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MEASURING SUBCONTRACTOR WORK EFFICIENCY IN POWER PLANT CONSTRUCTION

Master's thesis
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January 2022

ABSTRACT

Erno Koivumäki: Measuring subcontractor work efficiency in power plant construction
Master’s thesis
Tampere University
Master’s Degree Programme in Civil Engineering
January 2022

The purpose of this study was to define suitable measuring items and a proper way to use them when measuring subcontractor work efficiency in a power plant construction site. As a part of the study, a database that includes the definitions and will be used to store the collected data, was created.

In addition to studying existing literature on the topic, the documents and processes of the target company were examined and employees that are working on site and subcontractor related issues were interviewed. The database was created using the expertise of multiple people from different areas.

The results of the study are a database that is ready to be implemented and instructions how to do it. These instructions include recommendations for the roles in the company that are the best fit of handling the database, information about in which part of the project to import data to the database and what are the best situations to use and analyse the data that has been collected to the database.

The study succeeded in its goal for the most part. The use of the database was not tested during the study, so it only works as the basis for work efficiency measuring that needs to be continued and improved further in the future.

Keywords: Subcontractor, work efficiency, productivity, measurement, performance indicator

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

TIIVISTELMÄ

Erno Koivumäki: Aliurakoitsijoiden työtehokkuuden mittaaminen voimalaitosrakentamisessa
Diplomityö
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Rakennustekniikka
Tammikuu 2022

Tämän työn tarkoituksena oli määritellä sopivat mittausnimikkeet ja toimiva tapa käyttää niitä aliurakoitsijoiden työtehokkuuden mittaamiseen voimalaitosrakennustyömailla. Osana tutkimusta luotiin tietokanta, joka sisältää määritellyt nimikkeet ja niihin liittyvät muut tiedot, sekä mihin kerätty tieto voidaan tallentaa.

Olemassa olevan kirjallisuuden lisäksi työssä käytiin läpi kohdeyrityksen nykyisiä dokumentteja ja prosesseja, sekä haastateltiin työntekijöitä, jotka ovat tekemisissä rakennustyömaihin ja aliurakoitsijoihin liittyvien asioiden kanssa päivittäisessä työssään. Edellä mainittu tietokanta luotiin käyttäen apuna henkilöiden asiantuntemusta eri osa-alueilta.

Työn tuloksena syntyi käyttöön valmis tietokanta ja ohjeet sen käyttämiseen. Nämä ohjeet sisältävät myös suositukset siitä, mitkä roolit yrityksessä sopivat parhaiten tietokannan käyttämiseen, missä kohtaa projektia tietoa kannattaa kantaan tuoda, sekä missä tilanteissa kerättyä tietoa voidaan muun muassa käyttää ja analysoida.

Tavoitteet saavutettiin suurimmalta osin. Tietokannan käyttöä ei testattu työn kirjoittamisen aikana, joten tässä vaiheessa se toimii vain perustana sen käyttöönottamiselle ja sitä tulee kehittää edelleen tulevaisuudessa.

Avainsanat: Aliurakoitsija, työtehokkuus, tuottavuus, mittaaminen, suorituskyvyn osoitin

PREFACE

This master’s thesis was carried out as a part of a large development project. At the same time the target company was going through massive changes and improvements in multiple of its processes and software, which also affected the study. The execution of the thesis was unusual. I was working on it only one to two days per week instead of full time, and it ended up taking more time than originally planned. Thankfully all the parties understood the reasons behind this, and it ended up not being an issue.

I would like to thank all the people that participated in the study in any way, both in the office and at the university. I myself learned a lot during the study and a large part of that came from different people that I talked with either in the interviews, thesis meetings or just at the coffee table.

As this thesis is finally, after almost two years, closing its finish, I feel happy that at least for now, I can focus only on one thing when it comes to work. We will see what the future brings, but the way I see it now, my studying years are over for good.

Tampere, 19 January 2022

Erno Koivumäki

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

WBS	Work Breakdown Structure
ERP	Enterprise Resource Planning
OBS	Organization Breakdown Structure
PBS	Product Breakdown Structure
CBS	Cost Breakdown Structure
EPS	Delivery method, that includes engineering, production and supervision
EPC	Delivery method, that includes engineering, production and construction
RAM	Responsibility Assignment Matrix

1. INTRODUCTION

1.1 Background

Subcontractor evaluation and the measuring of work efficiency which is part of the evaluation, is an important part of a successful construction project. To be able to get a reliable and realistic image of the project, different kind of defining numbers for work efficiency are a good way to track the works. Collected and organized work efficiency data can be used in the daily tracking of progress on the construction site and later when selecting the subcontractors for future projects and making schedules for them. The author of this thesis is working for a company that operates as a main contractor in power plant building industry, among other areas. It is typical for this type of construction projects to be huge and therefore require careful planning and good management and control from the main contractor for the projects to be successful. The subject of the thesis is closely linked to authors everyday work, which makes it a natural choice for master's thesis subject.

At the moment the target company is superintending its subcontractors using different kinds of daily, weekly and monthly reports. Some of the reports are filled by the subcontractors themselves and some by the company's own supervisors. Detailed work efficiency numbers of separate tasks or work phases are however not used or documented, even though those are the basis for the broader reports. The efficiency of different subcontractors is known by the construction site personnel on some level but documenting the efficiency numbers can be helpful for example when pointing out deviations or dealing with disagreements with the subcontractors.

The target company is updating its ERP (Enterprise Resource Planning) system and with that its WBS (Work Breakdown Structure). The intention of this thesis is to take this into consideration, so that the new WBS items can be, if possible, directly used in the subcontractor work efficiency measuring as well. Typically, there are from one to three big subcontractors in target company's construction project when considering the work hours spent. In addition to this there are multiple smaller subcontractors that are specialised in important parts of the project but only represent a small part of the work hours needed to complete the project. Because of this, the focus of work efficiency measuring needs to be directed to the biggest subcontractors and the tasks they are normally performing.

1.2 The goal and framing of the study

The main goal of this study is to define suitable measuring items and a proper way to use them when measuring subcontractor work efficiency in a power plant construction site. The instructions of how to use the defined measuring numbers is written in such a form that it also explains the process behind it. Using pre-defined, standardised items and numbers to track the work efficiency, the progress tracking becomes more transparent and reduces the possibility of subjective estimation of the completed progress. To be able to define the items, the company's WBS system needs to be studied and possibly modified to serve the work efficiency measuring as well as possible. When defining the item names, all different parts of the project will be considered, so that the item names will stay the same throughout the whole project. For the follow-up of the definitions and processes to be possible, a database including all the relevant information needs to be established. In the study, the concepts of work efficiency and work productivity are used often, and they are very closely linked to each other, but do not mean the same thing. In the study productivity is used as a measure of efficiency.

The topic of the study is rather large, and a lot of different factors are linked to it very closely. Because of this the framing of the study has been set to be strict. The target company's constructions sites are very large, which also affects the number of things to be considered in the study.

The theoretical part of the study is outlined to deal with the work breakdown structure and the work efficiency measuring. There are multiple topics that are related or linked to these matters, but everything else will only be mentioned or briefly explained if that is considered necessary to understand the big picture. The practical part of the study is outlined to involve only the construction work that is done at the power plant construction sites. This means that other parts of the project, such as engineering or procurement, will only be mentioned but not handled further. Also, the commissioning phase and everything that follows it, that happens after the construction part, will be presented very briefly.

1.3 The methodology and output of the study

Existent literature and studies on the subject were used as the basis of this study. Even though the target company's construction sites differ from traditional construction, the main idea stays the same and studies of the traditional work efficiency measuring methods can be used to support this study. In addition to studying existing information of the subject, the target company's documents were studied. By connecting these two, suitable definitions and processes for the work efficiency measuring were explored and options that were surfaced in the study are presented. The study also includes interviews with people from different departments and areas of expertise to generate a view of the current status in the target company regarding productivity measurement and to help with creating the database.

The study represents functioning, concrete suggestions on how to measure the work efficiency of subcontractors in power plant construction sites. This includes validated list of recommended item names that can be used to track the efficiency and a process description on how to effectively do this at the construction site. The item names used are taken from the target company's WBS system and modified to fit their purpose if needed, avoiding adding new items. This study does not include instructions that are ready to be added to the company's database as they are, but rather work as a basis for the official process description which will be written afterwards and which the target company can use in the future. The reason for this is that the author of this study is not solely responsible for the processes or documents that are going to be implemented.

2. PROJECT AND SUBCONTRACTOR CONTROL

This chapter focuses on the theoretical side of things by studying the existing studies and texts on the subject. The chapter is divided into three different subchapters that are related the most to subcontractor work efficiency measuring.

The first subchapter is about Work Breakdown Structures (WBS). Because WBS should be a big part of project management, it also heavily associates with measuring the work efficiency of different parts of the project and is addressed because of this.

The second subchapter is about contracting in construction in general. The chapter includes important points of how the practices in construction industry are and what to take into consideration when making the subcontractor contracts. When addressing these matters the emphasis is on the subcontractor efficiency measurement.

The third subchapter is about labour productivity and performance indicators in construction industry. The chapter explains what affects the productivity and how it can be controlled and introduces methods of work efficiency indicators that are in use in construction and other industries. The information of this chapter is later used on how different parts of work efficiency on a power plant construction project could be tracked and analysed and what indicators should be used for them.

2.1 Work Breakdown Structure (WBS)

The basic idea of WBS was first introduced in 1957 (Fleming et al. 1998, p. 20), and since then there has been some changes and improvements to it, but in the grand scheme of things the idea has stayed the same. Norman et al. (2008, p. vii) declare in their book that *"at this time in the evolution of Project Management as an advancing profession, the WBS has emerged as a foundational concept and tool"*.

When used correctly, WBS ensures that the projects scope is defined clearly and helps the different parties of the project to communicate better. In his book, Haugan (2002, p. 33) states that the main purpose of WBS is to ensure that all the work to be done in a project is identified. WBS can and should be used in all phases of the project, as the foundation of different parts of the project planning and management, such as cost estimation and scheduling (Norman et al. 2008, p. xv). Because of how WBS is linked to schedule and what it includes itself, it should also be taken advantage of when considering what to measure when it comes to tracking the subcontractor work efficiency in construction projects.

2.1.1 Definition and description

The PMBOK® Guide – Fifth Edition (2013, p. 126) defines WBS as follows:

"The WBS is a hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables. The WBS organizes and defines the total fines the total scope of the project, and represents the work specified in the current approved project scope statement.

The planned work is contained within the lowest level of WBS components, which are called work packages. A work package can be used to group the activities where work is scheduled and estimated, monitored, and controlled. In the context of the WBS, work refers to work products or deliverables that are the result of activity and not to the activity itself."

While in many texts, the abbreviation WBS is defined to be a generic term when describing the hierarchy levels of a project, Lester (2017, pp. 54-58) reminds in his book that different type of breakdown structures exists and can be separated from each other. These different kinds of breakdown structures are presenting the information in a different way and therefore can be used for different things. Lester presents four different kind of breakdown structures:

- Product Breakdown Structure (PBS). In this structure, the elements are described as nouns (deliverables), which means that the way of naming the elements that is recommended in many other sources, is actually describing PBS instead of WBS.
- Work Breakdown Structure (WBS). In this structure the elements are described as verbs (tasks), which means that it is describing the work to be done instead of the product or service the work produces.
- Cost Breakdown Structure (CBS). This structure consists of prices instead of deliverable or task names. It is created by using the same rules as other structures, which means that the costs of lower level elements need to add up to the same amount as the gathering element on top of them.

- Organization Breakdown Structure (OBS). Lester states that once the names of the people who are involved with the tasks or deliverables are added to the work packages, that WBS (or PBS) becomes also OBS.

This kind of separation of the breakdown structures can be confusing and is not necessary to be used. Instead the elements in a structure can include multiple type of information mentioned above at the same time and be jointly called WBS. This text uses the word WBS as a generic definition of all the structures mentioned above.

Typically, WBS has only one element on the top level that is divided into multiple smaller layers of elements until the lowest level, called work package, is reached. The content and names of all the elements can vary depending on the size and type of the project or the industry in question. The lower level elements of the WBS, that are smaller and describe their contents in more detail, are used in the process when creating important tools for project management. Examples of these kind of tools are resource allocation, scheduling, cost estimating and risk assessment. (Norman et al. 2008, p. 12)

A work package is an element detailed enough, so that it can be reliably estimated, tracked and managed. It is defined at the lowest level of WBS. What the lowest level in the WBS is, is decided by how much control the project needs to be properly managed. (PMBOK® Guide – Fifth Edition 2013, p. 128) Haugan (2002, p. 34) agrees with this and adds that there are many answers to the question how much detail a WBS should include. He also mentions that each work package should be pointed to be a single person's or organization's responsibility.

According to Norman et al. (2008, p. 13), some of the most important key characteristics of a high-quality WBS are:

- The WBS is deliverable oriented. The definition of deliverable here is: a unique and verifiable product, result or service that is a part of a process, phase or project. Later in their book, Norman et al. (2008, pp. 21-23) clarify that when task-oriented WBS is used, the work is considered to be described as a process or action. While a process-oriented WBS might appear to be logical and complete, it can cloud the true objectives of the work and the boundaries of the completion criteria might be difficult to see. A good way to make sure that the elements of the WBS are deliverables and not tasks is to express them using nouns and adjectives instead of verbs and objects. The difference of this can be seen in Figure 2 and Figure 3.
- The decomposition of the WBS is hierarchical. This means that the broader the element, the higher (or lower if that is decided) the element is located in the WBS.

All the components in each level of the WBS need to also be understandable and manageable.

- The 100 % rule (Haugan 2002, p. 17) is used. This rule means that the WBS includes all the work in the project scope: internal, external and interim. The rule applies at all the levels of the WBS, meaning all the sub-levels of any taken level together equal 100 % of the work included in the upper deliverable. The rule also indirectly forces the WBS not to include anything that is not in the projects scope, because if that was the case, the sum of all the parts in the WBS would not result to 100 %.

Below Norman et al. (2008, p. 15) introduce a way of presenting the WBS, that is called “the outline view”.

1 House Project
- 1.1 Primary Structure
  - 1.1.1 Foundation Development
    - 1.1.1.1 Layout—Topography
    - 1.1.1.2 Excavation
    - 1.1.1.3 Concrete Pour
  - 1.1.2 Exterior Wall Development
  - 1.1.3 Roof Development
- 1.2 Electrical Infrastructure
- 1.3 Plumbing Infrastructure
- 1.4 Inside Wall Development: Rough Finish

Figure 1. *Deliverable-oriented WBS in outline view. (Norman et al. 2008, p. 15)*

Another way to present a WBS can be seen on the two figures below. One is deliverable-oriented and the other is task-oriented. The difference in these WBS’s looks very small, but because of the reasons stated on this chapter, the deliverable-oriented WBS should always be used.

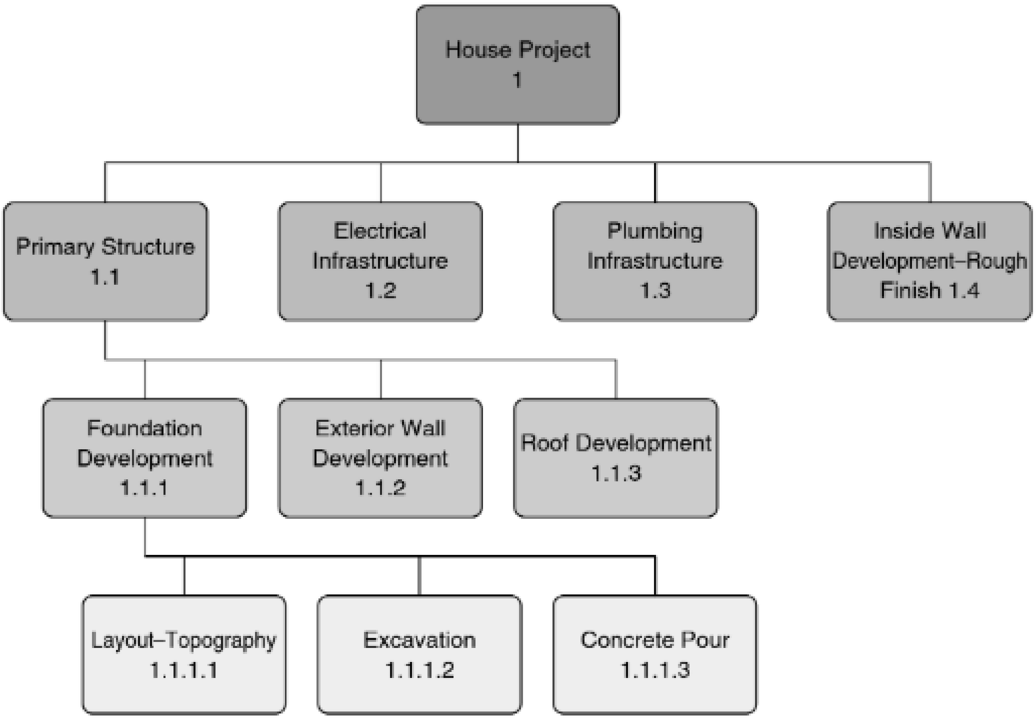


Figure 2. *Deliverable-oriented WBS. (Norman et al. 2008, p. 22)*

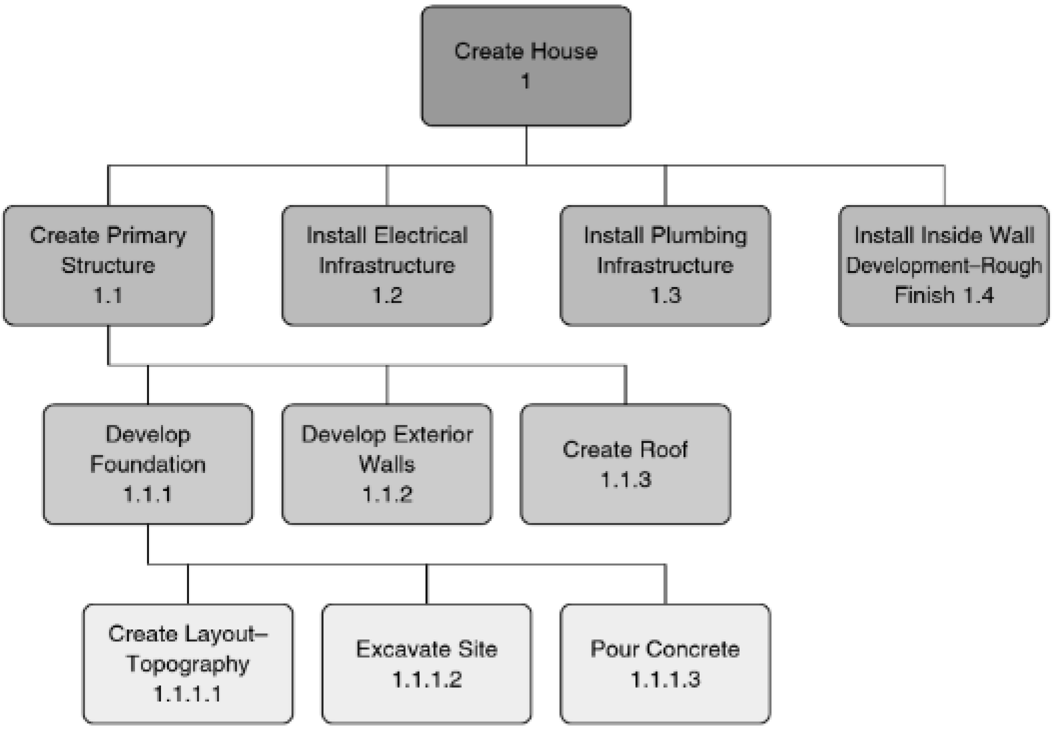


Figure 3. *Task-oriented WBS. (Norman et al. 2008, p. 22)*

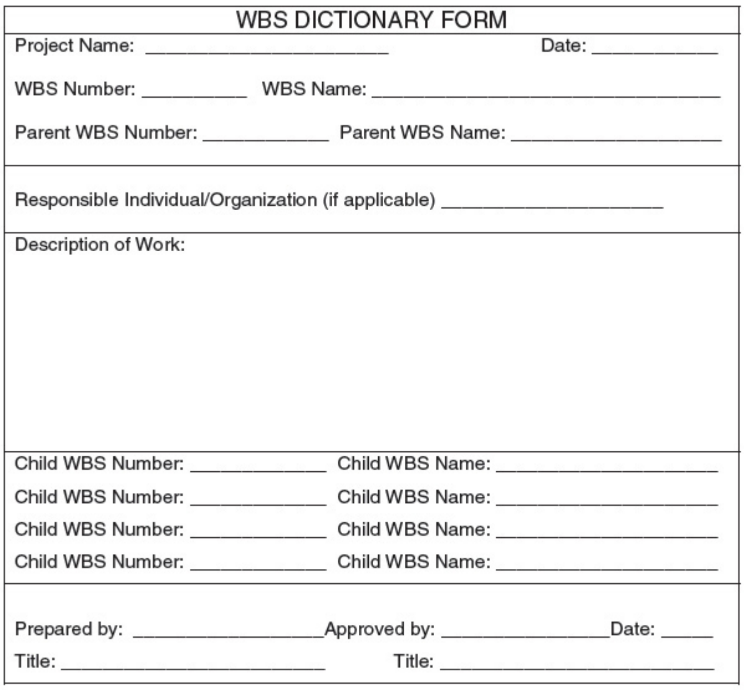
2.1.2 WBS Dictionary

When the WBS is created, a dictionary that describes the contents of the WBS should be made to support it. Often this might not seem necessary to the people who made the WBS, as they already know very well what each item means. WBS is, however, used by many different parties of the project and it has been discovered that the WBS Dictionary can be very important tool in clarifying the contents of different elements in the WBS for parties that have not been working with it before. Norman et al. (2008, pp. 65-66)

Haugan (2002, p. 28) gives an example of what a typical WBS Dictionary description can look like:

"WBS 1.4 Training. This element contains deliverable training services, manuals, accessories, and training aids and equipment used to facilitate instruction through which customer personnel will learn to operate and maintain the system with maximum efficiency. The element includes all effort associated with the design, development, and production of deliverable training equipment, and instructor and student guides as defined in the list of deliverables as well as the delivery of training services."

The format of the WBS Dictionary can vary, the important thing is that the information is clearly presented. According to Haugan (2002, p. 28), another way to describe a WBS element in the WBS Dictionary is a "WBS Dictionary Form", which is presented below in Figure 2.



WBS DICTIONARY FORM

Project Name: ______________________ Date: ___________

WBS Number: _________ WBS Name: _______________________________

Parent WBS Number: ___________ Parent WBS Name: __________________

Responsible Individual/Organization (if applicable) ____________________

Description of Work:

Child WBS Number: ____________ Child WBS Name: ____________________

Child WBS Number: ____________ Child WBS Name: ____________________

Child WBS Number: ____________ Child WBS Name: ____________________

Child WBS Number: ____________ Child WBS Name: ____________________

Prepared by: _________________Approved by: _______________Date: _____

Title: _______________________ Title: _________________________

Figure 4. *Example of a WBS Dictionary Form (Haugan 2002, p. 29)*

Norman et al. (2008, p. 139) offer an additional way of looking at the WBS Dictionary. In their example, it includes a Responsibility Assignment Matrix (RAM). In the example, only the RAM portion of the WBS Dictionary is shown. This example is presented below in Table 1.

Table 1. *WBS Dictionary showing Responsibility Assignment Matrix portion (Norman et al. 2008, p. 139)*

WBS#	WBS Element	Responsibility Assignment Matrix					
		Architect	Prime Contractor	Builder	Electrician	Plumber	Inspector
1	House Project						
1.1	Primary Structure						
1.1.1	Foundation Development						
1.1.1.1	Layout—Topography	C	A	R			
1.1.1.2	Excavation		A	R			C
1.1.1.3	Concrete Pour		A	R			C
1.1.2	Exterior Wall Development		A	R			C
1.1.3	Roof Development		A	R			C
1.2	Electrical Infrastructure		A		R		C
1.3	Plumbing Infrastructure		A			R	C
1.4	Inside Wall Development: Rough Finish	C	A	R			C

R = Responsible *A = Accountable* *C = Consult* *I = Inform*

2.1.3 Creating the WBS

According to Norman et al. (2008, p. 28), the development or creation of a WBS can be described as *"a process of decomposition culminating in a level of detail that accurately captures the entire scope of the project while providing an appropriate level of detail for effective communications, management and control."*

In the beginning and the early phases of a project, the WBS can only include a few levels, because the scope and details of one or more deliverables might not be defined to a full extend. As soon as more information is available, all the planning in the project becomes more detailed and with it the detail level of the WBS increases. It is also important to remember that the WBS needs to be updated if something in the project changes. If the WBS needs to be modified later after the planning phase has ended and the WBS has been frozen, these changes must be made through formal change control processes. (Haugan 2002, pp. 5-7) The following paragraphs describe the creation of the WBS with the assumption that all the necessary information is available.

A common way to create a WBS is to start from the bottom and move upwards from there. First all the different activities of the project are listed and grouped into work packages using a systematic way that is used throughout the whole process of creating the WBS. This can be very labour-consuming and depending on the project might need the contribution of multiple experts or departments that are part of the project, such as engineering and procurement. Next, these work packages are summarized to one level higher deliverables while remembering to keep all the elements as understandable and manageable as possible. This method is used until the top level is reached, while remembering to also use the 100 % rule at every level of the WBS. (Haugan 2002, pp. 19-20)

Haugan (2002, p. 20) states that asking the following two questions at each level while creating the WBS will help to do the work correctly:

- Does the sum of the lower level that is being summarized to one higher element equal to everything that the higher-level element includes?
- Is there something that is missing?

He continues that it is common that when these questions are asked while creating the WBS, often some activities that are missing are detected and that it can take several iterations to get the WBS into its final form.

2.1.4 Using the WBS

When the WBS is ready, it is locked. This is also referred as freezing the WBS. After the project execution has started, the frozen WBS is continually compared to what has been agreed. As the project progresses, some variances might occur, and these variances are then handled using standard change request procedures if needed. If a change request is approved, it leads to a series of steps, which among many other things, includes updating the WBS and WBS Dictionary. It can be stated that WBS is the tool that ties all the different components and parts of the project together. (Norman et al. 2008, p. 140)

In this study the WBS is used only as a structure for the productivity measurement database that was created as a part of this study. Because of this, using the WBS is not covered any further.

2.2 Subcontracting in construction industry

Construction is a huge industry and it can be defined and described multiple different ways. As the time has passed, the size and complexity of the structures that humankind build has expanded enormously, and when the complexity of a project increases, the number of unpredictable factors also increases. (Clough et al. 2015, pp. 1-2) This naturally also effects on how the contracts are made.

Below is a figure which is showing the parties and their relationships with each other in a typical construction project. There are countless possibilities how the contracts can be made, but the hierarchy usually follows the following pattern. The owner of the project has the power to decide how him and other parties of the project operate.

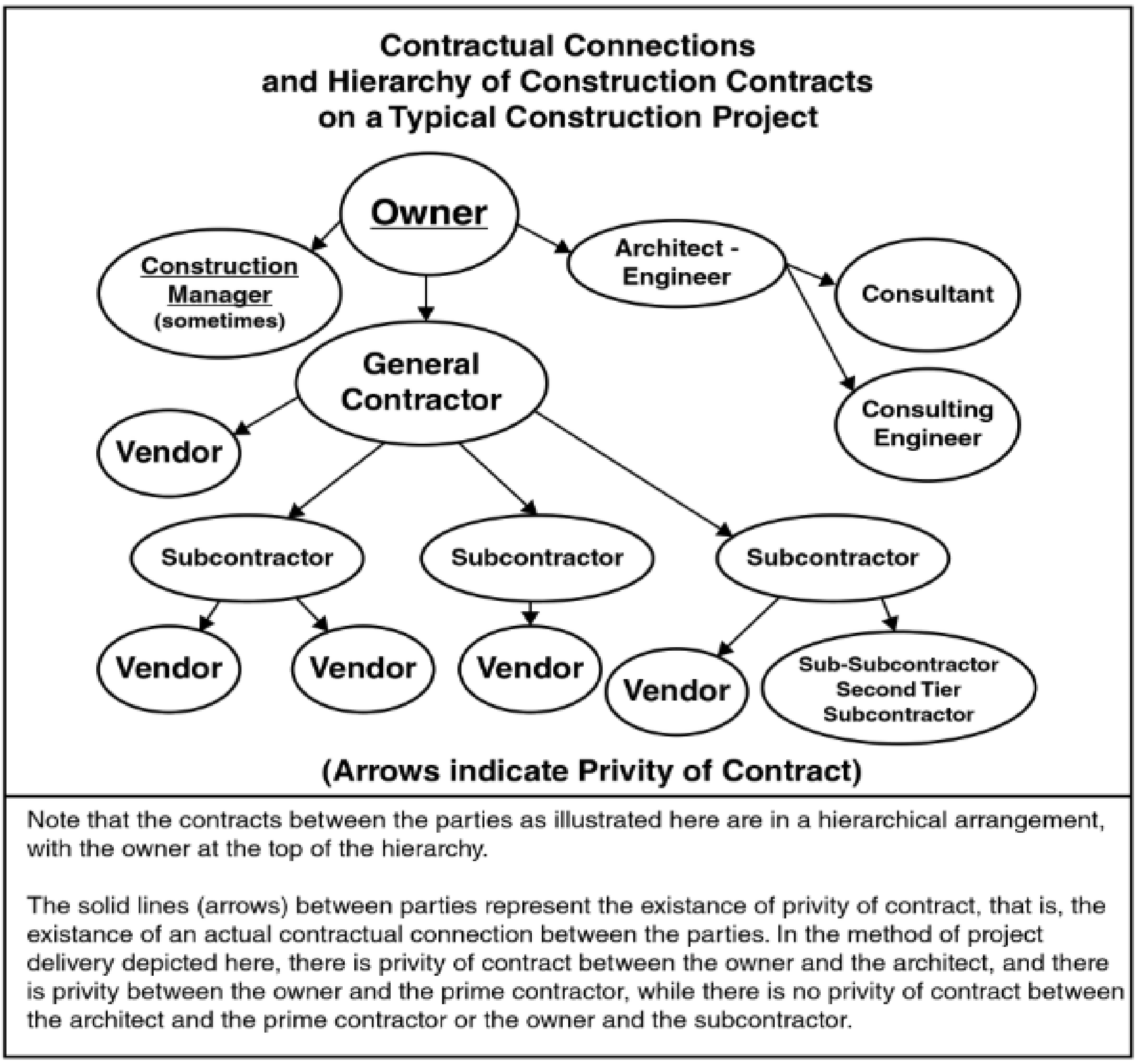


Figure 5. *People involved and hierarchy of contracts on a typical building construction project (Clough et al. 2015, p. 4)*

2.2.1 Project delivery methods

Clough et al. (2015, pp. 16-23) present multiple different methods of project delivery that the owners have available to them. These methods also affect subcontracts that the project will have:

- Construction Services Only, where the general contractor only takes part on the construction phase of the project and provides no input to the design. Often when using this method, the owner has an in-house design and engineering capabilities.
- Design-Bid-Build. This method is also known as linear construction method or design-then-construct method and it has been the most used method for some time in all kinds of construction projects. This method begins with the owner finding a need to construct something, considering the budget and financial side of the upcoming project and if the investment calculations allow, enter to a contract with an architect or an engineer for the design part of the project. After the designs are ready and approved by the owner, the project is announced to construction contractors and the bidding phase of the construction part can start. The designer of the project assists the owner with the questions and other issues the bidding phase might cause and in the end of the bidding phase, however it is decided to be carried out, the construction contractor is chosen.
- The Team Approach, in which the owner selects and teams up with an architect-engineer and construction contractor in the beginning of the project, after the decision to build has been made. These parties will then work together throughout the whole project and everybody's expertise are taken advantage of.
- Design-Build. This method has become more and more popular during the recent years and is believed to continue in doing so by most professional practitioners. It is also referred to as the turnkey project delivery method. In this method the owner enters to a contract with a company that will handle both design and construction of the project. This company can consist of multiple firms that are working together but are presenting themselves as one entity to the owner. This methods popularity can be explained by how much it supposedly reduces the problems related to cooperation and communication between the different parties in the project. It is also one of the simplest methods for the owner.
- Design-Manage, which differs from the previous method only by the single entity, being for example a coalition of a design firm and a construction management

company, not doing the work with their own employees but rather hiring independent contractors to do the works and only managing the matters. The difference shown to the owner is usually very small compared to Design-Build method.

- Pre-engineered Buildings. In this method the owner enters to contract with a contractor that have direct connections to manufacturer that is providing pre-engineered solutions for different structures that the owner is looking to build. In today's market these buildings are relatively flexible to be modified according to the owners wishes. The design phase is much faster compared to other methods and the components arrive to the construction site ready to be assembled, which makes this method very quick.
- Fast-Track, which is used when the time used for the project is important to be as short as possible. This method brings additional risks to the project and the risk/reward ratio is to be debated before using it. The idea of the method is to "leapfrog" different functions, mainly design and construction, to each other. This means that the project is divided into parts and when the design of one part is finished or almost finished, the construction of that part starts. The risks that this method has in addition compared to other methods is affiliated with this fact, but when everything goes as planned, a good amount of time and with it, money, can be saved when using the Fast-Track delivery method.
- General Conditions Construction. There are situations where the general contractor is subcontracting all the works of the entire project. In a case like this, the General Conditions Construction method is used. It means that the general contractor is still responsible to provide the subcontractors with predefined services, such as temporary electricity and heat, sanitary facilities and parking areas but does not take part in the actual works.
- Value Engineering, which is more of an additional element that can be utilized with a project delivery method than a method in itself. It means that the owner and the designer of the project can seek the input of the contractor(s) for example in order to use construction materials that better fit the project in question. This can be done in many ways and either before or after the contractor(s) have been selected.

The delivery method can be picked directly from the list above as it takes a lot of the important aspects of construction projects in to account, but it can also differ from the typical delivery methods if the owner so wishes.

2.2.2 The importance of known subcontractors

Liu et al. (2017, p. 1) say in their text that in many construction projects, the general contractor is in fact acting as a project coordinator, meaning majority of the work is being done by subcontractors rather than the general contractors' own personnel. They continue that because of this the cooperation of the parties is essential for successful project delivery and that usually general contractors prefer to work with subcontractors that they have worked with before. Having history of partnering relationship with each other, it is more likely that trust is established between the parties and this helps the projects to go smoothly and avoid all kinds of problems that might occur with an unknown subcontractor. In their study, Liu et al. (2017, p. 2) define "*Willingness to Cooperate*" as the likeliness that the subcontractor would like to work with the general contractor also in the future. This further emphasizes the importance of a long-lasting relationships to subcontractors.

Long-lasting contracting relationships are not always possible, however. In this case there are different public practices and procedures to follow when selecting the subcontractors. While Ulubeyli et al. (2010, p. 53) state that often companies choose the subcontractors based on their experience with them without using any selecting techniques that exist, it is possible that none of the subcontractors are known by the company beforehand. When this happens, it is worth considering using an existing, proven-to-be-good evaluation technique.

2.2.3 Subcontractor selection practices

After the delivery method of the project is decided, the next step is to pick the method of how to choose the designer(s) and contractor(s) for the project. Naturally the chosen delivery method affects this phase. The owner can do this however he wishes, but there are three basic methods that are usually used: competitive bidding, competitive sealed proposals and negotiation. Within each of these methods, different forms of contracts can be utilized. Competitive bidding normally uses either lump sum or unit price form and the two other options normally use one of the following forms:

- Lump sum
- Unit price
- Cost plus a fixed fee
- Cost plus a percentage of cost
- Cost plus a fixed fee or percentage of cost, with a guaranteed maximum

- Cost plus a fixed fee or percentage of cost, with a guaranteed maximum and a savings or incentive clause. (Clough et al. 2015, pp. 27-38)

All the delivery methods, contract awarding methods and contract forms have their advantages and disadvantages and it is up to the owners, possibly with the help of the architect-engineer and/or construction manager, to decide what combination of these will fit their project best. One thing for the owner to consider is also whether to make a single contract with one prime contractor or multiple prime contractors (Clough et al. 2015, p. 24).

2.3 Productivity and performance indicators

Park et al. (2005, p. 2) write in their text, that in year 1986 Thomas and Mathews stated that no standardized productivity definition had been established in construction industry. The reason for this at the time was that companies were using their own internal systems which were not globally standardized. Since then researchers have developed some common definitions, but these are not based on the consensus of academia and industry.

This chapter focuses on explaining what productivity and performance indicators are, what affects them and how they can be utilized in construction industry. As this is a huge area including lots of different kind of aspects, the content has been outlined only to the most important parts of the subject.

2.3.1 The definition of productivity

Dozzi and AbouRizk (1993, p. 1) state that productivity in construction industry can be described in many ways, such as performance factor, production rate, unit person-hour rate and others. They continue that in construction industry the labour productivity is usually measured by the physical progress achieved per person-hour or for example person-hours used to pour cubic metre of concrete. Whiteside (2006, p. 1) writes that *“Productivity is the average direct labour hours to install a unit of material”*, which is the simplified definition used also by other authors. He however reminds that in reality the true productivity is often poorly understood, because of multiple reasons, such as:

- The lack of common terms. For example, the use of term direct labour hours is not used consistently.

- Too much focus is placed on the individual worker, when often the reason for difference in productivity rate is caused by something else, like jurisdictional rules, technology or incomplete planning.
- The data that is used in productivity studies often have different kind of basis. When this is the case, one cannot reliably compare the results of productivity rates in different projects.

Typical misconception is that in lump sum contracts it is not necessary to collect data and track the subcontractors works, because the subcontractor can be held accountable for any delays and extra costs. In reality, it is always better to assist the subcontractor and for the project parties to work together in successfully completing the project. (White-side 2006, p. 1)

Like mentioned above, there are multiple ways to define productivity when examined on detailed level. Important to note is that in this case when talking about productivity the focus is on labour productivity, which is the main factor in construction industry (Ghate and Minde 2016, p. 1).

A common way to define labour productivity is:

$$labour\ productivity = \frac{input}{output} = \frac{actual\ work\ hours}{installed\ quantity} \tag{1}$$

As the equation (1) shows, labour productivity is measured by dividing the actual used work hours to the task with the amount of installed quantity. When measuring the productivity this way, the smaller productivity values are an indication of a better productivity performance. (Park et al. 2005, p. 2) The type of the quantity used in the equation varies depending on what kind task is been examined.

Another way of defining labour productivity is using the cost instead of work hours:

$$labour\ productivity = \frac{input}{output} = \frac{actual\ labour\ cost}{installed\ quantity} \tag{2}$$

These two equations are very close to each other but are used for different purposes when measuring the productivity (Ghate and Minde 2016, p. 1). Where equation (1) measures the time used for a certain task, equation (2) focuses on the cost of the task. If the cost per hour of the labour used is known, the cost can easily be calculated from the time used by multiplying it with the hours used and vice versa. In this text, when talking about (labour) productivity, equation (1) is considered.

2.3.2 Direct and indirect work

The works at construction sites are divided into direct work and indirect work depending on the roles of different personnel. All the tasks that directly contribute to the product, the building in construction industry's case, are counted as direct work. Examples of such tasks are welding, concreting, masonry work and fitting. Direct work tasks are usually easy to target to a specific part in the project's WBS. Everything else, meaning all the support work that is not directly contributing to the product, is counted as indirect work. Examples of indirect work tasks in construction are site management and supervision, crane driving, scaffolding and cleaning. Unlike direct work tasks, indirect work tasks can be difficult or impossible to target to a specific part in the project's WBS.

It is important to do this kind of distribution, because when calculating productivity, only the amount of direct work hours or is used in calculations (Dozzi and AbouRizk 1993, p. 7). This means that the amount of indirect work cannot be determined by looking just at the labour productivity numbers. While lack of indirect work resources can drastically affect the fluency of the works, it is not usually separately tracked, but can be calculated by reducing the direct work hours used from the total hours.

Hee-Sung Park, et al. (2005, p. 774) present a table of direct and indirect work differences. They have replaced the word "work" with "accounts", and the listing differs from what was stated in the previous two paragraphs. This is further showing that dividing the roles can be and is done in many different ways.

Table 2. *List of Direct and Indirect Accounts (Hee-Sung Park, et al. 2005, p. 774)*

Account		
Direct	Indirect	
Direct craft labor	Accounting	Orientation time
Foreman	Area superintendent	Payroll clerks/ timekeepers
General foreman	Assistant project manager	Procurement
Load and haul	Bus drivers	Process equip. maintenance
Operating engineer	Craft planners	Project manager
Safety meetings	Craft superintendent	QA/QC
Scaffolding	Craft training	Quantity surveyors
Truck drivers direct	Crane setup/take down	Receive and offload
	Document control	Recruiting
	Drug testing	Safety
	Equipment coordinator	Safety barricades
	Evacuation time	Security
	Field administration staff	Show-up time
	Field engineer project	Site construction manager
	Field staff (hourly)	Site maintenance
	Field staff (salary)	Subcontract administrator
	Fire watch	Supervision (hourly)
	Flag person	Surveying crews
	General superintendent	Temporary facilities
	Hole watch	Temporary utilities
	Janitorial	Test welders
	Job cleanup	Tool room
	Master mechanic	Truck drivers indirect
	Material control	Warehouse
	Mobilization	Warehousing
	Nomex distribution	Water hauling

Dozzi and AbouRizk (1993, p. 6) present an additional view on the matter and use these same terms in a completely different way. While a person that is doing direct work cannot participate on his normal, productive work for any given reason, he might still be able to do something semi-productive. If that is not possible either, the time is then spent on a non-productive action. Table 3 shows how this classification works. These two different ways of using the terms direct work and indirect work are not to be confused with each other.

Table 3. *Examples of activity classification (Dozzi and AbouRizk 1993, p. 6)*

Classification (equivalent classification)	Productive (Direct Work) (Working)	Semi-Productive (Indirect Work) (Support Work)	Non-Productive (Delay) (Non-Working)
Description	Using trade tools	Supporting the main activity	Not contributing to the activity
Examples	mason laying brick, labourer mixing mortar, electrician pulling wire, welder welding pipe	tradesman getting material, travelling to work location, taking instructions	personal breaks, waiting for equipment to be fixed, waiting for more instructions, late start or early departure

2.3.3 What affects productivity in construction projects

There are multiple factors that affect the productivity in construction projects. Dozzi and AbouRizk (1993, p. 2) mention motivation, job safety, physical limitations and environmental factors.

Below is Table 4 that lists factors that can severely impair the productivity in a construction project. These factors can be caused by a variety of things and are very difficult or impossible to predict. Because of this it is important to carefully analyse and find the real reasons for possible delays or cost overruns rather than just blame for example the labour productivity.

Table 4. *Factors seriously impairing construction productivity (Dozzi and AbouRizk 1993, p. 1)*

Category	Factors
Project Conditions	Weather variability
Market Conditions	Material shortages Lack of experienced design and project management personnel
Design and Procurement	Large number of changes
Construction Management	Ineffective communications Inadequate planning and scheduling Lack of sufficient supervisory training
Labour	Restrictive union rules
Government Policy	Slow approvals and issue of permits
Education and Training	Lack of management training for supervision, project management

2.3.4 Workforce Management

For the workers to be able to do their jobs efficiently, a proper workforce management needs to be implemented at the construction site. Some of the common deficiencies in workforce management are:

- Lack of organizing the work crews.
- Not having enough time buffer between activities.
- Not having clear expectations on the daily crew production.
- Failing to produce good working framework for high-value tasks. (Thomas et al. 2017, p. 155)

Thomas et al. (2017, pp. 156-157) also introduce a list of fundamental principles of Workforce Management, which is shown below.

Table 5. *Fundamental Principles of Workforce Management (Thomas et al. 2017, p.156-157)*

Number	Principle
	General
1.1	Where possible, use a 4-10 work schedule.
1.2	Staff the activity with labor resources that are consistent with the amount of work available to be performed. This includes taking adequate account of the variability in the project.
1.3	Have a good termination or layoff policy at the crew and project levels.
1.4	In instances of uncontrollable variability in workload, more labor than planned may need to be applied rapidly to complete work in the required time frame.
1.5	Superintendents and supervisors should not pick up tools and perform work normally done by workers.
1.6	The concept of a working supervisor is not a good idea.
1.7	Share with the crew expectations in terms of production, work hours, time, and completion dates.
1.8	Each crew must be allowed to work at an unimpeded pace to maximize labor efficiency.
	Daily Work Schedule
2.1	Daily schedules should be planned to prolong the periods of the most productive work activity.
	Work Assignments
3.1	Make the primary focus of the crew's work directed to high-value work. Never stop working on high-value work.
3.2	Efficient material handling and timely deliveries are important for good productivity, especially on labor-intensive operations.
3.3	Work on low-value subtasks concurrently with high-value work.
3.4	Perform incidental and cleanup work concurrently with high-value work.
	Crew Structure
4.1	A crew should be viewed as a collection of flexible size work teams.
	Disruptions
5.1	Minimizing or eliminating disruptions improves performance.
5.2	Keep the work face area free of trash and clutter.
	Multiskilling
6.1	Create multiskilled crews with individuals who have different skills, and who, when combined, form the multiskilled crew.
6.2	Where concurrent multiskilling tasks are applied, crew assignments need to carefully consider the size of the teams, the production output to be expected for each team, and how many hours the teams should be given to accomplish their work.
	Preassemblies and Modules
7.1	Preassemblies and modules are an effective way to reduce the field labor component of the installation activity.
	Symbiotic Crew Relationships
8.1	Where possible, avoid symbiotic activities.
8.2	There should be adequate time buffers between each activity.

The term 4-10 work schedule means that the contractors and their workers are working 10 hours in a day four days a week. This kind of schedule gives the workers three days weekend, and provides the contractor a makeup day, that they can use to catch up on the works if they are delayed for whatever reason. Working longer days also reduces the amount of startup and shutdown time in relation to effective working time, because the workers can work longer after setting up to their task. In addition to this, another important point that can easily be overlooked is to schedule the daily work to happen during the most productive time of the day without interruptions, which according to studies is between 10:00 and 14:00. It is also important to make sure that the labor resources are consistent with the amount of work to be done in any given task. If there are too few or too many workers participating to a task, the labor productivity is immediately affected. This is one of the reasons the superintendents and supervisors should not perform any of the work normally done by the workers, because they are the ones that have the best understanding of the daily situation at the construction site, and should use their time in planning, anticipating possible future problems, advice the workers and coordinating with teams and other contractors personnel. (Thomas et al. 2017, pp. 157-160)

Most of the tasks consist of multiple subtasks that can be divided into high-value work and low-value work, depending on their demand on the labor hours and effect to the schedule. The high-value work is to have more weight on it when deciding how to divide the labor resources to the tasks and should never be stopped to perform a low-value tasks. However, the low-value work cannot be forgotten, as it still must be done. The way to achieve the best productivity is to prioritize high-value work, but concurrently perform low-value tasks when possible. (Thomas et al. 2017, pp. 160-164) This philosophy is closely linked to what Dozzi and AbouRizk present in the Table 3. Thomas et al. (2017, pp. 165-170) continue, that because of the reasons mentioned above, it is important for the working crews to be flexible in size so that when a high-value subtask does not require the whole team to participate, some members of the crew can do other works. For this to be possible, it helps if the workers are skilled to do different kind of tasks and not just one, and the cooperation of different work crews and possibly different subcontractors is working smoothly.

It is important to have enough buffers when working and changing from one task to another. In construction projects there will always be some variation in productivity caused by many possible reasons and having enough buffers can drastically reduce the negative effect of the variability. Different kind of types of buffer exist. Some of the most common ones are: material stockpiles, variation in equipment and crew sizes, modules, alternate work assignments and time lags. The most common of these buffer types is probably time lag and it also links at some level to almost all the other buffers. Time lag means that there is enough buffer between when a task ends and when the following task starts. This is always important to consider when making the schedule, but there are also three situations where it is particularly important:

- Schedule acceleration. Even when the works are late and they are in desperate need of acceleration, one cannot forget to reserve some time between different tasks. When things are being rushed, this is often disregarded.
- High variations between sequential tasks. When the earlier task takes more time than the following task, enough time needs to be reserved before the start of the second task. This prevents the second task workers to run out of work before the earlier task is completed, and therefore considerably reduces the labour productivity.
- High variability in production. If the productivity and therefore time to finish a task is difficult to estimate and varies a lot, the following tasks should not be scheduled to start immediately after the estimated finish of these kind of tasks. In the worst case this might cause one or more work crews to have to wait. (Thomas et al. 2017, pp. 170-171)

In addition to previous points, it is also important for the managers and supervisors to have clear and realistic expectations of the amount of work the can be done in a given period. When not clearly stating or having low expectations can easily affect the productivity of the work crews, usually on the negative side of things. For the expectations to be realistic, it can be a good strategy to let the crew set the goals themselves and go from there. This can also help the crew to commit to the works better. Another thing to understand when thinking about crew sizes or overtime is that too many workers or hours for the workers reduce the productivity. This means that doubling the manpower or working double hours for a task does not necessarily mean that the work is finished in half time compared to the original. For the working crews to be able to work the most efficient way, also the circumstances must be ideal. (Thomas et al. 2017, pp. 172-173)

2.3.5 Defining and using performance indicators

Performance indicators are predefined numeric based definitions, which can be used to understandably monitor how different tasks are going or have gone. In other words, they are the tool used to measure the productivity. The type of task heavily affects what kind of indicator should be used and there is no one correct way to define these indicators. It is possible, however, to create a standardized group of performance indicators, from where they can be picked and modified if needed, when deciding how to measure the productivity of any given task in a project.

One collection of performance indicators, that has been made in cooperation by multiple Finnish construction companies and governmental construction agencies, is called *Aikataulukirja*. There are multiple versions of it, and it is updated regularly. This collection includes instructions what it is used for and how to use it. The goal of the book is to develop scheduling at construction sites and to offer basic information about controlling construction projects and it emphasises teamwork between all the different parties in construction industry. The information in the book can be directly used in multiple type of construction projects, such as row houses, apartment houses, commercial buildings and industrial buildings. It uses a WBS system called *Talo 2000*, that has been separately developed and is widely known and used in Finnish construction industry. (Talonrakennusteollisuus 2015, pp. 5-6)

The collection (Talonrakennusteollisuus 2015, p. 9) derives the performance indicators it uses from the equation (1) presented in chapter 2.3.1. It is possible to use cost here instead of hours, but when scheduling, the hours are typically more important.

$$labour\ productivity = \frac{input}{output} = \frac{actual\ work\ hours}{installed\ quantity} \tag{1}$$

The collection includes the size of the work group to the calculations, as many tasks have a thought-out number that fits the task well. The next performance indicator is called work capacity, which is the inverse of labour productivity.

$$work\ capacity = \frac{1}{labour\ productivity} \tag{3}$$

Because of the nature of the equation (3), the unit of the equation (1) is turned upside down, and the unit on work capacity is therefore *installed quantity per work hour*. Depending on what quantities are used in these equations, the result can be for example how many work hours it takes from a single worker to install one square meter of material or how many square meters the whole group are able to install during one work shift. Whichever is the most convenient unit, should be used. The collection shows different types of information depending on the task. An example extracted from the collection can be seen below in Table 6.

Table 6. *Example of performance indicator listing (Talonrakennusteollisuus 2015, pp. 59-60)*

WBS	Unit	Work Group	Productivity	Work capacity
		SW + W	wh / unit	unit / ws
4 CONCRETE CONSTRUCTION				
41 Concrete frame construction				
Board mold work for sensors				
- board mold	mold-m2	2 + 0	0,83	19
- slice mold	mold-m2	2 + 0	0,61	26
42 Precast concrete construction				
Concreting of sensors and low base walls				
- pump concrete	m3	3 + 0	0,08	286
- transport container concrete	m3	3 + 0	0,34	71
Foundation element work				
- sole and sleeve elements	pcs	3 + 0	3,48	7
- plinth elements	pcs	3 + 0	2,88	8

The explanations for the different names and abbreviations of the table are as follows:

- The WBS numbers and names are taken from the Talo 2000 WBS system.
- Unit column includes the information in which unit type the task is being tracked.
- Work Group shows the recommended number of workers for the task. The abbreviations SW and W mean Skilled Worker and (Normal) Worker. The difference between these two is explained in the collection.
- Productivity shows the number of work hours needed to complete one unit of the task. Wh is abbreviation for work hours.
- Work Capacity shows the number of units completed in a work shift using the size of Work Group recommended for the task. The standard number of hours in a work shift is eight hours.

Performance indicators like these are used in making the schedule for the construction site and when the works start, in measuring how well the works are going, in other words tracking the productivity of the construction site. It is important to notice that the numbers in these kinds of collections are averages of what the industry has determined from tracking the actual productivity numbers from different subcontractors on different construction projects. This means that they are not exact values and should be used with that in mind.

Hee-Sung Park, et al. (2005, p. 777) present a table of similar nature in their text. This table is much smaller compared to *Aikataulukirja* and only includes the unit information without the numbers, but the idea is the same.

Table 7. *Construction Productivity Metrics (Hee-Sung Park, et al. 2005, p. 777)*

Metrics	Unit	Metrics	Unit
Concrete		ISBL large bore (3 in. and larger)	
Slabs		Carbon steel	h/ft
On-grade	h/yd³	Stainless steel	h/ft
Elevated slabs	h/yd³	Chrome	h/ft
Ares paving	h/yd³	Other alloys	h/ft
Foundation		OSBL large bore (3 in. and larger)	
<5 yd³	h/yd³	Carbon steel	h/ft
5–20 yd³	h/yd³	Stainless steel	h/ft
21–50 yd³	h/yd³	Chrome	h/ft
>50 yd³	h/yd³	Other alloys	h/ft
Concrete structure	h/yd³	Instrumentation	
Structural steel		Loops	h/EA
Structural steel	h/t	Devices	h/EA
Pipe racks and utility bridges	h/t	Instrumentation cable	h/ft
Miscellaneous steel	h/t	Equipment	
Electrical		Pressure vessels	h/EA
Electrical equipment and devices		Atmospheric tanks (shop)	h/EA
Panels and small devices	h/EA	Atmospheric tanks (field)	h/EA
Electrical equip. 600 V and below	h/EA	Heat transfer equipment	h/EA
Electrical equip. over 600 V	h/EA	Boiler and fired heaters	h/EA
Conduit		Rotating equipment	h/EA
Exposed or above ground	h/ft	Material handling equipment	h/EA
Underground or embedded	h/ft	Power generation equipment	h/EA
Cable tray	h/ft	Pulp and paper equipment	
Wire and cable		Woodyard equipment	h/EA
Power and control cable: 600 V	h/ft	Pulp mill equipment	h/EA
Power cable: 5 and 15 KV	h/ft	Bleach plant equipment	h/EA
Other electrical		Stock preparation equipment	h/EA
Lighting	h/EA	Wet end equipment	h/EA
Grounding	h/ft	Dryer sections	h/EA
Electrical heat tracing	h/ft	Dry end equipment	h/EA
Piping		Other process equipment	h/EA
Small bore (2-$\frac{1}{2}$ in. and smaller)		Modules and preassembled skids	h/EA
Carbon steel	h/ft	Insulation	
Stainless steel	h/ft	Equipment insulation	h/ft²
Chrome	h/ft	Piping insulation	h/ft
Other alloys	h/ft		

Note: EA=each.

3. SUBCONTRACTOR PRODUCTIVITY MEASUREMENT IN USE

In this chapter the theoretical information introduced in chapter 2 is used to analyse the target company's current state, present a database for productivity measurement and make suggestions on how to improve its processes and tools. The focus is on how to effectively use performance indicators in tracking subcontractors work at the construction site and with that, forecast how the upcoming weeks or months are going to go and if the works will finish according to plan.

The target company is going through massive changes regarding its systems unrelated to this thesis, which are introduced in the first subchapter. As these changes have a considerable effect on the subject of this thesis, they are presented in a comprehensive way.

The next subchapter demonstrates what the database that was created as a part of the study consists of. This chapter has two parts in it, as there are two sheets in the database spreadsheet at the time the thesis was written. Creating the database represents most of the work done and hours used in this study, as it includes over 3000 rows of tasks and multiple columns of data for each task. Because of this, the process of creating and filling in the data to the database is described in detail.

The third and last subchapter goes through the process of filling in the information to the database and the interviews that were part of this. After that the work that have been done is analysed and points that were noticed during the filling are brought up. Last the chapter gives a recommendation how the scheduling and productivity tracking could be done in the future and what steps would have to be taken to achieve this.

3.1 Present day description

At the moment the target company is updating its systems and processes on a large scale, not just things related to subcontractor work efficiency tracking. Company's whole ERP (Enterprise Resource Planning) system is been changed into a new one step by step, and this also includes a complete update on the WBS system the company uses. In addition to this, a new scheduling software has been recently taken into use and it is still in transition phase.

While big changes cause a lot of adaptation, the situation also presents a good possibility to implement additional features, such as more detailed productivity measuring to the construction sites.

3.1.1 New ERP and WBS systems

As the target company's old ERP system was getting outdated and at least partially cumbrous to use, a decision was made to change the old system to a completely new one. Even though it is a huge investment, a new ERP system can take advantage of all the modern-day features and works better with external programs. The new system is also easier and more effective to use than the old one, which will help pay back the investment in time. Unlike the previous system, the new one is the same regardless of the country or office it's been used, which will bring the different departments and industry areas of the company closer together and unite the working practises. The direct effect to subcontractor work efficiency at the construction sites is small, as the basic principles are the same as before, but it will have indirect impact on how the data can be saved and examined for example.

At the same time the ERP system is been changed, the company's WBS system is also updated. This was a natural step, as the new ERP system allows more flexible coding of the WBS elements, which have evolved during the years and were also at least partially in need of an update. After the change in the WBS, the same system will also be used in all the business areas of the company, uniting the logic and practises of the company even more. Naturally, there are lots of similarities with the old and new WBS system, as the products have not suddenly changed, but there are also considerable changes to the logic behind the system.

In addition to the company having one WBS system, which includes the elements for all the business areas, the arranging of the WBS has been changed from discipline-based order to system-based order. This means that when tracking for example piping works in a project, tasks related to that are now located under multiple different systems rather than being under one discipline called "piping". Elements will have the discipline data in them in the future too, so arranging them in that way will not be a problem, but it has been learned in the company that the system-based planning and tracking serves the different phases of the projects better than discipline-based way, so it has been set as the new default view.

The coding of the WBS elements was changed completely. This will not cause any problems as long as the elements are created in a logical way so that each of them can be defined and further tracked the same way the old system allowed. Another thing that affects the order the elements can be found from the WBS, is the sequencing logic behind the system. The elements that are used in multiple different products are now moved to one shared location in the WBS. This means that all the different elements for any entirety will not be located under the main headline of that product. At first this might sound confusing, but with this change there are no duplicated elements in the WBS, which will constrict the size of it. It is also worth mentioning, that the new WBS has a section that can be edited for each product to serve the needs of a certain product better, which brings flexibility to the WBS.

Because the target company is large and the projects can last for multiple years, the transition to the new WBS takes time which means the two WBS systems are used simultaneously for some time. When defining the performance indicators, this needs to be taken into account. Because the general idea of the WBS and how it is linked to scheduling and progress tracking stays the same, in the end the WBS changes do not have as big of an effect to the concept of productivity measurement, but more on the everyday work that is related to it. It can be counted also a good thing that all these changes are happening at the same time, because this way there is no reason to expect a new change to these systems in the near future.

3.1.2 Scheduling and construction site control

The target company decided to invest in more detailed scheduling, and with the new scheduling software taken into use, all scheduling related processes and tasks have also been affected. It takes time for different departments, teams and individuals to get used to these new processes and ways of working, so making this big of a change at one go is not recommended or even possible. Instead the new scheduling software is implemented gradually using pilot projects, which will show what aspects of the new practises are working well and which need further improvement, without affecting all the projects. There have already been a few pilot projects in which the construction and commissioning phases are finished or well under way. The data from these projects can now be examined and the effects and strengths of the new scheduling tool can be assessed.

With limited amount of working resources targeted to the tool and limited number of scheduling software licenses for users, it has been decided that some of the projects that are starting will either not be using the new software at all, or that all the features of the software will not be used in them. There is also limited number of users that have been trained to use the new software at this point, so for all the planned future users to get the training for the software has not even started yet.

The new scheduling software needs more work to set up on a project compared to the old one, as it includes more data and because of this it is not used in the smaller projects. In some projects, usually these smaller ones, the target company's role also differs from a typical prime contractor to advisory one, in which case the company does not have as much control in the project due to different kind of nature of the contract(s). In these projects the company does not have access to all the necessary data to fully use all the features of the scheduling tool. At some point when the implementation of the tool is further this might change, but at the moment only some of the starting projects are using the new software. When there is more collected data that can be used when making the schedules of the new projects, the company is able to fully take advantage of the new features of the tool and one of the indirect goals of this thesis is to help make that happen.

The costs of projects are included in the new scheduling tool. Costs are used to define the weight values of tasks of which the target company will not have the quantity information, or measuring the quantities is not practical. Examples of such tasks are engineering bought from external sources and manufacturing of parts. The tracking of costs is to be kept separate from the time scheduling but incorporating multiple aspects of a project to one tool can be very rewarding. Even though the project budget, updated estimations, committed amounts and actual amounts of costs are tracked, controlled and modified in a separate system and only imported to the schedule from there, it helps when one can easily compare for example the curves of time used and costs accumulated in one chart that is produced by a single program. This is one of the reasons the scheduling software is been changed.

It is important to remember that these new practises also affect the subcontractors. While the target company usually has multiple own supervisors at the construction site, it is impossible for them to know all the details on for example about the manpower that all the different subcontractors have on the site each day and what tasks each worker is doing. Subcontractors also have their own site managers and team leaders at the site who are responsible for assigning the workers their tasks and keeping track of what is happening with all the different ongoing tasks. Because of this, the company has added new obligations for the subcontractors into the contracts. These obligations include, among other things, more detailed weekly reporting of manpower and progress, that are usually produced using templates made by the target company. These templates are trained and given to the subcontractors before the site work starts. With this type of practise, the target company has the ability to define the form in which the data is coming from the subcontractors, so that it is as easy as possible to import it to the tools that are been used. In some situations, especially when working with a small subcontractor, the subcontractor might not have the resources or expertise to produce all the required data. These situations need to be solved case by case, but the general idea is to try to keep the reporting practises of the subcontractors as easy and clear as possible to avoid these kinds of situations. This far this system has worked quite well and the subcontractors that have used the templates have been reasonably receptive with this kind of process.

The pilot projects that have been using the new scheduling tool have also used some performance indicators to measure and categorize the data, but standardized indicators for different tasks do not exist. A database where it is defined what tasks are related to what deliverables does not exist either. Because of this, the indicators for different phases, deliverables or tasks might differ and might not be the best possible measurement for the tasks in question. In other words, quite a bit of data about subcontractor productivity rates do exist, but it might not be in the best possible form and because of that it is more difficult to analyse. The detail level that is to be used when gathering the data is also not decided. Only after the detail level is locked and the tasks for all the deliverables have been defined can the units that are being measured for each task be decided.

Scheduling and with it, progress and productivity tracking, is linked to the WBS system. Because the WBS system the target company uses is also under heavy changes, the contents of the schedules need to be adjusted too. A clear, mutually agreed method on how to create the schedule has not existed in the company in the past, but instead the schedules have been different depending on the style of the scheduler. With the new scheduling tool and additional resources to scheduling in general, a template for scheduling is been created at the moment. This template is to be the starting point from which the new project schedules are made, which forces different projects and individual schedulers to use similar structure and style in their schedules. This template is linked to the WBS so that at a certain level of the two, the elements are matching. The schedule at its most detailed level is at least one level more detailed compared to the WBS, because the WBS does not include tasks but ends at one level before that. This is not a problem, however, because the tasks in the schedule can easily be summed together and presented on one or more level higher when needed.

3.2 Creating the database

The main goal of this study was to define suitable measuring items and a proper way to use them when measuring subcontractor work efficiency in a power plant construction site. To achieve this, a massive excel spreadsheet was created for documenting the definitions and storing the data that will be collected from projects.

The style of this spreadsheet was affected by the theory that was studied and by how the data can and will be collected with the scheduling tool. As a basis of the deliverables and tasks collected to the tables of the spreadsheet was the new WBS system of the company. This decision was made to make the scheduling, cost estimating & tracking and progress tracking to have the same type of logic and data to avoid compatibility issues. The first revision of the spreadsheet consists of two different sheets which are explained in more detail in the next two chapters.

3.2.1 Task information sheet

One of the secondary goals of creating the spreadsheet was to encourage the use of standardized task names in scheduling and progress tracking. In order to do this, the Task information -sheet was created. This sheet includes the following information:

- List of task names and their descriptions. When deciding what tasks that a deliverable should include, the tasks are to be picked from this list to make sure the same names for tasks are used for different deliverables. For each task, there is also a short description of the task and definition what works are included in the task and what works are not. The listed tasks and their additional information are as follows:
    - **Handling.** This is a jointed task name that includes unloading, moving and storing the materials of the deliverable. It is counted as indirect work.
    - **Preassembly / Prefabrication.** The task name that better characterizes the nature of the works out of these two options depending on the deliverable, is to be used. This task includes all preparative works that are done at the construction site before the actual installation, such as assembling the platforms on the ground where it is easier to do the work compared to the end location. This is counted as direct work.
    - **Lifting.** This task includes all the lifting works that can be clearly separated as their own working phases. It is counted as indirect work.

- **Hauling.** This task includes all the hauling works that can be clearly separated as their own working phase. Like lifting, it is counted as indirect work.
- **Erection / Installation.** The task name that better characterizes the nature of the works out of these two options depending on the deliverable, is to be used. This task includes all the works that are done directly to the deliverable in question at the construction site during the actual installation phase. This task name can include additional information about what is included in it, such as "including lifting". This is counted as direct work and in most cases will form most of the work hours used for the deliverable.
- **Welding.** Sometimes the works of a deliverable include a separate welding phase that can be clearly distinguished from the installation works. In these cases, it can be appropriate to present welding as its own task, so that the tracking of the works is easier. Welding is counted as direct work.
- **Concreting / Grouting.** Used in case the installation has a separate concreting phase. Counted as direct work.
- **Alignment.** Used in case the installation has a separate aligning phase, such as with the steel structure. Can be included in the erection task but must be mentioned if that is the case. Counted as direct work.
- **Cleaning.** Every task includes the basic cleaning of the area after the work is done. This task is meant to be used in situations where the works of the deliverable create a significant amount of clutter which takes considerable amount of time compared to the other tasks of the deliverable. It is counted as indirect work.
- **Finishing works.** This phase is normally included in the installation task because it is usually difficult or impossible, and not functional, to point out how much time exactly was used for finishing works. In some cases, though, this phase can be clearly separated from the other work phases and should be used as its own task. As an example of this kind of situation is when the finishing works are done much later than the other works. Finishing works are counted as direct work.
- **Commissioning.** In this context, the task commissioning means the commissioning works been done to a single deliverable after it has been installed. This task is not to be confused with the wide commissioning phase

that comes after the installation phase for the whole construction site. That phase of the project has its own task names and different personnel doing the works than at the construction phase. These tasks are counted as direct work.

- **Inspection.** In this context, the inspection tasks are meaning separate internal inspections that are made to individual deliverables after the installation is complete. These are not to be confused with the inspections that are made by a third party, which usually includes multiple inspections at once. Inspections are counted as indirect work.
- **Other.** This group includes all the tasks that cannot be defined as generic tasks as the ones described above. An example of this kind of task is “punch list works”. Depending on the task in question, it can be counted either as direct or indirect work using the standard selection criterion.

- List of units to be used. Each task needs to have one or more possible units linked to it so that the productivity calculations can be made. This list includes the abbreviations and descriptions of the units that are to be used for different tasks.
- Definitions to what is considered small, medium and large scope of works using hours as the measurement. Definitions to what is considered small, medium and large weight for the items that are been lifted using kilograms as the measurement.
- Multipliers to be used for tasks depending on the scope of the works or the weight of the unit for lifting tasks. These multipliers are suggestions and can be ignored or different multipliers can be used if desired.

Table 8. List of the tasks to be picked for the deliverables on the database sheet.

Standard values	
Task	Unit
Handling	kg / m / m2 / m3 / pcs
Preassembly / Prefabrication	kg / m / m2 / m3 / pcs / di
Lifting	kg / pcs
Hauling	kg / pcs
Erection / Installation	kg / m / m2 / m3 / pcs / di
Welding	kg / m / pcs / di
Concreting / Grouting	kg / m2 / m3 /pcs
Alignment	kg / pcs
Cleaning	m2
Finishing	kg / m /m2 / m3 / di
Commissioning	pcs
Inspection	pcs
Other	#

3.2.2 Database sheets

Productivity tracking is more important for the biggest subcontractors at the construction sites, and the number of these kind of subcontractors the target company uses is relatively limited. Because of this it was decided that these big subcontractors should have their own sheets in the database spreadsheet. These sheets were named using the subcontractor company names. The database sheet consists of multiple tables that include different kind of data. These areas are explained in more detail on the following paragraphs.

On the left of the database sheet is the company's new WBS listing. This listing has four levels: product type, discipline / system, deliverable and task. The first three levels come directly from the WBS, and the last level, task, is the one that was created in part of this thesis and is been defined to split the deliverables into more manageable elements when tracking the productivity of the works. The schedules of the target company have used tasks before, but the direct link to the WBS has not existed. The task names have also been differentiating from project to another, as no standard task name pool has existed. It is important to notice that this WBS listing is not meant to be used as a scheduling structure as it is, but rather only to define the tasks that the schedule is using for different deliverables. Because the schedules include the cost information, they need to match also the deliverable level listed in this spreadsheet, but the grouping can be very different, and more levels and headlines can be found on the schedules.

Right of the WBS listing area is a table, where productivity numbers for each task can be estimated. These estimates are meant to be used before the actual data for the particular subcontractor exists. Because all the projects and construction sites are different, these estimates should be considered more as directive and not absolute. The estimates can be filled on any of the four levels, but it is recommended to do this for as detailed level as possible, at least on the deliverable level, and calculate the numbers for the upper levels using the more detailed information. After more data exists, estimating the productivity numbers will become more credible and exact and can act as a good basis for new subcontractor estimating. All the estimates were not filled as a part of this thesis, but a couple of them were filled as an example and to test that the logic behind the productivity numbers is working. At this point it was considered more important to gather the information from past projects, because this information is useful when making the estimates later.

After the estimating table, the next table is for the tracked actual data from construction sites. As all the subcontractors have their own sheet, every project of a subcontractor can be reviewed next to each other, which makes it easier to see any deviations in productivity values for different tasks. As the new WBS has just been implemented, and the new task breakdown created related to this thesis, the data from old projects and construction sites is in different form and needs to be arranged to fit the new task distribution. In many cases this detailed data does not even exist, as the progress tracking has not been based on productivity numbers before.

Last part on the database sheets is the totals and averages calculation table. In this table all the relevant data is gathered, and practical elements of the numbers can be calculated. At the time this thesis is been written, this table is not finished, and it will likely get additional columns added to it later when the database has seen some use and interesting values have come up.

Table 9. A short example from the database sheet with fictitious data as a demonstration.

[name of the contractor 1] [updated by / dd.mm.yyyy]			General multiplier 1,00	Base estimation data					
WBS	Discipline / System	Deliv.	Task	Unit	Productivity [h/unit]	Work Group [h/shift]	Work Capacity [unit/shift]	Multiplier [value]	Total
403505	Structural steels construction works			pcs	1,13	35,00	38,00	1,00	38,00
403505-1			Handling	pcs	0,50	20,00	40,00	1,00	40,00
403505-2			Erection, including lifting	pcs	1,50	40,00	26,67	1,00	26,67
403505-3			Alignment	pcs	0,05	30,00	600,00	1,00	600,00
403505-4			Inspection	pcs	0,20	20,00	100,00	1,00	100,00
403506	Platform & staircase installation			t	29,59	33,33	16,36	1,00	16,36
403506-1			Handling	t	1,00	20,00	20,00	1,00	20,00
403506-2			Preassembly	t	20,00	40,00	2,00	1,00	2,00
403506-3			Erection	t	40,00	40,00	1,00	1,00	1,00
403506-4			Inspection	t	10,00	20,00	2,00	1,00	2,00
403506-5			Finishing works	t	15,00	20,00	1,33	1,00	1,33
403507	Cladding, roofing & interior structures works			m2	1,23	36,00	73,67	1,00	73,67
403507-1			Handling	m2	0,20	20,00	100,00	1,00	100,00
403507-2			Erection, wall	m2	1,20	40,00	33,33	1,00	33,33
403507-3			Erection, roof	m2	1,40	40,00	28,57	1,00	28,57

3.3 Filling in the data to the spreadsheet

After a draft of the spreadsheet was complete, the focus switched to determining what type of roles in the company to consult when defining the tasks of the different deliverables that are been done in the construction sites by the subcontractors. It was decided that the best way to start would be to consult a site manager with a lot of experience of a different kind of projects to get the big picture.

A separate document was created to act as a structure of the interviews. This document is marked as Appendix A. The whole WBS was studied with the site manager, and parts and deliverables that affect the power plant construction sites were picked to the list. After that the list was reviewed row by row and the necessary data was entered to it. As power plants consist of huge amount of different parts and deliverables, many were left blank at first and would be later examined with experts of that area. In addition to site managers, Site Operations Project Engineers, Project Managers and Site Operations Coordinator from different departments were consulted.

3.3.1 Gathering information about the interviewee

The purpose of the first part of the interview was to get a rough picture of the interviewee. This information could be used later when analysing the results of the filling of the database and how the spreadsheet succeeded in general.

The structure of the document that was used to do the interviews (Appendix A) is as follows. The bolded sentences are the questions included in the document, and normal text is written to describe what the questions mean and to clarify why the question was included in the document:

1. **Title and role of the interviewee.** This is documented to get the idea of what type of interviewees were chosen.
2. **Experience and nature of projects the interviewee has participated.** More experienced interviewees are more likely to have in depth understanding of the processes and ways of working. Different type of experience also affects the depth of the answers.
3. **How much does the interviewee know about progress and productivity tracking in general?** This question was added to see how much the interviewees have been dealing with productivity tracking, as there are multiple ways to approach different roles and some aspects of things might be more important to the person doing the work regardless of the title.
4. **Does the interviewee feel that work efficiency measuring (in more detail) is needed?** Similarly like the previous question, this question was added to get the idea if the interviewees were even interested in the topic of productivity measurement. If the interviewee is contented with the current progress tracking level and do not think there is a reason to change the current ways, this might have a significant effect on the answers. Reasons for the answer were appreciated.
5. **How the interviewee sees the control the company has at constructions sites?** This question was meant to further clarify how people in different kind of roles see things. Four follow-up questions were added to clarify this question more.
   a. **Is the current level of control and tracking enough?**
   b. **Are there any single tasks or phases that are more difficult to track and should get more attention?** As the power plant construction sites differ from residential and commercial construction and therefore less

data exists in the literature, a clear, well studied answer to this question does not exist. The practises of the target company also affect this a lot.

c. **What should be changed if anything?**

d. **What would be the best way to do this?** The last two questions were phrased vaguely and were meant to just see if the interviewee had been facing specific type of problems with the matter and had any suggestions how to improve things in mind.

6. **How much does the interviewee deal with subcontractors in the daily work?** As the actual contact with the subcontractors might vary a lot for different people and roles, the nature of the conversations was influenced on how much the interviewee had experience in subcontractor contact.

7. **Is it easy to follow how the works are going at the construction site using only the daily/weekly/monthly reports?** All the interviewees were familiar with the reports mentioned in this question. These reports have been created by the target company and have been in use for many years. They do not include much numerical information about the progress or any productivity measurement data. The question was meant to find out if different people in projects will be using this kind of information when it becomes available.

3.3.2 Filling process

In the second part it was explained in more detail to the interviewee what the idea behind the productivity measurement and the spreadsheet related to it was. The document focuses on the process, when adding tasks and performance indicators to the spreadsheet, as follows:

1. **Picking the deliverables**

   a. **Choose a deliverable that has clear scope and is related to subcontracted work at the construction site.** The new company wide WBS structure of the target company had been inserted to the spreadsheet beforehand. This list, however, includes many deliverables that are not used in the power plant projects. The list was studied row by row and all the lines that were not needed were removed.

2. **Divide the deliverable to tasks**

a. **Create/check the list of predefined tasks and if the list does not include one or more of the tasks related to the deliverable, add those tasks to the list.** The tasks are to be picked from the "Task information" -sheets list of tasks.

b. **Pick the tasks related to the deliverable in question from the list so that everything related to the deliverable is included.** The descriptions of the tasks are to be studied and learned so that it is known what each task includes. This way it can be clearly defined and made sure that all the work is included in the picked tasks for the deliverable.

3. **Add values for the picked tasks**

   a. **Add units for each task included, for example m2 or kg.** The unit is to be picked from the unit list in the "Task information" -sheet. This information needs to be filled next, before the following cells for the task can be filled. Depending on the task, the best fitted unit for it is decided. In cases where the task has many possible options for unit, the best fitted unit is the one that can be tracked most clearly. If possible, the same unit is used for all the tasks belonging to one deliverable. This way the works of the whole deliverable can be calculated together more easily. When this is not possible, the productivity for the deliverable needs to be estimated separately instead of summing the tasks together.

   b. **Estimate the productivity values for the tasks using the defined units, i.e. how many hours it takes one worker to produce one unit.** It is important to note that the productivity values are determined by the unit that was chosen. At this point it is automatically checked if the chosen unit fits this purpose well and it can still be changed. The productivity value can be very difficult to understand if a bad unit for the task has been chosen. The productivity values can be very difficult to estimate for some tasks, and therefore these estimates are looked more as guiding rather than facts. The actual values will be determined when data from actual construction sites has been collected.

   c. **Give all the tasks a default work team, i.e. the number of workers performing the task.** Depending on the task, a different number of workers will be contributing to it. In the spreadsheet, the work group is defined as work hours per shift. So instead of filling in the number of workers in the work group, the total hours these workers are going to be working on a shift is used. This means if there are three workers working 10 hours a day, the value to be used is 30. In the estimate section, the work group data is also only an estimate and the true values will only be known when the actual data is collected.

4. **Make the calculations**
    a. **Calculate the work capacity of how much the work team produces in a shift.** This value is automatically calculated, but it can also be manually filled. As the number of hours was already disclosed in the previous step, this is now automatically taken into consideration.
    b. **Give multiplier for the values of the task. The default value is 1.** This multiplier is used for easy modifying of the task values, if a separate reason for this was found. The multiplier can be used for example to reduce the time of a task when bad weather caused the delays throughout the whole task or if the scope of the task is much bigger than usually.
    c. **Check that the total values are correct.** The last column is called "Total". In this column, the work capacity numbers are automatically multiplied with the multiplier values. In most cases the result is the same as in the "Work capacity" column, because a value of 1 should normally be used. If for any reason these values are not correct, it is always possible to change them manually.
    d. **Sum all the data from the tasks the deliverable includes together.** On the deliverable level, the task values are automatically calculated using weighted averages. This, however, does not work correctly if different units were used in the tasks the deliverable consists of. If this is the case, these values can be manually estimated and changed. In cases where there are multiple different units among the tasks of one deliverable, pick a unit that best describes the total of the tasks and calculate/estimate the productivity and capacity values.
5. **Write down comments for the deliverable and tasks if needed (for example what logic was used to get to the conclusion of the used values).** Comments are optional but can be used to share additional information. This can sometimes be very important, as there are multiple people that are using the same spreadsheet.

3.3.3 Notes and outcome of the database filling

At this point, only the tasks and their units were filled for each deliverable in the list and all the estimation information was only filled for a few deliverables as an example. The reason for this was the lack of time and the fact that actual data regarding construction sites in various forms does exist and should be studied before filling in the estimations to make the estimations better.

When filling the tasks for the deliverables, it was emphasized that the chosen tasks need to be trackable as clearly as possible. It was also stated that only tasks that either had an important part in the total works of the deliverable or took a lot of work hours should be included, and all the minor tasks were to be included in these tasks. At times this was a little problematic, because the list where tasks were to be picked had been made with the motive of not including too many options to reduce complexity. In the end a good compromise for this was found, in which only a few of the tasks were added additional information for clarification, such as “installation, including lifting” in cases where these two tasks were done at the same time and no separate lifting task was rational to be created. This way the list of the tasks did not build up. There was a bit of vacillation in defining the units for different tasks, but all the cells were filled with a base proposal, that can, and most likely at least for some tasks, will be changed later when the productivity values are filled. The reason for this is that when the numbers are filled, in some of the example cases it was noted that the numbers did not work well with the chosen unit. This could mean for example that the productivity numbers became too big or small and it became difficult to interpret them. In situations where this was the case, it was possible that the understandability of the productivity values became the dominant criteria when choosing the unit.

Many of the deliverables ended up having either almost or exactly same tasks. This is logical, because in the end, construction is not very complicated process when looking it from the task name point of view and the list where the tasks were picked was made to be rather generalizing. This does not, however, mean that the productivity, work group and work capacity values would be similar to each other when comparing different deliverables with similar tasks. This means that even when the task names and their units would be similar for two different deliverables, the rest of the data will probably be very different and needs to be estimated separately.

After a while the filling of the tasks and the units linked to them got easier. The reason for this was that the same tasks and units that had been found good for one deliverable, were used for similar deliverables when possible. Each deliverable was still analysed separately, but as the fillers became more familiar with the list, the decisions were easier to make. It was noted, that there are large differences on the detail level of the tasks of different departments or areas. This is because of the nature of the WBS that was used as the basis of the listing and can addressed further later, but it will not be included in this thesis. At this point it was made sure that even if there are differences and room for improvement, the list can already be used as it is now.

As stated before, the productivity numbers were not filled for all the tasks at this point. This was still looked at and some examples were filled, and observations made. While for many tasks defining the productivity numbers were noted to be simple and straight-forward, for others it was found to be surprisingly difficult and complex. Depending on if there were many minor tasks included in the major task in question, in some cases it seemed to be almost impossible to estimate the average productivity. Because of this, in some cases it was decided that one or more of the minor tasks needed to be separated from the major one just to make the estimations more reliable. If the minor tasks that were causing problems had typically very small scope and because of that had very small effect on the productivity numbers, adjustments were made directly to the major task. It was also quickly noted, that the unit chosen for the task has a huge effect on the productivity number. A good example of this was when the chosen unit was kilograms for an object that weights multiple tons. The productivity numbers formed to be extremely small, which made them much harder to analyse. Because of this the unit had to be changed to tons. In some other cases the unit had a similar effect on the productivity number, but the unit had to be changed to a completely new type instead of just using multiplier like in kilograms vs tons. It can be stated that in some of the cases the unit type ended up being the dominating factor when defining the productivity, and because of this the unit type was switched to one that would have not been used otherwise for the current task.

Similarly, as the productivity, the work group numbers were mostly easy to fill, but in some cases, adaptations had to be made, because of the compromises made on the previous steps. Mostly this was because of some task names included more than one minor task that had different work group sizes compared to the main task but were not significant enough to be separated as their own tasks. In these cases, the work group could not be unambiguously defined, but an average size was calculated using weighted average from all the tasks included. It was also brought up that different companies can have surprisingly big differences in the work group sizes they use for different tasks. As there is not one right way to divide the workers for groups, assumptions on the group sizes had to be made. This is also an interesting factor to follow up on future projects, because the size of the work group heavily affects the work capacity numbers that are calculated in the spreadsheet. Even if the work group sizes might differ a lot from project and subcontractor to another, this information had to still be thoroughly thought out when filling it for these estimates to have a meaningful and realistic results.

While going through the deliverables, it was noted that some parts of the WBS were very compendious. These sections must be analysed carefully, and additional deliverables and tasks need to be added. This was not done immediately, because at this point the divination of the WBS needed to stay as it is. A good example of these kind of elements were the piping portion. Piping needs to be scheduled in a very detailed way, but in the WBS there were only a couple of deliverables related to piping. When rows and new deliverables and deliverable groups are added to the list, it will not match the WBS listing anymore, and this could be an undesirable outcome. As there is a section in the new WBS that can be locally modified, it could be a possibility to change these things directly into the WBS, so the two lists would match each other also in the future. As mentioned, this will be looked at later. Because the WBS was studied very closely during this process, there were also other inconsistencies and discrepancies that were raising questions or improvement recommendations. These points are not part of this thesis but were documented and will be handled separately. This is still worth mentioning, because the WBS is still new and it is good to do this kind of reviewing to it. Even though all the originally planned cells were not filled, the ones that were, are providing at least a good basis for upgraded task names to be used in the future schedules. This type of listing also helps making the linking of scheduling and cost tracking more straightforward.

3.4 Implementing and using the database

One of the goals when defining the performance indicators and creating the productivity database was to make the implementation of them as easy and straight forward as possible. This means that not much needs to be changed in the old processes and systems while taking the database into use.

Naturally when something new is added, it is going to have some effect on the current processes. These effects are explained in more detail in the following chapters.

3.4.1 Requirements for the schedules

As new content was created with the new database, this gives the schedules where the information is going to be imported from also some new requirements. The data can be extracted from the schedules even if these requirements are not fulfilled, but for the process to work as smoothly as possible, the schedules should include the following information:

- The structure and task names of the schedule should follow the database as closely as possible. It is not problematic if the schedule includes more deliverables and tasks than the database, as long as the deliverables include the same tasks as the database, and the task names can be found from the database. This is also to be expected, as the database is not meant to act as a schedule, but rather as a listing of what items the schedules can include. It is recommended that in the future the schedules would be as similar as possible with each other when it comes to the structure of the schedule, but this is a separate matter and will not be dealt with any further here.
- Schedules need to include two separate columns that show the actual used hours and the number of units used for each task. These columns can also be found from the tracked information table in the productivity measurement database and are used when calculating the productivity numbers for tracked data. This will cause some extra work when making the schedules but is necessary information for the database.

All new schedules should be made these requirements in mind.

3.4.2 Using the existing data from old schedules

The subcontractor productivity measurement database was created in mind that it would be good if the information of the old projects could also be used in it. This was not the primary priority, and for some cases this turned out to be impossible to carry out, but with the flexibility that was included in the database, this was made possible. It should be evaluated if this is worth the work for each old schedule individually.

Many older schedules do not include any information about the unit amounts or hours used for different tasks. When this is the case, it is either impossible or very difficult to try to gather this information from other sources, and because of this, it is suggested that these projects are not to be included in the productivity measurement database. As most of the existing schedules that have the unit and hour information included do not follow the new WBS and use at least partly different kind of task names compared to the new task names used in the database created, this data cannot be directly used, but needs to be modified to right kind of format. Using a less detailed, even rough information for the database is possible, however, because of the different levels of elements included in the WBS. It is always better to use as detailed data as possible, which in this case would mean the data from the task level, but when this data does not exist, the next level can be used. In the databases case this means the deliverable level. Even now that the structure of the WBS has changed significantly, the deliverable names and contents have stayed the same in many cases. This means that if an old schedule includes the needed information on the deliverable level, this data can be taken and used in the database on the deliverable level and leave the task level empty. It is important to carefully analyze the data while doing this, and use this information with reservation, but it can be used at least as a directive information.

3.4.3 Process for using the productivity measurement database

The process of gathering the data to the new scheduling tool from the subcontractors will not change when the database is taken into use. This will be done using excel templates made by the target company that are given to the subcontractors and are filled by the subcontractors on a weekly basis during the construction.

The work of importing the data from the schedule to the productivity measurement database needs to be done by a person who has access to the scheduling tool, good skills to use it and a good understanding of the scheduling and tracking practices. In current situation, this means the planners who are working with the schedules as their main job. It can be decided if the data is imported already during the construction, or only after the project has ended. The database is not directly linked to any other parts of the scheduling process, so it can be used in complete isolation which gives the planners freedom to choose when to import or analyze the data. If the data is imported during the construction, it can be used to forecast the upcoming tasks right away, but as the scheduling tool already has this kind of feature built-in, this is not the primary purpose of the database, but rather to collect and store the data from multiple different projects after they are finished. It is also important to notice, that with a small amount of data, the productivity numbers can give faulty information or at least be relatively dubious and should be treated with caution. The data should be examined with critical mentality as it is, especially in the beginning of the use of the database, and improvements and changes should be made to it when opportunities present themselves.

The process of exporting the right data from the scheduling tool and importing it to the database should be pretty simple in cases where the schedule structure matches with the database structure at least for the most part. In the simplest situation, the unit amounts, and hours used can be copy pasted from their columns in scheduling tool to the matching column in the database. In situations where these lists do not completely match, a temporary table can be created to another excel sheet and the data can be pasted there and modified to be suitable for the database. If the two structures are very different from each other, a lot of manual work must be done and in cases like this it needs to be evaluated if it is worth doing the import at all or just at the end of the project, so the import needs to be done only once. Manual work here means copying the tasks or deliverables manually from one list to another in small groups or one by one, sometimes combining the tasks at the same time so that they fit the database structure, as the database structure cannot be changed to match every independent project but has to stay on a general level to serve multiple projects at the same time. The productivity measurement database spreadsheet will be maintained in a server where all the planners have access to edit it, and other users, such as project managers, have the reading rights to the file.

It is good to remember, that the data is not collected just for the sake of gathering it to a database, but to be used to analyze the projects and different subcontractors. This means that plans should be made to do the analyzing, and it should be made sure that this is actually been done. If for any reason the productivity measurement database turns out to not be useful or it is too labor consuming to keep it up and update, it can be changed or additional ways to track data can always be created. This kind of tools are after all meant to help the daily work and preferably reduce the manual part of it instead of just adding new processes and work phases that do not really give any value.

4. CONCLUSIONS AND FUTURE SUGGESTIONS

This chapter goes through the study and evaluates how well the goals of the study were fulfilled. The chapter has first a part in which the study is evaluated on a general level and after that three subchapters which follow the structure of the study and assess the success of the study on a more detailed level.

The main goal of this study was to define suitable productivity measurement indicators and a proper way to use these in a power plant construction site. This goal was fulfilled relatively well. The indicators were defined, and a database was created in which these indicators are stored and used, but due to a lack of time, this database and its functionality was tested only slightly, and therefore it cannot be properly evaluated how much work using the database and the productivity indicators will cause or how useful this data can be. Because of this, the database that was created as a part of this study ended up been only a starting point for the use of thorough analyzing that it is capable of being after further development. It was also originally planned that the estimation area of the database would have been fully filled during this study, but this was not achieved. This area was partly filled and during that it was noticed that filling the estimates without first importing actual tracked data and studying that, would not be a good way to approach the issue. The usefulness of this kind of estimated data would have not been as good as the collected data from finished projects either, because of the subjective nature of it.

The structure and with that the secondary goals of the study were changed a little during the study. This was however expected at least on some level, and therefore was prepared for. The reasons for these changes were the obtaining of new information and getting to understand what the most important elements of productivity measurement are. Even when the goals changed, the framing of the study was kept strict and clear which helped the study to keep a suitable size and focus on the right topics.

4.1 Using the existing studies on the subject

Existing literature and studies on the subject were partly easy and partly difficult to find. One reason that explains this is the fact that the topic was about power plant construction, which is not studied as much as traditional construction, and even though most of the traditional construction material could be used in this study, some of it was not suitable for it. The number of different sources used in this study ended up been low. One reason for this is that most of the sources used were several hundred pages long books, from which multiple pages was referred.

It was noticed that even though Work Breakdown Structure (WBS) is rather simple matter in its core, explaining it extensively is not so simple. This topic was not covered very well in this study as it would have needed more attention and space and the focus of the study would have shifted to a displeasing direction with this. For the author of this study it became clear how much a good WBS can help with the project management and also how much extra work and confusion it may cause if the WBS is either poorly made or does not exist at all.

Subcontracting and contracts in general in construction industry was also looked over relatively superficially. Even though this side of the projects can end up affecting the productivity at the construction site more than anything else, it was still considered to be a different topic, that has already been studied a lot. Like WBS, this topic has a lot of existing studies that will explain it very well.

The productivity indicators were the main topic of the study. It could have been possible to go through the theory part of these much deeper than it was eventually handled in this study, but it was decided to concentrate on the main points of the indicators instead of trying to give a really deep presentation of them. This was also not necessary to be able to understand the functionality of the database that was created as a part of this study. It was considered more important pointing out that there is not one correct way to define these kinds of indicators and that defining them will always have some level of subjectivity. The amount of studies that were found about the productivity indicators was surprisingly low.

The decision to introduce the workforce management and direct & indirect work chapters in this study ended up been really good. These topics are important individual parts of productivity measuring but can be easily forgotten or left with minor attention.

4.2 Productivity indicators in practise

The need of disclosing the present-day situation in the target company or not was considered carefully in the study. Eventually it was included in the study to work as a natural link to the part which introduces all the necessary steps required to take the productivity measurement database to use. Present-day situation was also an important factor when creating the database.

Creating the productivity measurement database turned out to be a rather complex and laborious task, so it was described in detail in the study. It also was in the center of the main goal of the study, for what all the other parts of the study were priming or the outcome of. As mentioned before, the database was not finished during this study and if it is going to be taken into use, it will shape up a lot from the form it is at the end of this study. Most likely the biggest problems with the database will be connected to already known issues related to scheduling and progress tracking. An example of such problem is the schedules been different from each other in many ways. This means the technical aspect of using the database will not be a problem, but the practices and processes around scheduling and progress tracking.

The interviews were an important addition to the theoretical part of the study. As power plant construction includes many different disciplines and types of work, it is not possible for one person to be an expert in all the areas. The WBS listing which worked as the basis for the productivity measurement database naturally includes deliverables and tasks from all the different disciplines. Having at least one interviewee from each of the disciplines made it possible to much more reliably fill in the tasks. Like mentioned before, these tasks at least for some parts will change when more information is learned, but the starting point is much better compared to the author of this study doing the fillings alone. The fact that going through the WBS with multiple experts of the different areas also raised many good observations and issues that were not directly part of this study but helped to fix the WBS itself among other things. This can be expected to happen in the future too, when the database is further used and optimized. It was also positive to notice that most of the interviewees were interested in the topic and learned about the productivity and progress tracking in the process themselves.

4.3 Follow-up suggestions to productivity measurement

The most important thing to follow-up after this study is to make sure the database is taken into use. When this is done, improving it will happen automatically as time passes, as the issues will be noticed the best when using the database. Using the database effectively will also force the schedules to follow similar structure with each other, which will help to unify them. As of now, the database is using the company WBS as structure, but as the database was created with excel, modifications or additions to the list are possible when needed. Unifying the schedule structures is a very extensive and difficult task to do, but it will have a huge effect on routinising scheduling and reducing the workload related to schedules. Because of this, it can be stated that doing this is paramount, regardless whether the productivity measurement database will even be taken into use or not. It is especially important to make sure in the beginning that the data is collected in correct form and style. If big amounts of data have been imported in wrong or ineffective form, it is most likely very difficult and work consuming to start modifying it afterwards.

After data has been collected to the database for some time, should using this data to be included in the standard process. One of the important functions of the database, at least how it is seen right now, is to be a helping tool when making decisions about contracts with possible future subcontractors. The database can also give good information to the first revisions of the schedules, in which the elements usually are on a much rougher level and therefore the durations of the tasks are longer. To get the database included to the process, it must be made known to the relevant parties and personnel, such as project managers. The use of the database could even be made mandatory after the usefulness of it has been verified.

Overall, it is impossible to evaluate the possible future benefits of this study at this point. It brought up some issues during it was written and the productivity measurement database was created, but these points were not the main purpose of this study, even if they were very useful. If the amount of used resources for this study is taken into consideration, this study has the potential to be a very good development project. It can also be noted that if the output of this study will not be used by the target company any further, it is not a big loss for the company due to the small investment that was needed to make it.

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APPENDIX A: INTERVIEW TEMPLATE

Structure template for the interviews/discussions

Frame for the questions and topics related to productivity measurement and performance indicators in power plant construction sites

1. Title and role of the interviewee
2. Experience and nature of projects the interviewee has participated
3. How much does the interviewee know about progress and productivity tracking in general?
4. Does the interviewee feel that work efficiency measuring (in more detail) is needed?
5. How the interviewee sees the control the company has at construction sites?
   a. Is the current level of control and tracking enough?
   b. Are there any single tasks or phases that are more difficult to track and should get more attention?
   c. What should be changed if anything?
   d. What would be the best way to do this?
6. How much does the interviewee deal with the subcontractors in the daily work?
7. Is it easy to follow how the works are going at the construction site using only the daily/weekly/monthly reports?

The process for dividing the WBS deliverables to tasks and adding the performance indicators to them

1. Picking the deliverables
   a. Choose a deliverable that has clear scope and is related to subcontracted work at the construction site
2. Divide the deliverable to tasks
   a. Create/check the list of predefined tasks and if the list does not include one or more of the tasks related to the deliverable, add those tasks to the list
   b. Pick the tasks related to the deliverable in question from the list so that everything related to the deliverable is included
3. Add values for the picked tasks
   a. Add units for each task included, for example m2 or kg
   b. Give all the tasks a default work team, i.e. the number of workers performing the task
   c. Estimate the productivity values for the tasks using the defined units, i.e. how many hours it takes one worker to produce one unit
   d. Calculate the work capacity of how much the work team produces in a shift
4. Make the calculations
   a. Calculate the amounts that the whole team can produce in one hour/one shift
   b. Sum all the data from the tasks the deliverable includes together. In cases where there are multiple different units among the tasks of one deliverable, pick/create a unit that best describes the total of the tasks and calculate/estimate the productivity and capacity values
5. Write down comments for the deliverable and tasks if needed (for example what logic was used to get to the conclusion of the used values)