to improve the speed in projects. It implies that success can be related to the planning and monitoring of the critical chain. CCPM is a relatively new time management approach and not widely acknowledged in the construction business. Building on other time management approaches and claiming to acknowledge typical human behaviour, it can be regarded as an interesting scheduling technique. The question is whether it would be suitable for the hydropower refurbishment business and what the major barriers are for its implementation.

3.2 Data selection

At Fortum, the size of the budget decides the type of project process (Nordell 2015, pers.comm., March 20). The bigger the budget the more administrative procedures in the project process. Moreover, in HPP refurbishments at Fortum, turbine and generator refurbishment are viewed as the most technically challenging projects with respect to time management. Many parallel activities by several subprojects and a range of suppliers and sub-suppliers should be coordinated.

The strive has been to hold as many parameters similar without stepping away from the projects that are viewed as challenging. Thus a large material has been filtered by interviews and reading of documentation. Two project dimensions have been developed by Shenhar (1998) and have been a benchmark for the selection. These are *system scope* and *technological uncertainty*. The system scope dimension of the project relates to the characteristics of the final product, the function performed by the final product and the organizational structure of the project. The technological uncertainty dimension relates to the level of uncertainty at the time of project initiation. The common denominators are related to both the planning and implementation of the project with regard to:

requirements of documentation and the planning procedure and the technology. To be comparable the projects have also had a similar critical chain during the outages. Seven criteria have been identified.

The project

1) is considered as a large project with regard to budget by the definition of Fortum (this also means that the project should have the same administrative procedures);
2) was executed between 2006-2014;
3) was finished or at least one outage period has been performed;
4) documentation was available in the internal database;
5) involves turbine and generator modifications;
6) has included the disassembly, assembly and erection of the generator and the turbine during the outage;
7) has been following a "normal" planning procedure, that is, not being initiated due to a major failure or similar circumstances.

After reviewing the documentation and discussions with employees, the choice was to conduct a qualitative study with the PMs in focus. The PMs, as responsible for the scheduling, the monitoring and the documentation process of the refurbishment projects, should be the most engaged in the issue of time management. The PMs have been selected if they have been in any of the chosen projects. 28 employees have been interviewed of which 10 was PM's. The PM interviews have been more structured with a length of 1,5 hour. The interviews have often touched different aspects of the project. In all but three projects, the PM has been interviewed. In those three exemption cases, the documentation has been seen as satisfactory to get a good picture of the outages. The interviews have been semi-structured which means that the questions have had some decided topics without following a strict questionnaire. The structure of the interviews has been as follows. Firstly, open questions about the project manager's background and his role at Fortum. Secondly, discussions about which projects that might be of interests in this study. Thirdly, each relevant project has been addressed with questions in the following arrangement.

- The pre-conditions of the project: how was the project organized? What was the motivation of the project? What was most significant for this project? What was included in the scope? Etc.
- The deviations of the project: what were the causes of the deviation? What consequences did it make for the time schedule? What mitigating actions were taken? What could be learned from this incident from a planning perspective? Etc.
- The time management practices: On what knowledge is the time schedule developed? Who is participating in the time management? How is the time schedule used in the procurement? Which activities are critical? Etc.

Here, it would be appropriate with a discussion about the interview method. In the start of this study, one suggestion was to find qualitative measures that could be explanatory of the success or failure of meeting time targets. This mission is however increasingly difficult, the more similar the projects are to each other. In this study, the selected projects have (by definition) had the same organization, the same technical uncertainty level and the same objectives with only small differences. The explanatory factors of project success or failure must therefore be found in other domains. A semi-structured interview will allow for discussions that encourage the respondent to bring up relevant topics. This approach also resulted in an additional investigation of the success/failure factors.

Apart from the interviews, the documentation of each project has been reviewed. The documentation can be divided into three categories depending on its proximity to the outage in question. These are planning, monitoring and review. The documents from the planning phase are representing the expectations of the project implementation and include project reports, time schedules, risk management plans and condition reports of the power plants. The monitoring documents are monthly reports and meeting protocols. These are written just before, during or just after project implementation and gives insight in the decision making process in action. Last, we have the review document (called the Final Report). It is summarizing the project actual results compared to the planned expectations.

All documents are written by the PM. They are representing the project manages view of the project during the planning, implementation and closure stages of the project. The documentation has been accessible in varying degree. The reason for the varying degree of accessibility can be:

- Different requirements for documentation for older and newer projects,
- Different practices between PMs,
- Different practices between work places,
- PM has left the company,
- The lack of time for search of documentation

In Appendix A, the availability of documentation and interviews is complied.

3.3 Method

Two different methods are used in this study. The first method is "bottom-up" where deviations are derived from each outage. The second is a top-down method where potential success/failure factors are compared to the time target performance of the outage.

3.3.1 Deviation analysis

The deviations (i.e. explanations to the delay, see section 2.3). addressed in the interviews or in the documentation, are related to each of the 20 outages. The deviations are categorized into a classification scheme, which is developed by looking at similarities of the outages periods (see Chapter 6). Each class is discussed in relation to the identified deviations. The most frequent and similar deviations are exemplified. Classification boundary issues are discussed when the classification is particularly difficult. The frequency of the deviations of each class is measured and divided into sub-groups if such were found.

3.3.2 Investigation of potential success/failure factors

Here, some potential pre-execution success/failure factors are investigated based on suggestions from interviews and literature. The outages are divided into three different groups depending on percentage of delay and compared to each other. Also, the findings from the deviation analysis are used to find differences and similarities between the groups related to the project implementation phase. The method is described in detail in Chapter 8.

3.4 Empirical discussion

Finally, there should be a discussion about the appropriateness of using documentation and interviews as the empirical basis. As mentioned, one differences of the character of the material is the proximity to the event. Another one is intentionality. Where the documentation are closer to the event compared to the interviews, the texts might also be written for special purposes. For example, if a supplier has been delayed, the PM has to prove the delay in order to address penalties on the supplier. This will affect the way in which the PM explains the delay in the documentation. Conversely, the information from the interviews might have issues related to the difficulty to remember but does not have the same intentionality related to the supplier. The interviews and the documentation will therefore be complementing each other very well. Despite this, the issue of bias cannot be avoided. Considering the amount of stakeholders in a project with different goals and interests there will also be many explanations of a delay. In this study, the explanation is only related to the PM of the project thus it only deals with the project managers perspective. One question on the issue of bias is how we shall interpret the results? The answer is that the results of this study should rather be interpreted as the aggregated opinions of the PMs in the organization rather than the holistic view of the deviations.

4. Background

In order to understand HPP refurbishment projects, one should be familiar with the environment in which it exists (see Engwall, 2003). It is important to understand which technical, legal and economic factors that affects the project in order to understand (1) what kind of processes that are required in the project, (2) what achievements that are defining project success and (3) what role time management has compared to the management of quality and economy in the project. This chapter has three sections: section 4.1 describes how hydropower production and the electricity market is related to each other. Section 4.2 continues by describing the hydropower technology in relation to refurbishment considerations. In section 4.3, a more explicit discussion is being held about the implications of the results: how the project process is shaped, how trade-offs are being made, what is defining project success, and the role of time management. By no means is this chapter intending to be a comprehensive study of all the above-mentioned aspects of hydropower refurbishment projects. Instead, the chapter should be viewed as background information to the discussions about refurbishment projects and the time management practices of Fortum in the case study.

4.1 The project environment

Hydropower differs from other energy sources. The energy carrier, "the fuel", of renewable energy sources (in contrast to non-renewable technologies) is characterized by a flow instead of being extracted from an inventory such as an oil basin or coalmine. But renewable energy sources (such as photovoltaic, wave or wind power) are often unable to effectively store their energy carrier. In contrast, water can be stored in river basins for a shorter or longer period of time. Furthermore, hydropower plants in contrast to all other energy sources can quickly vary their production as well as be turned on and off on short notice. These are highly desirable features of power plants that give them many advantages. For example, the possibility to optimize energy production to times with higher demand and higher electricity prices, or quickly respond to frequency and voltage fluctuations at the grid. Since the deregulation in Sweden 1996, electricity trading has developed into several markets and the quantity (i.e. price/kWh) is no longer the single commodity (EI 2015). This is partly due to a changing production portfolio at the Nordic electricity market. As the share of variable renewable energy production (e.g. wind power) increases so does the fluctuations in the grid, and the reliability of the total production degrades. To keep availability and reliability of the grid, the Swedish Transmission System Operator (TSO, in Swedish: Svenska Kraftnät) has the overall responsibility of the balance of the national grid. In order to keep control of the balance, SvK has established other means of electricity market structured products. Increased value has thus, in recent years, been given to power availability and regulatory abilities of the plants (Pettersson 2015, pers.comm. February 9). This is also creating higher incentives for these investments to the electricity companies.

But plants with regulating capacity were often built for continuous operation, not for frequent start and stops and highly varying production. The implementation of regulating features therefore requires the development of new operating lifetime prediction models.

Though the general concept of the hydropower technology has not changed much since the end of the 19th century, the variation within the concept is vast. The plants have been constructed according to the existing technology, the legal framework, the market structure and the social norms of its construction time (see for example Jakobsson, 1996 or Fridlund, 1999). Today, the Nordic rivers are protected by legislation and, consequently, few new plants are being built. Any major modification of an existing plant requires permission and an assessment of the environmental impact is required for a new adaption of the plant (Ribbing 2015, pers.comm. April 1). Furthermore, for each plant there are agreements on maximum and minimum water levels along the river. These agreements can vary depending on the season. As each power plant in a river is unique they are also dependent on each other. The discharge of one plant will affect the discharge of the plants downstream etc. Hence the optimal production of one single power station will not necessarily be optimal for the entire hydropower system of the river (Pettersson 2015 pers.comm. February 9). The dependence between the power plants extends if one also consider their connection to a common grid. The dependence between production and consumption is one of the considerations. The main criteria's for the availability and reliability of electricity from the grid is that production and consumption need to be matched at all times and the frequency of the grid strives to be constant.

4.2 The hydropower plant

In this study, the most interesting distinction between different plants lays in its ability to be turned off for a longer period of time without the need to "spill" water in the spillway gates during the outage. This might depend on water storage capabilities up-stream or number of turbine-generator pairs (units) and their capacity. This will significantly determine the loss of income of the outage. A broad distinction can therefore be made between plants with and without substantial reservoirs. The latter are often called run-of-river plants. A large upper reservoir provides great opportunities to schedule production to maximize profit and secure availability, both daily and annually (Munoz-Hernandez 2013 p.17-23). The storage capability of the power plant is therefore also affecting the potential losses of income in case of an outage.

The main parts (counted from up-stream to down-stream) of hydropower plants are: the upper basin, dams, the inlet (channel), the intake gate, the penstock/inner waterways, the turbine, the generator, electrical and control equipment, the draft tube gate, the outlet (tunnel/channel) and the lower basin. Some of the components might not be existing in all designs. For example, there might not be an draft tube gate or intake gate in a smaller unit. Moreover, some of these parts can be considered to have their own sub-systems. While electrical equipment usually consists of a multitude of different systems, the switchgear and the transformer is common for all plants. Naturally in a refurbishment project, each of these components might be in concern for the refurbishment. But a refurbishment does not necessarily require a long outage period of the unit. Works in the waterways, major dam works as well as refurbishments of generators, turbines and other active components usually require an outage. The following section will deal with the parts of major concern in a larger refurbishment project with substantial outage time.

4.2.1 The turbine

The most complicated part of the turbine is the runner. The water enters the turbine through an inlet channel (penstock) and is guided to the runner through stay vanes and guide vanes. The stay vanes in contrast to the guide vanes are fixed. They both have the purpose of distributing the water evenly to the runner. The guide vanes are regulated in order to increase efficiency and control the flow of the water. The runner and the generator is connected by their shafts which is mounted to each other. The shaft has thrust and guide bearings to carry large stresses. Finally, the water goes through a draft tube which is designed to preserve the water head of the unit. The head is the difference in height between the upper and the lower basin. Although there are no universal distinction of heads sizes, they can be divided into low (< 30 m), medium (30-300 m) and high (>300 m) heads (IEA, 2012). There are several types of turbines and the configuration and selection of type mainly depends on the rate of flow and the head of the water.

The Francis turbine is used normally at medium heads with large flow. It is categorized as a reaction turbine but is partially functioning as an impulse turbine due to the specific s-shape of the runner blades. The water flows horizontally in through a spiral casing and is distributed by the stay vanes and guide vanes to hit the runner blades at an optimal angle. The difference between the higher pressure at the front side and the lower pressure at backside of the blades creates a momentum in the runner. The blades are designed to change the horizontal flow to a vertical flow out of the runner. When the water hits the s-shaped blades vertically it creates an extra impulse to the runner. **The Kaplan turbine** is an axial flow reaction turbine. Like the Francis turbine, water enters through a spiral casing with stay and guide vanes but it is diverted axially onto a runner whose blade pitch can be controlled. The Kaplan runner looks like a big propeller with 3-7 blades. It tends to be used at sites where the head is relatively low (<100 m, mostly <50 m) and are very common in rivers in Sweden. Kaplan turbines can handle large water flow. Kaplan turbines can also be installed with a horizontal shaft and are then called bulb turbines. This configuration lacks a spiral casing. Sometimes they are equipped with a gear box to increase the speed to the generator. **The Pelton turbine** is an impulse turbine and is used in upper medium to high range heads with low flow. The water is transported into tubes where it is concentrated to jet streams. Its runner consists of spherical shaped buckets that convert the kinetic energy from the jet stream to rotational energy (Bjerhag 2015, pers.comm. May 27).

Many hydropower plants in the Nordic countries were built in the 40s, 50s and 60s, have been operating since then without any major refurbishments. Long operation leads to deterioration of the components and causing decreased efficiency of the turbine. After half a decade of technological development, there could also be opportunities for improvements and the operational function might be different today. Considering the increased demand for regulating capacity, there might be incentives to re-configure the plant to have more power capacity instead of the conventional focus on energy production.

The runner blades are a common concern in turbine refurbishments and the problems include cavitation, blade cracking and deterioration from rough operation and seal clearance. Cavitation occurs when the water pressure is so low that it starts vaporising. Small vacuum bubbles of vapour are formed. When the vapour implodes back to liquid state again, it creates a highly erosive, "explosive" reaction, which erodes the surface of the runner blades and runner chamber walls. In Francis turbines, efficiency improvements can often be obtained by reshaping (grinding) runner vane edges and cutting back runner tips (which can increase the runner vent area, admitting more flow). Another action might be the restoration of runner vane surfaces to original shape, which could lead to a "dramatic improvement in performance and power" (Goldberg and Espeseth, 2011 p.20). Cavitation repairs in the past can in some cases have significantly choked the runner. Other parts under water during operation, such as the distributor, can also suffer from cavitation damages. If there is oil based lubrication in the bearings, the change to water based lubrication mitigates the risk of pollution from leakage.

4.2.2 The generator

The generators of hydropower plants are most often of synchronous type. The main components are the stator and the rotor. The rotor consists of field poles made of electromagnets, a rotor ring, a hub and a shaft that is connected to the turbine. The electromagnets are created by the feeding of direct current through loops of wire around an iron core, normally made of stacks of lamination. In old machines the iron core might be cast in one piece instead of made of laminations. The system that feeds the rotor is called the excitation system. The stator encloses the rotor. The distance between the rotor and the stator is called the air gap and is an important factor in the generator performance since an unsymmetrical gap leads to mechanical vibrations. The active parts of the stator are the windings of the conductors and the iron core. The rotating electromagnets in the rotor create an alternating electromagnetic field along the stator that induces an electromotive force in the stator windings and creates electricity.

The most sensitive parts of the generator are the windings in both the stator and the rotor and re-winding is a common activity in refurbishment projects (EPRI, 2006 c.4 p.1). The windings are exposed to several strains during operation: high intensity electrical fields which can lead to corona discharge; thermal strains which make the material contracting and expanding, and mechanical strains due to vibrations and wear. The thermal strains can make the insulation in the stator winding to loosen, making the adherence between the copper and the insulation poor that develops partial discharges in the cavities of the insulation. In addition, coronas that occur between the windings and the core can create ozone, which is very corrosive for equipment and unhealthy for the staff (Feurst, 2007 p.19).

The iron plate lamination in the stator core is another consideration for refurbishments. Due to mechanical and thermal strains, the iron laminations can get buckled which means higher risks for short circuits between the sheets. Moreover, when the sheets are in contact, the induced current increases in the core, which leads to more iron losses, higher temperature and thus more thermal strains, more buckling of the laminations, more induced currents, decreased efficiency of the generator and in the end breakdown. Other things that might be in concern of a refurbishment are cracks in the welding's of the generator rotor hub and the foundation bolts (Feurst, 2007 p.20). According to EPRI (1999) mechanical aspects of the generator is often overlooked due to the general conservative approach to design of older units and they suggest several considerations if the unit is upgraded. In situations with increased torque or heavier load, the shaft, the coupling bolts and the rotor spider have to be evaluated. Furthermore, older castings can be of relatively low quality and the hub-to-spider area is particularly vulnerable in old castings.

4.2.3 Other functional units

When a unit is taken out of operation, there is a good opportunity to change some electrical and control equipment. **Electrical and control equipment** is just a generic name for various electrical sub-systems such as governors, control systems, monitoring systems, transformers, relay protections, breakers, isolators etc. Much of electrical equipment provides or enables so called "ancillary services". Ancillary services are "the services necessary to support transmission of energy from resources to loads while maintaining reliable operation of the transmission provider´s transmission system" (EEI, 2005). These services could provide: the ability to start the unit without support from the grid (i.e. black start); non-spinning, spinning and replacement reserves; regulating and frequency response, and voltage support. Electrical and control systems often does not have the same operating life time as the generator and the turbine has. The expected life time is usually 10-15 years for computer systems, 20-30 years for other control equipment and about 20-30 for other electrical equipment such as switchyards and transformers (Bjerhag 2015, pers.comm. May 27).

Civil work includes all of the work related to the civil engineering or construction matters of the power station and can include work on the dam or on other facilities of the power plant. It also includes works in the waterways. It is especially the works in the water ways and in the turbine that requires the unit to be shut down that is of interest in this study. Dam work projects are usually separated from generator and turbine refurbishment projects because they do not necessarily need an outage period. Works in the waterways can increase the water head and the flow. The refurbishment of turbine parts such as the spiral casing and the draft tube can increase efficiency of the unit by increased flow efficiency and discharge capacity. Major civil work around the turbine can call for longer periods of outage time. For example, if the draft tube should be modified and concrete has to be removed, the equipment of the unit has to be protected from the dust and the turbine-generator pit has to be sealed.

Mechanical systems can be gates (spillway, intake and draft tube gate) hydraulic systems. It also can also be turbine hydraulic systems. Mechanical systems that are not directly related to the active parts of the hydropower plant can instead be viewed as auxiliary systems.

Auxiliaries are everything else in connection with the hydropower plant. It can include station electrical, compressed air, water and sanitary systems but can also be fire protection, cranes, building ventilation and elevators. These systems are mostly regarding the power house and are particularly of interest considering the safety of the personnel of the power station. Often, these systems do not need to be refurbished during the outage time (EPRI, 1999). For example, overhead cranes can be refurbished before the outage but are required to be functional during the outage.

4.3 Summary and discussion

As illustrated, there are many factors in a refurbishment project to consider besides the technical issues regarding the plant. On a short term, each project requires production planning and legal permissions. On a long term, strategies regarding the specific utilisation of the plant have to be settled. The big variation of hydropower plants where each plant has its own location, construction time and legal settlements makes each project unique.

4.3.1 Time, cost and quality

In the literature, the targets *time cost and quality*, called the "iron triangle" and are common measures of success (Atkinson 1999). Customer satisfaction and environmental impact are other suggested targets. Even though large efficiency or power improvements are rare due to both legal and technical constraints, the long operating lifetime can make small gains count. But an expensive investment (such as the projects in question in this study) with refurbishment or renewal of a turbine or a generator can seldom be prioritized by its upgrade potential. In the selection of projects in the portfolio, the risk of a major failure will most often override the opportunity of an upgrade. A strong focus during both planning and during the outage will be on, for example, minimizing mechanical or thermal strains that wear the equipment during its operation. An outage is linked to production losses hence the importance of meeting the time target will depend on the character of the plant, the water level and the market prices more than on other issues. Table 1 shows the major interpretation of the different targets and relates it to the factor that affects the target importance the most.

Table 1: Time, cost and quality attributes

Target	Major interpretation	Major affecting factor
Time	Production system losses	Plant type
Cost	Plant importance	Company strategy
Quality	Securing operation reliability	Plant condition and upgrade potential

During an outage, adjustments to enhance the quality of the equipment can be time consuming and the progress can be uncertain. The trade-off between time and quality during the outage will therefore be the same as the question of long term or short term return of the investment: is it better to delay for further adjustments with a resulting instant production loss or can we risk a faster deterioration and save production? Because the client is also the planner of these projects, costs and loss of income due to production losses are very much related. A delay is therefore highly measurable in terms of impact (in comparison with, say, a new product development project) and can be almost directly compared to the costs of speeding up the progress. This enables a high degree of preparation for handling deviations during the outage. For example, what an additional week of outage is worth compared to more manpower and overtime working, can be fairly accurately calculated. Table 2 illustrate how some decision-making during planning and implementation can be related the time target.

Table 2: Decision-making about quality and costs having impact on time during the planning and implementation phases

Targets	Affecting trade-offs during planning	Affecting trade-offs during implementation
Time & Quality	Increased scope vs increased outage duration	Further adjustment vs prolonged outage time
	Renovation vs increased outage duration	Scope creep vs prolonged outage time
Time & Cost	Increased scope vs increased outage duration	Increased working hours vs shorter outage time
	Renovation vs increased outage duration	
	Fast supplier vs decreased outage duration	

5. Fortum: organization and project management

The chapter describes the project organization and the project management practices of Fortum. The first section deals the organization from company to project level. The second section is a review of the time management practices and the PMs opinions of the organization based on the interviews.

5.1 Project organization

Fortum is a Finnish energy company with business in Sweden, Finland, Russia, Poland, India and the Baltics with focus on hydro and nuclear electricity production and district heating. Besides the main areas, Fortum has solar, wave and wind power production, and until recently (2015) electricity distribution in its portfolio. In 2013, Fortum employed almost ten thousand people, had a turnover of 6,1 billion euro and an operating profit of 1,7 billion euro. Fortum operates 160 hydropower plants with 265 power units in Sweden and Finland, which produce around 22 TWh of electrical energy annually. The company is handling the planning and management of the refurbishment projects internally in a business division called Hydro Power and Technology, while the project implementation is outsourced. The division is divided into three business areas called: Physical Optimization and Trading (POT); Renewable Energy (RE) and New Markets and Business Development. POT and RE are the main business areas involved in the refurbishment projects. While POT's main objective is to optimize production in the hydropower plants on an hourly, weekly, monthly, yearly and long term basis, RE is responsible for the assets (the major part is hydropower plants and dams) and to operate smoothly and planning refurbishment projects. While POT is focusing on the decision of picking optimal dates to perform the outage of an investment project, RE is working on the planning and implementation of the refurbishment projects. In recent years, POT and RE have more strongly recognized beneficiaries in a closer collaboration between the business areas. RE is also divided in three subunits for: development of the assets (AD), project implementations (PMP) and management of the assets (AM). The organization is summarized in Table 3.

Table 3: Organizational structure of Fortum RE

Organization Level	Name (Abbreviation)
Division	Hydro Power and Technology
Business area	Renewable Energy (RE), Physical Operations and Trading (POT)
Subunit/Department	**RE:** Asset Development (AD); Project Management and Purchasing (PMP); Asset Management (AM).

Fortum is using a stage-gate model for its project process where a project is divided into *stages, phases and gates* as illustrated in Figure 2. In a Stage-Gate model, decisions at the gates usually have to be approved by steering committees or managers in the organization. By engineering and planning, Fortum is making the technical specifications for the contracts. The Request for Proposals (RfP) is then sent to potential suppliers and the tendering starts. During the procurement, plans and specifications are settled in contracts. The contracts can be described as arms length's contracts where the parties are independent of each other. If new equipment is ordered, the supplier starts the manufacturing according to the specifications. For major equipment, the manufacturing can start two years in prior to the outage period.

Fortum's project model is inspired by PROPS (PROjekt för ProjektStyrning), a famous Stage-Gate project model.

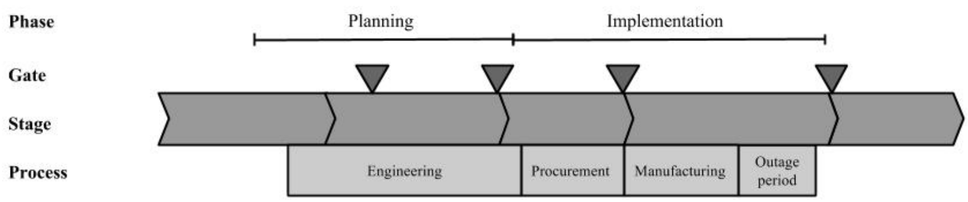

Figure 2: An example of a Stage-Gate model

5.2 Project management

Fortum is using a wide range of classic project management tools such as: time scheduling, quality plans, cost control, project reports, and risk management plans. The scheduling starts with a top-down approach. Answers such as "we know how long an outage usually is, we have done many projects" was frequent. External milestones for delivery dates and certain procedures during the implementation are common practice. Meeting an external milestone often means payment. One milestone during the outage that always is present in the contracts is "turbine shaft free" during the erection of the generator and turbine and takeover (see section 4.4).

Bottom-up scheduling is also utilized in a later phase. The main time schedule is designed with the help of subproject managers and technical experts. The project managers are using experience within the company. Often, time schedules from earlier projects are sources of information. The main time schedule is first used externally in the tendering. Here, general milestones and a proposed outage period are already relatively solid. In the competition of getting the contract, the suppliers are rarely negotiating the milestones. The project managers agreed on the notion that if a supplier would suggest a shorter time for their job, it was a competitive advantage for the supplier. There was also consent of the importance of a thorough review of their strategy to handle the work within the time schedule. In some interviews it was mentioned that the project managers were asked to review their time schedule with the objective to shorten its duration. However, on the question of whether they in general felt that they had control over their projects, the consent was that they had.

6. Classification of deviations

This chapter intends to describe the outage period from a project management perspective with emphasis on time management. Focus will be on the challenges during this period. Next, a discussion of an appropriate classification scheme to make sense of the planning of the outage time is being held. This classification is described and followed by an analysis of the 20 outages where the deviations are connected to the classes. Each class-section ends with a discussion about the major findings of the analysis. The most important feature of this classification should be that it makes the different outages comparable. It should also be meaningful from a project management perspective, in particular regarding time management.

6.1 The outage period

Many refurbishment activities can only be made when the plant is out of operation. The most obvious ones are perhaps those that involve the turbine and the generator, but also control equipment, intake gates, transformers and switchgear refurbishment or renewal, requires an outage. Of course, the required outage time for the refurbishment of these subsystems varies, but it can often be advantageous to make many minor refurbishments during the same outage in order to lower the total outage time and thus the production losses. In the refurbishment projects there are usually around four or five subprojects divided by the technical expertise required: generator, turbine, electrical and control equipment, civil work, mechanical and auxiliary systems (the common content of each subproject is described in section 4.2). It was found that the vast majority of all delays was related to either the generator or turbine, whose work packages are on the critical chain. It was also noticed that the refurbishment work packages follow a certain order. Each part of subject for refurbishment or replacement during the outage has to be taken out of use, dismantled, manufactured or refurbished, assembled and taken into operation. This is valid for both the turbine and the generator. Moreover, and more importantly, this division of different phases of the outage into work packages was commonly used by the PMs to make sense of deviations in the project.

The work packages in this study are illustrated in Figure 3 and called: ***shutdown***, ***disassembly***, ***manufacturing***, ***renovation***, ***assembly***, *and* ***commissioning***. The term *interface* is used as a word to describe that there are resource dependencies between different work packages. A proposition in this study was that these work packages share common characteristics in terms of risk and deviations and therefore require different actions from the PM in regard to both planning and the implementation phase.

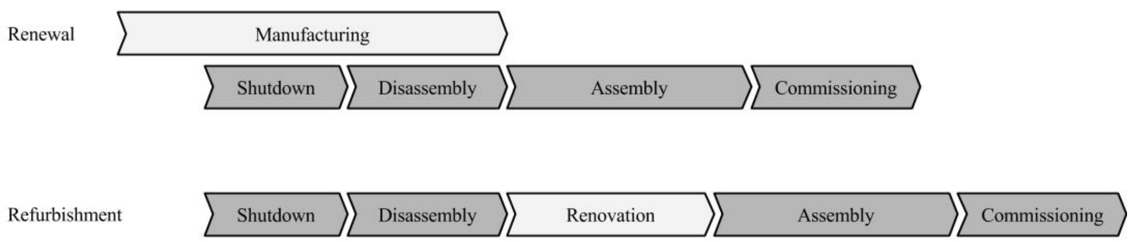

Figure 3: Schematic picture of the work packages

6.2 Description of the work packages

An outage period starts with a ***shutdown*** of the unit. In the shutdown the unit is taken out of operation and the turbine area is drained. Often, this is not a major challenge since there exists a system for this with intake and draft tube gates and pumps. Sometimes though, there are some additional actions required. For example, in order to refurbish and paint the intake gates they have to be removed from their position in the waterway and instead a coffer dam, e.g. segments of arc stop logs, is used to keep the water out of the intake of the plant. This requires additional construction machines and normally also the work of divers. After the cofferdam is in place, the intake gates can be removed, the inlet penstock and the turbine area are drained by pumps. Water leakages from the coffer dam or stop logs are fixed by putting cinder in the slots. The turbine dismantling cannot start before the turbine area is dry and the commissioning (later explained) cannot start before the intake gates are in place and the cofferdam is removed, which make these activities critical.

Next work package is ***disassembly*** where all the parts in question of refurbishment or disposal are removed. During the disassembly measurements are taken and inspections of the dismantled parts are made. The condition of the turbine and the generator can only be fully revealed during a dismantling. For the turbine, only the dismantling takes three to four weeks and is not economically feasible to perform in prior of the refurbishment. There are however other methods to reveal some of the condition in prior without the dismantling of the turbine with, for example, ultrasonic and visual inspections. This is done according to an inspection scheme that is used as a basis to prioritize the refurbishment project in the investment planning stage. Sometimes, further minor inspections are done with the contracted suppliers. Because of the difficulties to have full control of the plant condition it is very important to make good measurements and inspections early in the disassembly. Late discoveries of parts in bad condition can lead to "scope creeps" and potentially threaten the critical chain. An interface between the generator and the turbine work packages is the elevation of major equipment from the turbine pit illustrated in Figure 4. It is a critical part regarding coordination. The runner has to be mounted on a scaffold and then the turbine and generator shaft can be dismantled and the rotor removed. When the rotor and the stator are gone, the turbine is elevated form the pit. Considering the heavy weights of the parts, the interface and the small space in which the activity is performed, this task requires accuracy, experience and coordination.

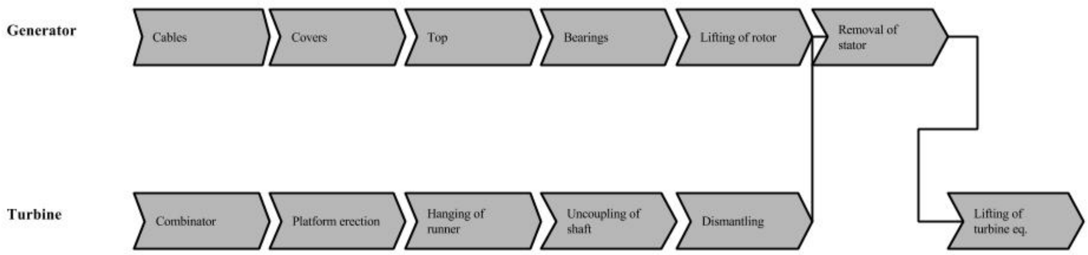

Figure 4: Schematic picture of the disassembly with interfaces

There are two separated work packages that are required to be finished in order to proceed to the assembly, namely ***manufacturing*** and ***renovation***. The advantage of manufacturing is that the manufactured part can be assembled (conceptually speaking) as soon as the old part is removed. The manufacturing work package starts as soon as the procurement is settled and ends with the assembly work package. Manufacturing should not be on the critical chain of the outage time and should therefore, according to CCPM be scheduled with buffers in order to protect the critical chain. Technically, more gains in efficiency and lifetime can be accomplished by deciding on new parts. On the other hand, manufacturing of big parts takes long time, costs more to purchase and often requires the whole chain from engineering to delivery. For the biggest parts such as stator frame, stator core, rotor poles and turbine runner, the delivery time may be 1-2 years. Even smaller components such as guide vanes can have delivery times of 6 months (Boberg 2015, pers.comm. March 26). There is also an economic dimension of the delivery time. If the client needs a short delivery time, the supplier will naturally demand higher prices. The advantages with renovation are the lower price and the proven compatibility of the part. Not surprisingly, renovation in comparison with manufacture can only be conducted within the outage period. Common activities such as rewinding of the stator can be done on the site whereas re-insulation of rotor poles, guide vanes and other turbine parts requires workshop renovation. If a bigger part is decided to be renovated and is discovered to be in dubious condition for a renovation work, the risk of prolonged outage period is significant. For bigger parts, manufacturing and renovation both ends with inspections, tests and approvals of the delivery.

Assembly is the work package when refurbished and new parts are assembled and the generator and the turbine are erected. One challenge is to fit old parts with new parts, which requires flexibility in the workmanship. If any part has been designed wrongly, it will most likely be discovered here. The assembly work package has several interfaces: between the generator and turbine subprojects; between the turbine and the electrical and control subprojects, and; between the generator and the electrical and control subprojects. The most difficult part of this work package is the erection of the whole unit (see Figure 5). This procedure requires collaboration between the turbine and the generator subprojects and has to be thoroughly planned. In the case of two different contractors for generator and turbine refurbishments, responsibilities of each subproject have to be very clear in order to address penalties. First, the turbine team erects and aligns the turbine and the turbine shaft. If there are separate contractors, the generator contractor has to approve the turbine erection, the so called "turbine shaft free". Next, the generator team will centre the stator in relation to the turbine shaft and begins the erection of the rotor. When the rotor shaft is erected the coupling work of the turbine and the generator shafts starts. With separate contractors one has to be responsible for the coupling in order to address responsibility in case off disputes.

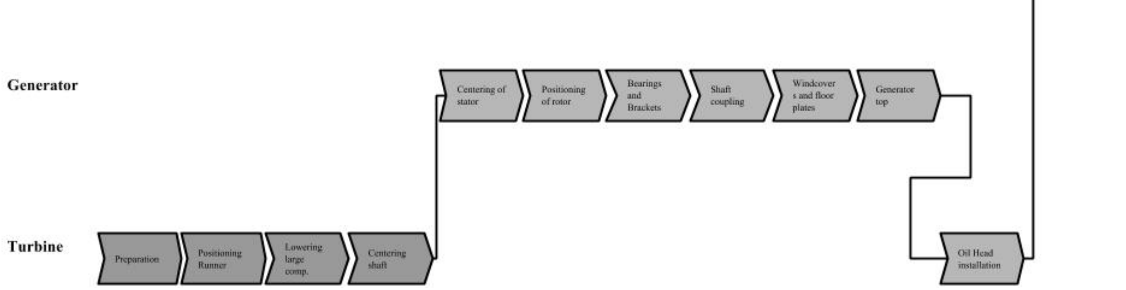

Figure 5: Schematic picture of the assembly with interfaces

When the critical parts are assembled and functionally tested, the ***commissioning*** work package starts. For simplicity, this work package can be divided into: mechanical tests, electrical and automation tests, grid connection tests and trial run. The most critical phase in this work package in terms of risk of delay, are the mechanical testing, being conducted in the beginning of the commissioning. Overheated bearings, hydraulics not working properly, shaft vibrations and axial throws in certain frequency are some of the things that might occur, risking time schedule overrun. The last period of the commissioning is the trial run in which the plant is operating as normal. After this work package, the plant is put into normal operation.

7. Deviation analysis

This chapter presents the major findings of the deviation analysis presented. For each outage, the deviations have been sorted into the work packages. When the categorisation is difficult, a discussion about the selection is made. The work package is analysed by looking at similarities of the deviations as well as identifying themes related to time management success. The themes are coming from the interviews or have been identified in the discussion sections. The most interesting sections are followed by a discussion of the results. The analysis has been made on 14 projects including 20 outages (see section 3.3).

7.1 Shutdown

The shutdown is the shortest work package. Of the 14 projects, three required the installation of arc stop logs. Of these, one project had problems during the shutdown. The reason was due to a rail that was broken. The action was costly but did not affect the time schedule. No additional findings and conclusions could be made here.

7.2 Disassembly

In only one of the projects was an overrun in the disassembly realized directly when the turbine head cover was dropped and destroyed. However, actions (or inactions) during the disassembly work package resulted later in realized delays. Here, most decision making concerns whether or not to increase the scope and it is therefore of high importance to have the right competence at site as well as good understanding of the project targets to avoid unnecessary scope creeps. In two projects, the runner chamber needed extra action.

Adjustment of the roundness of the runner chamber was held as an option until the outage in one project and not included in the scope of the other project. Extra lathing was the resulting activity. In first project, it was required because the runner did not fit into the chamber. The manufacturer blamed the chamber size but the PM thought that the runner was too large. In the project, the choice of lathing is more unclear. In at *least one of the project, most of the overrun was due to the summer vacation period and the search of a lathe for the mission. The issue of turbine chamber roundness is very expert oriented. Even with measurements in prior of the outage, the decision can be difficult. In order to minimize water bypassing the runner, the distance between the runner blades and the runner chamber/discharge ring should be as small as possible without the blades touching the wall in any mode of operation. In the issue of including lathing or not in the scope of a turbine refurbishment, one expert explains that in the recent years, he has changed his view and may be changing it again in the future. Furthermore, among the expertize of Fortum, different views are held. One expert emphasized the importance of the decisions being made by Fortum and not by the supplier, and suggested that standards should guide the decision.* (Boberg 2015 pers.comm. April 27).

This example shows how postponed decision making/design-freeze is delaying the project implementation. But in this case, the decision making looks particularly difficult when more information can be obtained in the beginning of the outage.

7.2.1 Discussion

A categorization issue should be addressed here. There is a very fuzzy line between a deviation regarded as a disassembly issue and one regarded as a renovation issue. Suppliers frequently (in at least 7 outages) addressed the need of prolonged renovation due to unexpectedly poor condition of parts of the turbine. However, this opinion should be regarded as very biased as the supplier can take advantage of this claim by avoiding delay penalties. The risk of discoveries of extra renovation activities during the disassembly is well perceived in the organization. An action list of all possible scope creeps that might delay the outage should be discussed carefully with the supplier to increase the certainty of resource (workshop) availability. Due to the interpretative flexibility of the condition of the parts, expert opinion and awareness of the project targets are important. The themes to avoid disassembly overrun or delay of the projects are listed in Table 4.

Table 4: Major findings and themes in the disassembly

Challenge	Themes: Planning	Themes: Implementation
Disassembly	-	-
Scope creep	Early design freeze	Be in charge of the decision making at site.
Existing renovation prolonged	Action list of major uncertainties	Be in charge of the decision making at site
	Additional workshop resources	
Accident	-	-

7.3 Manufacturing

Delays in the manufacturing of equipment were found to be a common reason for outage delays. Because of the worry to be exposed to penalties for not meeting the milestones, the supplier is not willing to admit a potential delay: with a little bit of luck, another supplier may be causing the delay of the project and thus cover up for the supplier's delay. Inspections are often made to follow up the progress. In the monthly project meeting protocols written during the outage period the follow-up of the delivery can be investigated.

At the start of the outage, the supplier was working according to plan. Approximately five weeks into the outage time, the PM was notified that the delivery of the runner was late. An employee at Fortum got the mission to travel to the supplier. Another five weeks later, the forecast of the delivery of the runner was two month later than planned. In this state of the refurbishment, the strategy was to prepare everything else as good as possible in hope of cut the project delay to five weeks. In the end of September, three weeks after the planned date for commercial operation, the runner was delivered after further delays, one month after the inspection and 10 weeks delayed. (Fortum 2009, Monthly Report May-October)

The inspections require technical expertise to be efficient and are resource demanding since they require a person in the workshop. A PM at Fortum has several projects in different phases and it can sometimes be difficult for the PMs to control and prioritize their own time. Consultants can be hired for the inspection job but it can be hard to find the right competence (Boberg 2015 pers.comm. March 26).

The importance of the right expertize in supplier follow-ups can be illustrated by the following story from a generator expert working with the experience of being a supplier.

In this project[1], the outage was postponed three weeks because of the generator supplier. The PM in this project had met the supplier frequently. 'You can only press them to a certain limit, then they will promise whatever' he explained. He discovered that they were delayed when he was at the factory. 'I saw […] what was going on, things came up: that they were missing some things, and they had no explanation. […] You need to know how the manufacturing goes and you have to recognize [the delay of the supplier] as early as possible. (Ahtiainen 2015 pers.comm. March 30)

The most common practice at Fortum is to schedule the delivery within the outage period with no or only small buffers to the required-on-site date. Instead, the focus to handle this uncertainty is arranged around the Factory Acceptance Test (FAT). If the equipment has passed the FAT, it is often viewed as a security of the delivery. For major equipment deliveries such as the runner, guide vanes and stator, milestones are set for the accomplishments of approved FATs of the equipment. The stator comes in one or several parts and is depending on the design and if winding work is made at the site or not. The stator assembly is always scheduled before the outage period. A technical expert and sub-PM was sceptical to have a promised delivery date in prior of the outage. *"Then you´ve reached a point when you´re completely mistrusting the supplier´s ability [to deliver]"* (Boberg 2015, pers.comm. March 26). Furthermore, if you want to have the runner delivered on site before the outage, it requires thorough and early planning in the pre-engineering as shorter time until delivery dates often means higher costs of the delivery. A PM emphasized the foresight in the planning at Fortum as a challenge for the company.

"[…] you may have the procurement two years before the delivery, maybe it is a model test that takes half a year, and this [the procurement] is always in the last moment, and it always takes more time when we're evaluating [the suppliers], and it is pretty often when you´re sitting at the final negotiations and he [the supplier] says: 'well, we have to sign the contract now, otherwise we´re not going to catch-up', and at that point, they have already tightened their production schedules for their runner […]. In my opinion, it is better to have margins in the beginning". (Lejdstrand 2015 pers.comm. March 26)

Many overruns are not realized until the last moment of the manufacturing. These overruns are due to the quality of the renovation and are revealed in the testing. This was the case in three projects and four outages and related to the winding of the stator. For the stator, tests are made to measure corona discharges in the winding. It is made

[1] The project is in the moment of writing not executed and is not included in this study

when the stator is assembled and the last assembly is usually made at the site and approved by a Site Acceptance Test (SAT). In two cases, the corona tests were found unacceptable by the requirement of Fortum and resulted in delays. One of the cases can explain how the supplier and the client can interpret quality differently when the parties are unexperienced of working together.

The stator had been manufactured and winded at site by a new supplier. A generator expert mentioned that there had also been problems with the same supplier in a later case.

"They were not sufficiently detailed [...].There is another philosophy in [that company]... they define different types of corona: yellow, red and blue. They can accept certain types of corona but at Fortum we can´t accept any kind of corona" (Bjerhag 2015 pers.comm. April 21)

The corona problem could not be solved for this object but the erection work was decided to go on. The warranty period of the generator was prolonged as compensation and the supplier was planning to come back within a year with a solution. (Frödesjö 2015, pers.comm., March 9)

In this case, the quality was compromised and postponed in favour of the time target. Here another target issue should be discussed. Even though contractual agreements are settled by followed standards it is not always easy to address the responsibility of undesirable quality concerns. For the example, if a stator is found to be in unexpectedly bad condition after winding works at-site, adjustments can be made to enhance the quality. It is, however, hard to estimate the duration or the outcome of this adjustment. So, when is the quality of the stator sufficient? How much manufacturing overrun can we afford to enhance quality? Answering these questions, again, requires a good technical understanding as well as a clear understanding of the project´s targets. It can therefore be disputed whether an overrun was caused by quality issues or by a very quality target oriented mind-set.

7.3.1 Discussion

Manufacturing was found to be a common work package of overrun and delay. To mitigate delays due to quality, one suggestion is to be very careful in the review of the FAT tests with good expertize in workshop or on site. A good awareness of the supplier's interpretation of quality is also important. Late deliveries are very hard to manage. A review of effective supply chain management methods can be an issue of further studies. To further get control of the processes, milestones for different stages of the manufacturing could be implemented. According to scholars of CCPM, this might only lead to more time waste when each supplier is putting up buffers for their deliveries depending on the final delivery time. According to CCPM, it is suggested to schedule uncritical activities "as late as possible" with a feeding buffer in order to create urgency. This feeding buffer can be interpreted as the difference between the promised-delivery-date and the require-on-site date. Of course, this action might be more costly if the supplier regards this as enhanced risk. The themes of success to avoid manufacturing delays are summarized in Table 5.

Table 5: Major findings and themes in the manufacturing

Challenge	Themes: Planning	Themes: Implementation
Manufacturing		
Quality	Review of FAT	
	Knowledge of the suppliers	
	Expertise and clear target awareness	
Late delivery	Buffers	
	Procurement margins	
	Manufacturing milestones	

7.4 Renovation

Six of the delays were due to renovation overruns. In the two most severe cases, de-prioritization of the renovation in the workshop was the probable cause. Worth noting is that these projects was among the smallest project in the study in terms of budget and scope. They were the only two where the runner was refurbished instead of renewed. Furthermore, while one plant had a relatively small rated output, the other project had a very special scope. In the latter case, the site work was frequently stopped to activate other units of the plant for production. In this study, these projects can be viewed as "outliers" in the selection of refurbishment projects but pins out an interesting topic. To choose renovation instead of manufacturing is generally viewed as more risky. Considering the choice of renovation of major equipment in this case, these projects strived at being cost effective or income loss reducing thus de-prioritized the outage time objective. The next question should be why also the suppliers of the renovation chose de-prioritization. The answer in the frequently stopped project was described by the PM.

"[The overrun] was due to workshop prioritization of [the supplier]: it was a small project with a tight schedule and not very high penalties [of delays in the contract] compared to other jobs, and they didn´t even seem to be aware of the [contractual] penalty" (Lejdstrand 2015, pers.comm., 26 March)

In the small rated output project, the explanation is seemingly similar although not as precise. There had been disagreements between renewal and refurbishment of the guide vanes in the planning of the project. During the refurbishment the supplier seemed reluctant to inform the project team and blamed the overrun exclusively on the unanticipated amount of refurbishment work.

In the workshop, the condition of the guide vanes was discovered to be in unanticipated poor condition. The guide vane taps were suffering from severe cavitation. The project team accepted a prolonged reparation time of six weeks after negotiation internally and with the supplier. A consultant was hired to make workshop follow-up, and he alerted the project team that there were risks for overrun of the renovation of other parts of the turbine. The supplier said that this was not a problem due to the prolonged time of guide vane refurbishment. Within the originally scheduled commission period, the project team received an e-mail where the supplier mentioned that they were in phase with the re-negotiated time schedule. However, the delivery got delayed another eight weeks. (Fortum 2013, Monthly Reports June-October)

7.4.1 Discussion

The major finding in this work package was down prioritization. To mitigate this requires a high degree of supplier knowledge. As in the manufacturing, a study of effective supply chain management methods is a good suggestion for improvement. In the interviews it was mentioned that frequently held on-site inspection is an effective way of putting pressure on the supplier. This requires resources and should be of consideration in the supplier evaluation especially when the supplier is a new or uncertain contractor for the company. The renovation challenges and suggested mitigating actions are listed in Table 6.

Table 6: Major findings and themes in the renovation

Challenge	Themes: Planning	Themes: Implementation
Renovation		
Carelessness by supplier	Supplier evaluation	
Unclear late delivery	Awareness of the workshop-prioritization problem	Workshop inspections
Accidental		

7.5 Assembly

The assembly is the work package in which overruns are most frequent. This is not very surprising and can be explained theoretically in two different ways. First, in this stage all the subsystem are converging to one single system. The convergence is increasing the number of interfaces between the work packages making the system more tightly coupled and highly interactive. Second, the project learning curve is steep in this phase, which means that the certainty of the project outcome is increasing very fast. During the assembly, design flaws and subsystem misfits are more likely to be revealed.

The assembly work packages overrun delayed nine of the outages. The explanations of the overrun were very varying: misfits in the guide vane assembly, misunderstanding due to language barriers, unexpected movements of the shaft, new generator technology and slow assembly. The variety of explanation supports the notion of this work package duration as being particularly difficult to predict. Mainly two types of explanations are addressed by the PMs. The first is the difficulty of the erection moment.

"The [erection] method is rather established, but the procedure is complicated in the making. We talk about hundredths of a millimetre on stuffs that weights tens of tons and are twenty metre long." (Bergman 2015, pers.comm., February 24)

The recipe of a successful erection was suggested to be an experienced and skilled erection leader; a skilled assembly team and good communication between the generator and the turbine subprojects. In the projects the erection of the unit has either been conducted by a supplier or by an internal assembly group of Fortum. The importance of detailed scheduling in order to avoid access conflicts between different activities were emphasized by several PMs. Milestones are a very common utilization and Fortum has developed guidelines for this process.

The second explanation was slow assembly. For slow assembly there were two cases that illuminates different challenges of time management.

In one case, the rotor had been late in delivery but the supplier thought that the overrun could be compensated by working overtime and weekends. But the progress was not as fast as expected.

"They worked a lot of overtime. I believe the guys were very tired, so… then if you work overtime week after week, although you do a lot of hours, but if your are very tired, maybe the work is not very efficient anymore." (Tella, 2015 pers.comm., March 30)

According to this reasoning overtime and shift-working hours cannot always be considered as effective as regular working hours. In the centre of the other explanation is, again, the personnel.

This project was divided into two outages of two separate units. In comparison with the assembly and erection work of the first and the second outage, it was noticed that many *similar activities took "[…]significantly more hours already from the beginning of the assembly […]". The conclusion was that "you cannot compare working hours because there is not the same assembly personnel at site". The assembly personnel was completely changed from the planning to the implementation and the PM suggested that this should have reflected the time schedule. In addition, the lesson to learn was that "it is important to have an obligated time schedule from the assembly responsible person".* (Fortum 2010, Meeting protocol April)

7.5.1 Discussion

The abundance of interfaces between these work packages suggests that an emphasis should be put on the scheduling of this work package. The high amount of overruns suggests that this work package duration is generally underestimated. One way to mitigate this could be to develop a framework to estimate the time duration. This could be done by the use of an expert panel and statistics from former projects. Since a contributing factor of the duration of the assembly is the personnel, this should also be considered in the time scheduling which could be very hard. Due to the importance of skilled personnel, supplier evaluation criteria might include an assembly skill rating. Themes for assembly are listed in Table 7.

Table 7: Major findings and themes in the assembly

Challenge	Themes: Planning	Themes: Implementation
Assembly	-	-
Slow assembly	Supplier skill evaluation	-
Difficulty	Development of framework Supplier evaluation criteria	Acquire good supervision at site
Language barriers	Require communication skills by supplier	Support communication
Unscheduled activities	Review and emphasis on scheduling	

7.6 Commissioning

In this work package the mechanical testing was the most critical moment. As this is the last work package, it is very hard to handle overruns. In four cases, problems during mechanical testing occurred. In one case, the removal of arc stop logs couldn't be performed due to strong water streams that prevented the necessary diving work.

During electrical and control equipment testing, an experienced commissioning leader mentioned, *"you know if there is going to be problems"* (Jonsson 2015, pers.comm. March 26) depending on which supplier and personnel that have made the installations. Often in the case of a problem during this phase, the corrections only take a couple of days for trouble shooting and switching cables. Hence, it is rarely making any serious impact on the time schedule. A skilled commissioning leader and teamwork skills were addressed as success factors. Accuracy in the design work and assembly are also affecting the outcome. Again, there is a fine line between delays related to commissioning and delays related to assembly: an assembly who finish on time may instead cause delays in the commissioning. A more thorough study of this work package has to be made in order to draw further conclusions.

8. Investigation of time management success/failure factors

By the study of documentation, literature and interviews, some factors where addressed as being of interest to investigate. The outages are categorized by amount of delay to see if there are any differences between them. The aim is to find potential indicators to meet time targets successfully. Due to the small sample size, no hard facts can be settled, but the results can suggest further studies and suggest potential success/failure factors (see section 3.3). The chapter ends with a table that summarizes potential success/failure factors identified in this study.

The outages are divided into three groups (Group A: Minor delay, Group B: Medium delay and Group C: Major delay). The group size is: Group A=6, Group B=8, Group C=6. Three indicators of the importance of the project are: budget per outage, strategically importance index, and number of refurbishment options of major equipment. The equipment of consideration is: stator, rotor, runner and guide vanes, which are refurbished or not refurbished. For each outage, the number of refurbishment options is summarized to a value (0-4). The choice of the equipment was made by selecting the most frequent major equipment of topic in the interviews. The deviations from the deviation analysis are also compared to the groups.

8.1 Group A (Minor)

Group A consisted of six outages. Three of them were the project's second outage. They also had the highest budget on average and none of the projects had as small budget per outage as the projects in Group C. The overruns found in this group were mostly related to manufacturing, occurring in five outages and caused delay in two. Only two outages had assembly overruns. In several of the projects in this group, the manufacturing overruns were handled with overtime work and effective resource allocation. Two examples can illustrate this. In the first example, the quality of the windings was regarded as too poor and corona problems were discovered in 120 places at site.

Due to excessive overtime working in the first outage, it was decided to increase the outage time of the next unit by one week. The reason for the overtime, the PM remembered, was a tight time schedule and some unexpected additional work. According to the PM, the time schedule had been very tight: in prior to the project, the turbine supplier had expressed that the schedule was "impossible". To catch up a manufacturing delay in the next outage, extra manpower, over time and weekend working was being used. (Tuohimäki 2015, pers.comm., May 14).

In the other example, own resources handled the bad condition of guide vane bearing efficiently. The PM explained.

"There weren´t any bigger actions planned on the distributor in this project. When the unit was dismantled, it was noticed that the bearings of the guide vanes were damaged

and had to be repaired. This was additional work to do within the time schedule: we had to make new bearings. […] We bought our own material, and then we machined them in our own workshop […]. We [also looked for other manufacturers but] couldn't get the complete machine bearing part delivered in time, so it was done with own workforce." (Tella 2015, pers.comm. March 30)

8.2 Group B (Medium)

The Group B consisted of eight outages. They had the lowest amount of equipment refurbishment options and had middle score on budget and strategically importance mix. Two of the outages were second unit outages of the project. The delays in one of the projects, including two outages, in this group were reallocated to another outage in both cases. This project was the only project where the manufacturing caused delay. Apart from this project there were assembly overruns in all of the six other outages. As illustrated in section 5.8, this work package is difficult to predict. Having in mind that this group is the middle class projects in terms of delay, and since the groups is fairly homogeneous regarding the amount of delay, this group can be regarded as having the highest potential for improvements (see discussion in section 8.5).

8.3 Group C (Major)

Group C consisted of six outages and had lower budget per outage than the other groups. It also had the highest average of refurbishment options. In three of the outages, the equipment delivery was severely delayed. The explanations are interesting to study.

(1) *The new runner was delayed. "[The supplier] had at the moment a lot of workshop jobs and the Fortum job was down-prioritized in favour of bigger jobs. In other words, they took the delay in order to not delay other jobs"* (Frödesjö 2015, pers.comm. March 9)

(2) *The new guide vanes were in worse condition than expected and the supplier got six extra weeks to do the refurbishment, which was made by a sub-supplier. The supplier blamed the sub-supplier for bad communication about the progress. Six weeks became fourteen. In the pre-engineering, there had been disagreement whether or not to refurbish instead of renewal of the guide vanes. The supplier recommended renewal. They had also been late in previous projects.* (Holmgren 2015, pers.comm. March 26)

(3) *The refurbishment had been extended due to unexpectedly bad condition of the plant including the guide vanes. The supplier was also late with the delivery of the runner but argued that the extended refurbishment made the delivery uncritical. The PS suspected that the supplier waited with the inspection of the guide vanes because they were delayed with the manufacturing of the runner.* (Ingfält 2015, pers.comm., March 17)

These explanations are very similar and were the biggest factors for the delay in those outages. The same problem did happen in some of the Group B outages as well.

8.4 Group comparison

The investigation points at budget per outage as a factor that could affect the delay. As seen in Figure 6, Low budget outages were overrepresented in Group C outages compared to B and C. In comparison between the Group A and B one difference was the assembly delays which were much more frequent in Group B. This difference is interesting because it seem to suggest that assembly success is the major difference between medium performing outages and good performing ones. As shown in figure 7, Group C projects had also more refurbishment options compared to the other groups

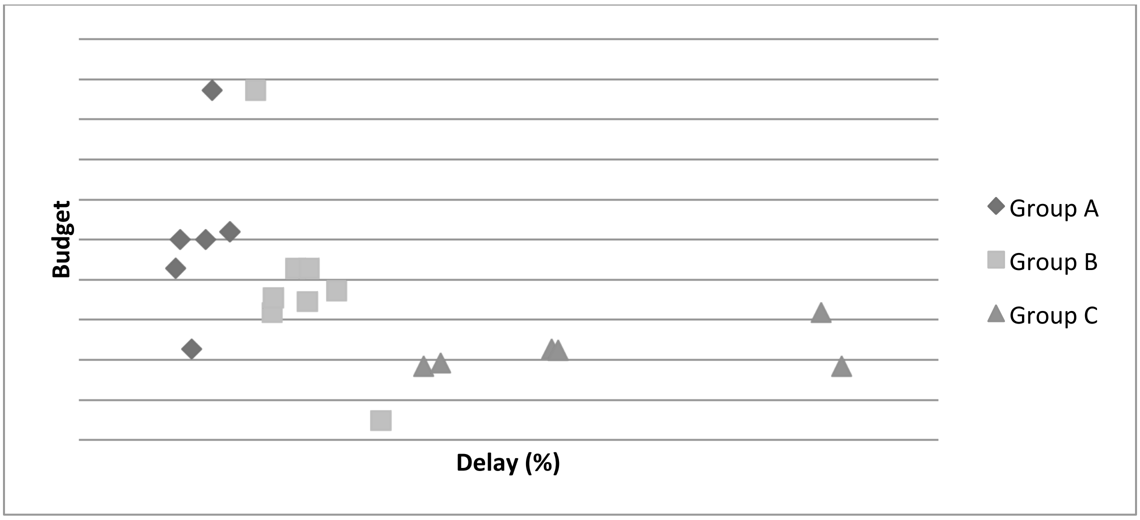

Figure 6: Scatterplot of budget/outage (y-axis) and percentage of delay (x-axis) divided in the groups

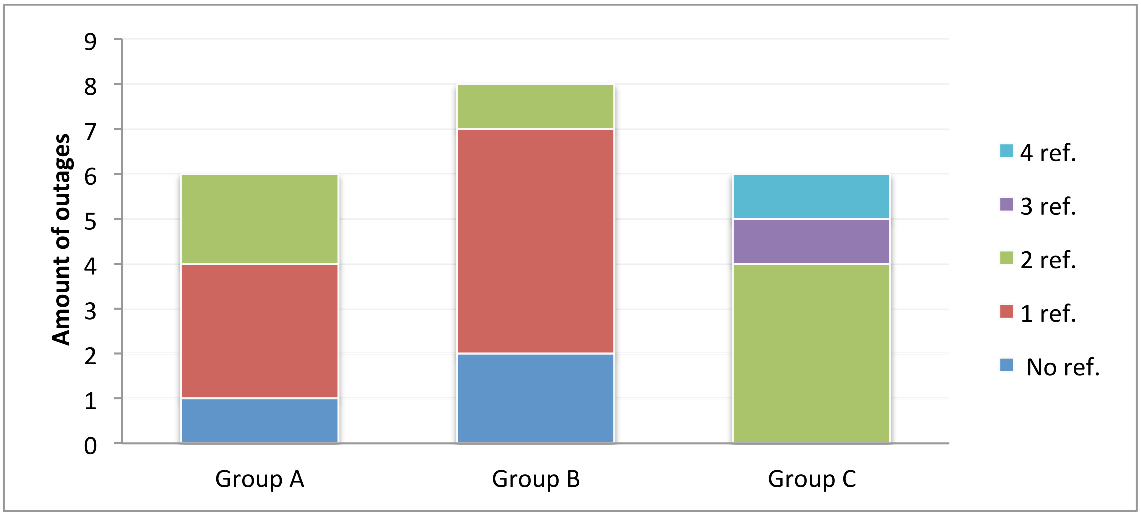

Figure 7: Number of refurbishments instead of renewal of major equipment (0-4) for each outage divided in the groups

8.5 Discussion

Budget per outage, strategically importance, and refurbishment choices were investigated in relation to three groups of outages depending on the amount of delay. The factors should be regarded as dependent of each other: refurbishment is generally more expensive than renewal and top management should more likely give higher funding to plants with higher priority.

The results suggest two things that were significant in Group A compared to the other groups: the amount of second outages of the same project, and a high budget per outage. Making several unit refurbishments in the same project seem to be a good option to decrease the total outage time which was also mentioned in the interviews. Often the units in a plant are very similar to each other, which make the learnings of the first outage to be very usable in the next. A lessons learned feedback meeting was often being held in the projects with two unit refurbishments. Another advantage can be related to team building: people start to know each other and communication will work smoother. Regarding the amount of Finnish projects in Group A, the overtime working hours and dedication to keep time targets might explain the success. This was illustrated by two examples. It is hard to say whether these examples indicate that there is a higher dedication to time targets among the Finnish project team or not. For another study, it would be interesting to investigate overtime-working hours in relation to the factors studied here. It would also be interesting to compare project management differences between teams in the organization. Finally for Group A, a higher budget can be related to many things such as type of plant, equipment and supplier choices, scope etc. In the literature, project prestige and top management support are mentioned as success and failure indicators and were also connected to the project size (se section 2.1).

Assembly delays were the most significant in Group B. As mentioned in section 5.8, a successful assembly can be related to the skill of the personnel and to site coordination. Underestimation of time duration of the work package was another suggestion. An improvement of this work package, regarding both actual performance and duration estimation would have the largest impact in improving the overall project time performance. Interestingly, Group C did not have the same amount of assembly delays. Instead, more problems occurred during commissioning. Two other more likely explanations could be the interpretation issue discussed in section 3.2 and the work package dependence between assembly and commissioning (see section 7.6).

Group C had a high number of refurbishment options and small budget per outage. The conclusion is that considerably delayed projects tend to be small and/or less prioritized than projects with time target success. In section 5.7, it is illustrated how minor renovations could be down prioritized in workshops by the supplier in favour for other jobs. Small contractual penalties for delays were one explanation. Other relations between small budget and time failure might be the choice of inexpensive but uncertain suppliers and less support from top management.

It should be considered problematic if small project is regarded unsuccessful only because they are small which would lead to undeserved negative feedback. If further studies can prove the relations investigated in this study, the trade-off between time and cost can be more established during the planning phase. The PM can argue, by analysing budget, refurbishment options and importance of the plant, whether longer outage durations are appropriate or not. It should be noted though, that an increase of the delay acceptance with about 10 % would qualify only a few more outages to Group A. Hence the major challenge of increasing the amount of projects with time target success should not be primarily considered a matter of overambitious time targeting, say, for small projects. Instead, the focus from a PM perspective should be on improving assembly performance and assembly duration estimation. In table 8, potential success factors derived from the Group analysis are presented for both planning and implementation.

Table 8: List of potential success/failure factors related to project planning and implementation derived from the group analysis

Group	Distinguishing feature	Potential success/failure factor: planning	Potential success/failure factor: implementation
A	Amount of 2nd outages High budget/outage projects	Choice of same project org for both outages Choice of supplier Renewal instead of renovation Strong top mgmt. support Time mgmt. dedication	Learning Team building Project prestige More resources to handle deviations Dedication to time schedule Overtime working hours
B	Assembly overruns	Duration underestimation Allocation of experienced people	Personnel skills Erection coordination
C	Low budget projects High amount of refurbishment options	Small contractual penalties Lack of top mgmt support Plant condition evaluation	Project prestige Supplier down-prioritization Time target subordination Increased activity duration uncertainty

9. Conclusions

This chapter reviews the study and discusses the results. The main conclusions and suggestions are outlined.

9.1 Summary

The challenges of time management in major refurbishment projects have been investigated by looking at 14 similar types of projects including 20 outages. By looking at similar projects, the explanatory focus has not been on the project scope or the technological challenges. Instead, the project management practice has been under the microscope. It has been clear that the challenge of meeting time targets cannot be viewed as a solitary issue. As pin pointed in the background chapter of this study, time targets are instead closely linked to both cost and quality targets. Awareness of the relations of these targets is a very important asset for the PM. Otherwise the project will, in the quest of succeeding equally in all these aspects, fails in the quest of meeting the goals of the company. At a company with hydropower assets, the relations between the targets will strongly depend on the character of the plant: what loss of income that is associated with an outage and what impact the company would be exposed to in case of a major failure.

The outage period of hydropower refurbishment projects is viewed from a time management perspective. The process has been divided into work packages, that is, sequences of activities related to a functional unit of the project. The divisions between the work packages are made with regard to the role of the PM. The question has been what the major challenges are of these work packages, with an analysis of the deviations of the outages. The dependence between them has also been clarified by the term interface. This methodology can be regarded as an analysis of the critical chain of the outage time where the study of deviations has been related to project management challenges. The work packages were also evaluated by categorizing the outages into three groups depending on their performance of meeting time target. Except from the work packages, some additional indicators were included in the comparison.

9.2 Major Findings

Overruns in manufacturing have been identified as the most common deviation. Some of those can be related to quality problems and in other cases explanations have not been addressed. A common theme was the struggle to attain information about the supplier's progress.

Assembly was the work package, which caused most delays. Moreover, outages that reached medium time performance did seem to have more overruns during the assembly than the best-performing group. Therefore, improvements in assembly can be viewed as the best way to increase the overall time performance. The high frequency of assembly overruns and the variety of deviations suggest that the duration is frequently underestimated.

The groups' comparison indicated that budget has an impact on the time performance. This was mainly evident in the outages with the highest degree of delay. This can be related to the choice of refurbishment instead of renewal. It can also to be related to workshop down prioritization and time target subordination in relation to other objectives such as minimizing short-term production losses or minimizing costs.

9.3 Discussion

Four major topics are interesting to discuss in relation to the methodology and to the findings.

9.3.1 The methodology

The choice of using project managers delay explanations from interviews and documentation has proven to be efficient for an initial study of the time management challenges of a company. The deviations have been a good way to bring up challenges in relation to both the planning and the implementation of the projects. By being semi-quantitative, this study has also pointed at frequently occurring problems and given directions for further investigations. As explained, this methodology should not be viewed as a comprehensive study of the explanation to the delays. Instead, it takes a project management perspective and problematizes their working environment. Categorizing deviations into different work packages has proven to shed light at challenges along the critical chain. As showed in this study, project success/failure can be related to different work packages. This framework builds a closer relation between the decision-making during planning and the consequences it get for the duration of the implementation. It also serves as a basis for manage and monitoring the time schedule. The results can be used as reference to prioritize actions during the implementation.

9.3.2 How to manage manufacturing overruns?

In an EPC perspective, this study suggests that a big challenge in handing the critical chain can be related to the information exchange between the client and the supplier. In several cases, the suppliers were not willing to give information about their progress. This leads to the lack of a good basis for the project manager to make time management decisions. Indeed, many of the challenges related to both the renovation and the manufacturing work package can be connected to the struggle to control and acquire knowledge of the supply chain. At a global level, this struggle is related to an increasing complexity in the way of doing business.

Managing supply chains in today's competitive world is increasingly challenging. The greater the uncertainties in supply and demand, globalisation of the market, shorter and shorter product and technology life cycles, and the increased use of manufacturing, *distribution and logistics partners resulting in complex international supply network relationships, have led to higher exposure to risks in the supply chain.* (Cristopher et al. 2004)

An increasing amount of literature has paid attention to the implementation of Supply Chain Management (SCM) to successfully manage the supply chain (see for example Saad et. al. 2002; Wolf and Jahns 2008). However, this would require a through change of the view of the contractual setting, towards partnering instead of arm's length relationship. This could be an interesting research topic: would the implementation of SCM be appropriate for an EPC projects in the hydropower business? What are the major gains and highest risks with such implementation? A less radical suggestion to improve control over supplier is manufacturing milestones and buffers to required-on-site dates. This solution could be effective for certain projects, but what happens if it gets a common approach in the business? Could it lead to mistrust from the supplier and with compensating increased costs or ad-hoc processes? This is another interesting research topic for EPC projects.

9.3.3 Time management challenges in the multi-project setting

From a multi-project perspective, the recognition of the project's relation to other projects in the organization should be clarified in order to give it the right measure of success. This study point out what others also have stated: that priority matters. The PMs should be aware of how his project is viewed in relation to other projects. To be able to motivate longer outage times, particularly in the case of smaller projects, the PM should be equipped with a good basis of information about the risks related to delays in different circumstances. This study can be regarded as one such basis. In case of top management intervention in decisions, say, scope or the choice of supplier, *feedback loops* of the targets are important for a realistic adaption. For example, a choice of a supplier regarded as more unreliable has to be met with a change of the outage duration. Otherwise, the project is at risk to be regarded as unsuccessful instead of being regarded as having unrealistic targets. The use of time target feedback loops becomes certainly important in a multi-project setting organized in a matrix structure, with unavoidable conflicts between divergent managerial interests. Here, the project has to be flexible to be able to deal with these conflicts and relate them to the targets. But flexibility will compete with the work of creating a stable definition of the project. As mentioned, it is important both to decide on the scope of renovation and manufacturing work and to set the contracts early. Since the time target is a part of the contractual arrangement, it is hard to adjust the schedule after this procedure without giving the supplier more room to avoid penalties from time overruns.

In an EPC hydropower refurbishment project, the client is not the only organization with a multi-project setting and resource allocation problems. For example, the turbine and generator companies are also struggling with the challenge to allocate resources to several projects and keeping their time schedules. As illustrated in this study, down prioritization in EPC projects does not stop at the border of the client. An overcommitted supplier in another multi-project organization might not prioritize a small contract. Furthermore, the unrecognition of mutual gains beyond the return of the investment between client and contractor creates no incentives for prioritizing smaller orders from bigger ones. Thus, in the rational world, the resources will be allocated where it gets most revenue, which will often be at the bigger contracts. When multi-project organizations are linked together by arms-length connections, the project will compete on the market of resources. Consequently, the time target will be at stake.

9.3.4 Outage scheduling potentials

As noticed, tackling the assembly challenge would have the biggest impact of the overall time performance of the projects. To avoid a negative spiral of late projects a better start for Fortum would be to strive at keeping time targets in order to later be able to shorten durations. CCPM has been used as a reference to scheduling techniques in this study. It builds on other scheduling techniques such as PERT/CPM but offers a rather different way of thinking about time management. It should be noted however, that other scheduling techniques should be more preferable for the company. A successful implementation of CCPM would require a closer relationship between client and contractor. For example, in order to reduce time waste in the activities require a mutual thrust among the partners. Otherwise such implementation would only lead to an unnecessary long project buffer. Another issue is how penalties should be addressed when all durations are scheduled in shortest completion time and all suppliers are sharing a common project buffer. For scheduling techniques like PERT, there are methods to use stochastic models to estimate time durations by the use of mean, average and boundary data. These methods have been met with critique for assumptions such as independence between the data (see for example Pontrandolfo 2000; Trietsch and Baker 2012). A suitable and comprehensive methodology for estimating time durations could be a topic for further investigations. It can be preferable to take advantage of the similarities among the project time schedules. Due to their similar structure of the outages including the shutdown, disassembly, manufacturing, renovation, assembly and commissioning work packages, there are opportunities to acquire information about work package durations. This is particularly true for the assembly. The path to more detailed top-down scheduling could go through an evaluation of the different work packages. Actual durations for each project can be saved to a development of a guide line. An important question that should be addressed in such evaluation was pointed out in this study: who are performing the assembly and what trust do we have in their ability? This requires a good understanding of the technical challenges of this period. Some of these have been brought up here. An expert panel is good option to utilize as a reference in such evaluation. The question of assembly should also be of concern in the evaluation of the supplier to give a fair comparability between time and cost targets. Skilled leaders and assembly teams seem to be the key to success during the assembly. This study suggests that there are good reasons to increase the understanding of the success factors of this work package.

9.4 Main conclusions

- The developed methodology in this investigation has been shown usable for addressing time management challenges at an initial phase at a company.

- Linking success/failure factors to work packages can help project managers to relate decisions during planning to their effect on the time schedule. It can also provide a basis for prioritizing actions during implementation.

- Strategies to decrease the abundance of manufacturing overruns might include manufacturing milestones and buffers to required-on-site date. In a long term perspective it can be interesting to investigate partnering contracts and SCM implementation and their adaptability to EPC projects and the hydropower business.

- When multi-project organizations are linked together by arms-length connections, the project will compete on the market of resources. Regarding the time target performance, the choice of scope concerning renewal or refurbishment and the choice of suppliers affects particularly small projects negatively. It can lead to down prioritization in the workshop by the supplier if not carefully evaluated. Small projects have to be met with another perspective on time targets in order to avoid an unfair perception of failure.

- An increase in assembly performance and/or duration estimation has the highest potential of improvement on time target performance. On the planning side, one suggestion is to use company experience to create a guideline for estimating assembly duration. On the performance side the focus can preferably be on finding skilled assembly teams, as this seems to be a key success factor. Assembly skill should also be regarded in the evaluation of suppliers.

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Appendix A: Availability of documentation

Outage	*Project plan*	*Final Report*	*Risk management plan*	*Monthly report*	*Meeting Protocols*	*Interviews*
1	X	X	X	X	X	PM, PS
2	X	X	X			PM, PS
3	X	X	X			PM, PS
4	X		X			PM
5	X	X				PM
6	X	X	X	X	X	PM
7	X	X				PM, PS
8	X		X	X	X	PM, PS
9	X		X	X	X	PM, PS
10	X	X				SPM
11	X		X			PM, PS
12	X	X		X		PM
13	X	X				PM
14	X	X		X	X	PM
15	X	X	X	X	X	PM, SPM, PS
16	X	X				PS
17	X	X	X			PM, PS
18	X		X	X		PM
19	X	X				SPM
20	X	X				PS