

# Understanding Construction Productivity

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*by defining critical factors affecting productivity from site execution perspective in the process industry*



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*MSc Construction Management and Engineering*

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*by defining critical factors affecting productivity from site execution perspective in the process industry*

**Thesis Report** to obtain a Master's degree in Construction Management and Engineering at

**Delft University of Technology**, to be defended on the 10<sup>th</sup> July 2018 by

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*Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker.*

*~ Nobel Prize-winning economist, Paul Krugman*

## **Executive Summary**

This master thesis was developed as a final deliverable for obtaining the MSc in Construction Management and Engineering at Delft University of Technology and was done in cooperation with a large international engineering, procurement, fabrication and construction contractor. The aim of this study is to identify critical factors affecting construction productivity from a site execution perspective in the process industry.

This research study was triggered by a continuous drop in productivity of the construction sector. The construction productivity has been widely addressed in the literature without reaching a consensus on the construction productivity definitions, measurements and it was even questioned if the productivity was indeed in decline. The literature has also investigated critical factors affecting productivity mostly through a survey methodology. The results of those surveys are concluded in a list of different amount of factors with slightly different ranking per each survey study. Furthermore, there was no information provided in those studies neither on the context of the project nor on the initial productivity considerations. Moreover, the surveys were assessed from the craft and managerial perspectives.

The critical factors affecting the productivity in the literature are categorized in this research study into the following groups of factors: Labor, Industry and Management. It is accomplished by identifying the most repetitive factors affecting the productivity from the available literature and used as a framework for the case studies. Case study methodology is chosen due to a lot of inconsistencies and variety of information on the productivity in the literature and aims at conducting an in depth study on the productivity as a complex problem. Thus, the main goal of this research study is to investigate complex interrelations between critical factors that impact construction productivity and investigate how productivity is defined and measured during the construction projects in the process industry.

In order to do so, the critical productivity factors are investigated by analyzing five case studies and interviewing ten construction managers, two managers per each case study. The case study methodology shed a light not only on the critical factors which affected the construction productivity on the projects, but also on the interdependencies between those factors and further challenges with respect to assessing and reporting the accurate productivity measurements on site. The main factors which affected the construction productivity on the investigated case studies are categorized in three interdependent areas: (i) construction strategy, (ii) design and (iii) labor related considerations. In each category several critical productivity factors are identified also being represented at a certain point in time of the investigated projects. During the front-end engineering and design phase main factors are attributed to utilized construction strategies, construction methods, early involvement of construction discipline, alignment across stakeholders and reliability of initial estimates. During the engineering and procurement phase the critical factors are identified in design processes which needed to be aligned with construction strategies, standardized and complete before construction starts, in order to facilitate the onsite productivity. Finally, during the construction phase the most critical factors are found in subcontracting, late changes to the project, logistics, overtime and shift work, consistency of construction metrics and visibility on the actual workflow on site. All of the aforementioned productivity factors are further influenced by complexity and cost factors.

The main issues of this research study with respect to the construction productivity measurements are identified in nonstandard productivity terminology and inconsistencies of construction metrics within and across different projects in the process industry.

Construction strategies are related to decisions over Advanced Work Packaging strategy and the level of Modularization. Both strategies are found to have a highly positive impact on the construction productivity. However, those construction strategies have a specific impact on other disciplines and the main challenge lies in convincing the client over those strategies. Any changes with regard to the pre-set construction direction are found to have a detrimental impact on the onsite productivity. Furthermore, the role and influence of construction experts is lacking during the pre-construction phases of the project and has a significant impact to the major construction changes.

Moreover, those construction strategies are impacting the following engineering and procurement disciplines and require a close cooperation with subcontractors in the field. Standardization of design processes and completeness of the engineering deliverables are crucial to facilitate the workflow of construction activities.

The main challenge coming out of this research is to report the construction progress in a consistent way within and across the projects and to further provide the project controls department with reliable data. Thus, main issues in the field occur with respect to the reporting of construction progress. For each project slightly different construction methods and metrics are utilized. Without the consistency of construction metrics, it becomes difficult to compare and evaluate the productivity performance. Thus, the reported productivity trends in the literature and the questionable nature of whether the productivity is indeed declining or rising are further strengthened through this research study.

The most important recommendation is to include productivity measurements in the procedures as a mandatory construction deliverable, and to further measure, report and evaluate the construction productivity in a consistent and standardized way. The other areas of improving the productivity could be accomplished by enhancing the construction influence during the pre-construction phases, enhancing the cooperation of construction and engineering and finally, to include subcontracting team into the contractor's planning team.

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## List of Abbreviations

AC	Actual Cost
AWP	Advanced Work Packaging
BAC	Budget At Completion
BLS	Bureau of Labor Statistics
BPPII	Best Productivity Practices Implementation Index
CIDC	Construction Industry Development Council
CII	Construction Industry Institute
COAA	Construction Owners Association of Alberta Institute
CWA	Construction Work Area
CWP	Construction Work Package
ECI	European Construction Institute
EPC	Engineering, Procurement and Construction
EPFC	Engineering, Procurement, Fabrication and Construction
EV	Earned Value
EVM	Earned Value Management
EWP	Engineering Work Package
FCN	Field Change Notification
FEED	Front-End Engineering and Design
IWP	Installation Work Package
PDDM	Project Document and Data Management
PV	Planned Value
RFI	Request for Information
T&M	Time and Materials
TOE	Technical Organizational External
TRIR	Total Recordable Incident Rate

# 1 Introduction

## 1.1 Problem Area

On average 98 percent of megaprojects experience cost increase of more than 30 percent and 77 percent of the megaprojects are finished 40 percent later than originally expected (Changali, Mohammad, & van Nieuwland, 2015). In the performance measurements of megaprojects the oil and gas industry is represented by 22 percent success rate. The rest of the 78 percent is considered to be modestly successful obtaining around 30 percent cost and schedule overruns. The success rate in the oil and gas industry is considered to be as a substantially low figure in comparison to the other industries which sustain approximately 50 percent success rate (Morrow, 2012). These numbers depict that despite that all industries face difficulties in achieving the desired objectives; the challenges are especially severe in the projects of the oil and gas industry.

The poor performance is clearly mirrored in the construction productivity levels. While examining the productivity differences among various industries, construction performance is set at the bottom as illustrated in figure 1 below (McKinsey & Company, 2017).

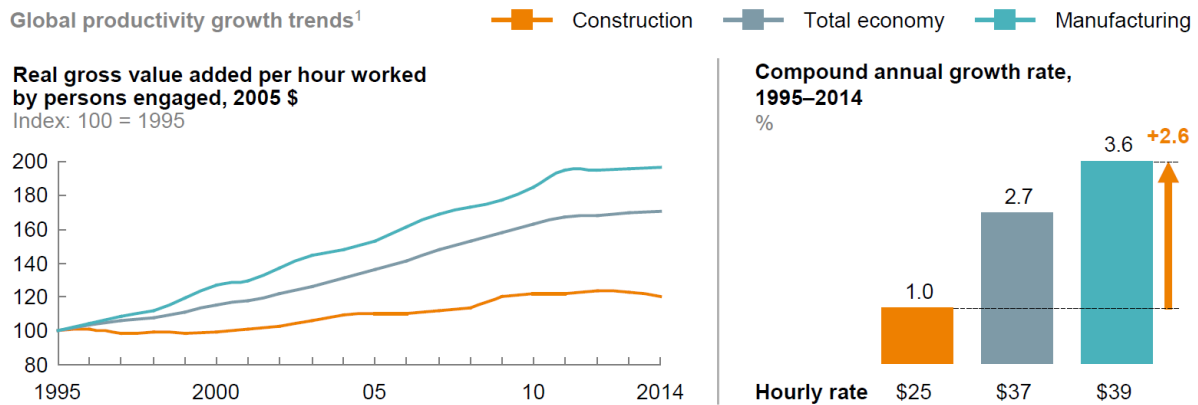


Figure 1 Global productivity growth trends (McKinsey & Company, 2017)

Moreover, the construction productivity has not been changing much throughout the past decades. The main reasons for the stagnation of the productivity are claimed to be found from the fragmentation, inadequate risk allocation, informality and lack of investments in innovations (Barbosa, Mishke, & Parsons, 2017).

If the construction industry would catch up with the total economy, the existing gap of possible added value is estimated to be approximately 1,6 trillion dollars. The highest investments, and thus the most promising possibilities for improvements, are found in North America, Europe and Asia-Pacific (Barbosa & Woetzel, 2017).

According to the McKinsey Institute the existing productivity gap could be filled by addressing seven levers. They have identified that the main reasons for the productivity loss lie in the following aspects: regulation, collaboration and contracting, design and engineering, procurement and supply-chain management, on-site execution, technology and capability building (McKinsey & Company, 2017).

Although the possible areas for improvements have been identified in the literature, their broad orientation makes them challenging to implement, at least not to the degree that would affect reaching the desired productivity growth. Hence, the problem statement is defined as follows:

*Despite rising productivity in other industries, the construction sector performance remains the same as back in the 90s, also not satisfying the desired objectives. This indicates that closer attention should be given to the construction industry and its specific needs. The lack of changes in productivity over time reveals certain challenges; either the existing strategies are not correctly identified or there are certain obstacles in implementing them.*

Construction is the final phase of the project where the actual design comes into reality. As figure 2 shows the project costs for construction represent 40 percent of the total project cost allocation (CLMA, 2017). Therefore, any improvements in the construction will have a significant effect to the construction productivity and thus to the overall project execution in general.

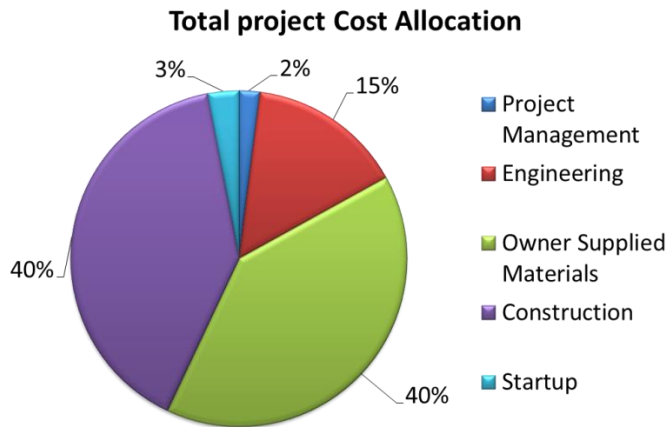


Figure 2 Total project cost allocation (CLMA, 2017)

The main focus of this research will be placed at the construction perspective and thus the on-site execution lever. This entails primarily investigating the construction perspective and deriving what is actually needed for the construction phase in order to effectively execute projects on-site. This will be done by analyzing how productivity is tackled during construction projects with further evaluation of critical factors that have affected the construction productivity.

This research study includes literature review (chapter 2) on the main concepts related to the construction productivity. Chapter 3 provides research propositions, selection criteria for a research study and description of Company A. In chapter 4 the actual analysis is made through cross-case analysis. Furthermore, it provides research results and main findings. Finally, chapter 5 will conclude the findings and give further recommendations to the academic research and to the investigated Company A.

## **1.2 Problem Context**

Poor construction productivity performance has been widely recognized in the academic research. Despite numbers of available articles there is wide variety in researches with respect to construction productivity definitions and ways of measuring it (Tangen, 2004).

The lack of consensus over the aforementioned productivity definitions and measurements creates confusion in correctly assessing the construction productivity. The magnitude of confusion on construction related to productivity is reflected for instance in the Bureau of Labor Statistics (henceforth BLS) data in the United States. Despite keeping track on the productivity rates of the major industries, BLS has not been presenting any construction rates due to the lack of suitable data (Allmon, Haas, Borcharding, & Goodrum, 1998). In 2017, BLS came up with construction rates, but this was limited to only few construction sectors, and the process industry was not included (BLS, 2017).

When it comes to the governmental European data, construction productivity rates are limited to construction of buildings, civil engineering and specialized services, with no differentiation across different industries (i.e. infrastructure or oil and gas). European Commission is also highlighting that construction is much different from any other economic sectors; requirements are usually project specific and it take several years from design phase to project completion and a final deliverable has long durability (European Commission, 2016).

Furthermore, literature sources were not even consistent on whether the construction productivity was rising or declining (Allmon, Haas, Borcharding, & Goodrum, 1998). Rojas and Aramvareekul (2003a) have conducted analysis in which they questioned whether the labor productivity was really declining over the period between the 1979 and 1998. They concluded that data used for productivity measurements was further manipulated, to the extent that the results cannot be deemed reliable (Rojas & Aramvareekul, 2003a). The aforementioned questionable productivity trends could be related to the nonstandard terminology and measurements for construction productivity.

The academic literature suggests different factors that affect the construction productivity (Borcharding & Garner, 1981; CII RT-252, 2013; CIDC, 1984; Naoum, 2015; Rojas & Aramvareekul, 2003b; Klanac & Nelson, 2004). The aforementioned research studies have identified and ranked factors affecting the productivity through surveys, providing questionnaires to large amount of participants. However, the feedback from participants was not set in a specific project context. The only contextual information was related to the analyzed construction sector. Also, there was no information within the aforementioned studies on how productivity was understood and tackled in a first place, nor about the applied construction methods.

Construction Industry Institute (henceforth CII) has recognized fragmentation of the information on the construction productivity and further lack of integration of this knowledge on the specific projects (CII RT-252, 2013). CII members have combined their efforts to create a comprehensive handbook, analyzing over 150 sources on construction productivity with respect to productivity definitions, measurements and factors affecting it. Despite providing a comprehensive handbook on the construction productivity, CII has not tested its findings against specific projects within their context.

Overall the academic research provides extensive information on the construction productivity. Starting with poor construction productivity performance, academic research also recognizes variety and confusion over the available definitions and measurements on the productivity. Although factors that

adversely influence construction productivity have been identified, there is a small amount of research done on the placement of those factors within specific project context and its effect on the productivity.

Despite multiple recommendations have been drawn on the construction productivity, it is still somehow unclear on what would be the most successful way for improving the construction productivity performance and where the biggest challenges lie.

### 1.3 Research Question and Objectives

The main goal of this research study is to investigate how productivity is tackled during construction projects in the process industry and to identify challenges that have occurred with respect to reaching the desired productivity rates. The construction phase and its perspective will maintain the focal point of this research. The research study is narrowed down to analyzing the on-site execution lever with regard to the aforementioned objectives.

Problem area and context imply a hypothesis for the construction productivity to be a complex phenomenon that should be considered within its specific project context and with the variety of factors affecting productivity. In order to thoroughly address the identified problem, the **main research question** is drawn up as follows:

*What are the critical factors affecting construction productivity from a site execution perspective in the process industry?*

**Main Objectives** of this research paper are:

- To investigate complex interrelations between critical factors that impact construction productivity.
- To investigate how productivity is defined and measured during construction projects in the process industry.

The main idea is to set literature findings against the actual experience from the recent projects in the process industry. Due to the existing inconsistencies in the academic research over the productivity terms, any further investigation will have a high level of relevance. Also, research objectives are feasible to accomplish due to the close cooperation with Company A.

### 1.4 Research Methodology

Research methodology comprises of research approach, main research strategy and provides further guidelines on how gathered data will be analyzed.

#### 1.4.1 Research Approach

Research study will consist of two complementary parts. Firstly, desk research will be performed through extensive literature review. This part will result in a theoretical framework that will be further used in a second part of the research (i.e. case studies) (Verschuren & Doorewaard, 2010).

Second part will consist of case study analysis in the Company A. In this particular research area, case study approach was chosen over the other strategies (e.g. surveys) due to the following aspects. The productivity factors described in the problem area were mostly analyzed through surveys. This

methodology helps in obtaining a large amount of data from multiple projects. The gathered qualitative data can be easily transferred to a quantitative analysis due to the large sample. However, surveys facilitate simple way of obtaining data, complex relations can be hardly derived from this type of research methodology (Sapsford, 2007).

Case studies, on the other hand, help in getting a holistic insight into the real life events and their casual links. This methodology is used when dealing with complex problems, opposed to surveys or experimental strategies conducted for simpler problem areas (Yin, 1994). Yin (1994) describes that case studies further facilitate investigating contemporary phenomenon within its natural context; in this research area, the poor construction productivity (i.e. contemporary phenomenon) impacted by the external factors (i.e. natural context).

Verschuren & Doorewaard (2010) describe that case studies should focus on depth of the qualitative research through multiple methods of data gathering. This depth will be accomplished by conducting face-to-face interviews with experts, observations during site visits and studying available documents on productivity in the Company A. The sample for case studies should be strategically chosen, consisting of a small number of research units with minimum number of differences between those units (Verschuren & Doorewaard, 2010). Comparable sample of the case studies will help in investigating specific context of chosen projects with respect to the productivity aspects. For this research part, explanatory case studies were chosen to evaluate how and why projects ended up with lower productivity than intended (Yin, 1994).

#### **1.4.2 Research strategy and sub-research questions**

Sub-research questions are developed in pursuance of answering the main research question and will drive the research strategy. Figure 3 shows the overview of the strategy with the following phases: Theory Development, Case Study Preparation, Case Study Analysis and Conclusions.



Figure 3 Research strategy (own figure)

Case studies benefit from development of a theoretical framework. This framework will guide data gathering and analysis in the later research phases (Yin, 1994). Three sub-research questions out of five in total form the basis for an extensive literature study. The aforementioned three sub-research questions will result in the theoretical framework for further interviews with experts. The remaining two sub-research questions will be answered via Case Study analysis.

**Sub-research questions** comprising Theory Development in chapter 2 are formed as follows:

- *What is construction productivity?*
- *What are the ways of measuring construction productivity?*  
The main objective of those questions is to present existing definitions on construction productivity and different ways of measuring it.
- *What are the critical factors affecting construction productivity in the literature?*  
Answering this question will give a general overview on what influences productivity on-site. Only factors that are predominant in the literature and are considered to have the highest impact on the construction productivity will be taken into account. The intention is to present certain categories as an indication and test them further via the case studies.

Case Study research design will consist of the two following phases: Case Study Preparation and Case Study Analysis (chapter 3 & 4). Main objective for conducting case studies is to evaluate real life events with respect to construction productivity based on the developed theoretical framework.



**Sub-research questions** comprising Case Studies are formed as follows:

- *How are industry experts viewing productivity and its factors?*  
The goal of this question is to gather feedback from the construction industry experts based on their experience on specific projects. It will be done through Case Study Interviews and developed in the Case Study Preparation and Case Study Analysis chapters.
- *To which extent do critical factors in the literature match with the factors identified from the examined projects?*  
The objective of this question is to set literature findings against experience from the projects and identify root causes for low productivity.

Answering the aforementioned sub-research questions will be followed by drawing conclusions and recommendations in chapter 5.

### 1.4.3 Research Analysis

The main research analysis will be performed following the case study methodology. There are certain steps indicated by Yin (1994) in order to conduct a successful case study research and are briefly described as follows:

**Case Study Preparation** will consist of the following components indicated by Yin (1994): *(i) Study questions:* Interview questions will be developed based on the theoretical framework. *(ii) Units of analysis:* Five case studies will be analyzed with two interviews with experts per each case study. Prior to the aforementioned analysis, specific criteria will be developed for case studies and separate criteria will be developed for interviewees. The aforementioned criteria will be placed in the context of the investigated Company A. *(iii) Propositions:* Prior to conducting interviews certain propositions are drawn based on the literature review. (Yin 1994.)

**Case Study Analysis** will be conducted and tested against its quality via the following aspects indicated by Yin (1994): *(i) Construct Validity:* Multiple literature sources are analyzed during the theory development. Furthermore five case studies are evaluated in order to create a strong construct for further findings. *(ii) Internal Validity:* This part will be determined based on whether event x led to event y. It will be accomplished through pattern-matching analysis and an explanation building from the conducted interviews. *(iii) External Validity:* This part will be tested through replication process on the other case studies. Cross-Case Analysis should result in same findings for the projects within the same context. When contrasting results are produced it should be done for predictable reasons. *(iv) Reliability:* This part means that study can be repeated with the same results. Furthermore, it can be generalized on new case studies. (Yin, 1994.)

The results will be presented based on the pattern-matching analysis. If at least two analyzed case studies within the same context will predict similar results, it will be considered as a finding and used for further recommendations. If other case studies result in opposite findings, but for predictable reasons

due to their context, it will also support validity of results. After conducting analysis of the case studies, initial propositions will be evaluated based on the findings from the interviews. The analysis will be summarized and further utilized in drawing up conclusions and recommendations.

## 2 Theory Development

In this chapter, most significant theoretical and empirical works that have influenced this research study are presented. This chapter serves as a basis to tackle variety of construction productivity terms and different methods for tracking and measuring the construction productivity. After getting insights into what the construction productivity de facto is and gaining a common understanding on what is being studied, the main goal of the theory development will be to identify predominant factors affecting the construction productivity. The confusion around the construction productivity terms implies that any data with regard to it, should be studied carefully, taking into account applied methods for the productivity measurements.

### 2.1 Introduction to Construction Productivity

This sub-chapter will give an overview on different ways of defining and measuring construction productivity. The main goal is to standardize existing terms and introduce consensus definitions that will be carried on throughout this research study.

#### 2.1.1 Construction Productivity definitions

The most generic definition describes labor productivity as a ratio of output represented by an installed quantity and input represented by actual work hours (Park, Thomas, & Tucker, 2005). Some sources present the opposite comparison, of input to output, however the logic remains the same (e.g. CII RT-252, 2013). With regard to the output to input ratio, the greater the ratio, the higher productivity it represents. For that reason, in order to keep consistency throughout this report and associate the greater ratio with the higher productivity, all productivity measurements will be presented as the output to input ratio.

$$(2.1.1.1) \text{ Labor Productivity} = \frac{\text{output}}{\text{input}} = \frac{\text{installed quantity}}{\text{actual work hours}}$$

*(Park, Thomas, & Tucker, 2005)*

Construction productivity can be also presented as a raw productivity, calculating the ratio of installed quantities to actual direct construction work hours, excluding the indirect construction work hours (CII-BMM, 2011). When it comes to the construction work hours, they are differentiated by direct work hours and indirect work hours. The former refer to the hours spent on constructing the unit, whereas the latter do not directly add to constructing the unit but help in reaching the construction deliverables. As an example, the construction direct work hours will refer to a direct craft labor or scaffolding hours, whereas the construction indirect hours will refer to craft training or job clean-up hours (CII-BMM, 2011). This measurement focuses solely on the craft members and their hands-on-tools performance (i.e. amount of hours which craft members spend on the actual work). The output can be measured in for instance as follows: meters of laydown materials, cubic meters of poured concrete or number of welded pipe racks.

$$(2.1.1.2) \text{ Raw Productivity} = \frac{\text{output}}{\text{input}} = \frac{\text{installed quantity}}{\text{actual direct construction work hours}}$$

*(CII - BMM, 2011)*

Governmental agencies like department of Commerce use total factor productivity, as a measure of construction productivity, as presented below (Shehata & El-Gohary, 2011).

$$(2.1.1.3) \text{ Total Factor Productivity} = \text{Construction Productivity} = \frac{\text{output}}{\text{input}} = \\ = \frac{\text{installed quantity}}{\text{labor, materials, equipment, energy, capitals}}$$

(Shehata & El-Gohary, 2011)

This measure takes into account, besides actual work hours, also materials, equipment, energy and capitals, used in order to install certain quantity. The equation for total factors productivity seems more complicated, however when all input and output factors are represented by costs, the comparison can be easily made. Nevertheless, this type of productivity is rarely used in the industry due to changes in pricing and higher complexity of considered factors. Also, contractors tend to opt for productivity related directly to labor (Dozzi & AbouRizk, 1992).

Other definitions for Construction Productivity oscillate between the basic labor productivity and total factor productivity, excluding for instance energy and capitals from the input factors, depending on the project specific goals (Shehata & El-Gohary, 2011).

### 2.1.2 Construction Productivity measurements

CII Productivity Measurements Task Force (1990) disclosed that many contractors in the construction industry do not measure productivity for the following reasons: (i) contractors do not know how to do it, (ii) contractors have perception that the productivity cannot be controlled or (iii) the productivity measurements add little to the already known information (CII Productivity Measurements Task Force, 1990).

Construction productivity in the process industry can be measured with respect to the following construction categories: (i) concrete, (ii) structural steel, (iii) piping, (iv) instrumentation, (v) equipment, (vi) electrical, (vii) insulation and (viii) scaffolding, as depicted in figure 4. The work hour distribution for oil refining projects and chemical manufacturing depicts that the greatest amount of work hours is allocated to piping and civil (i.e. concrete and structural steel) construction disciplines (CII-BMM, 2011). Thus the highest efforts should be directed at the productivity measurements of those two disciplines.

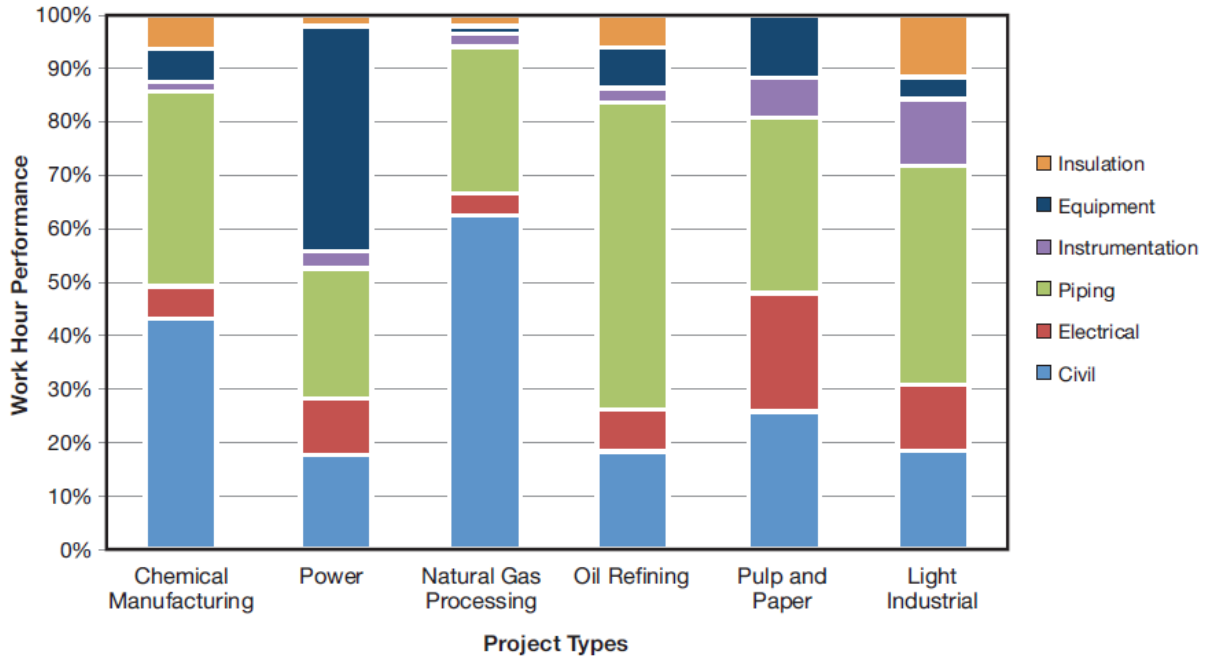


Figure 4 Construction work hour distribution by project type (CII-BMM, 2011)

Productivity measurements will comprise of the following steps: (i) selection of activities to be monitored, (ii) reporting of installed quantities, (iii) reporting of work-hours expended, (iv) calculating productivity and finally (v) using the productivity measurements for evaluating performance, forecasting and estimating, as depicted in figure 5 below (CII Productivity Measurements Task Force, 1990).

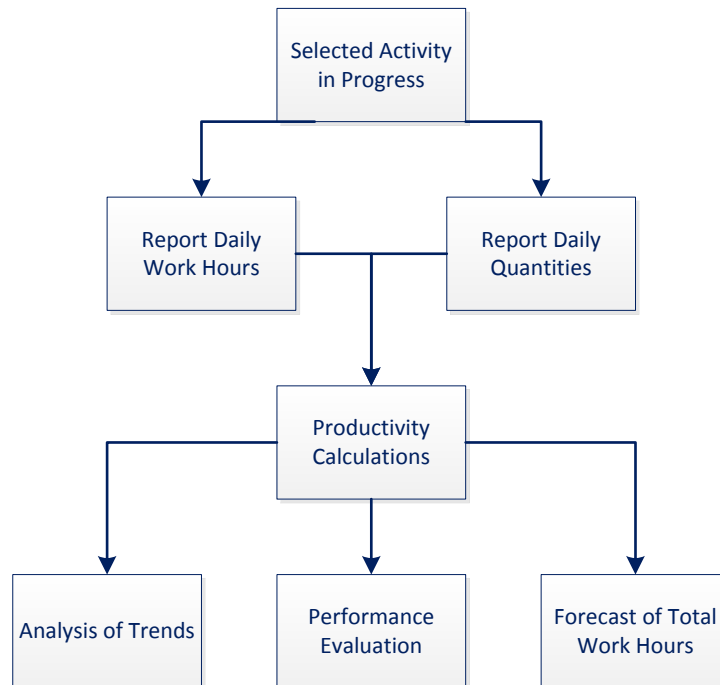


Figure 5 Productivity data collection and analysis process (CII, Productivity Measurements Task Force, 1990)

First challenges with respect to the productivity measurements occur already during the selection of the construction activities and during the progress reporting. Those activities will differ per construction discipline and most likely will vary for the same discipline, but among different projects. The next challenge lies in choosing the right metrics for the output quantities (CII RT-252, 2013). The aforementioned challenges create inconsistencies in productivity measurements across the projects in the construction industry. There has been realized lack of the common definitions for the activity split per construction discipline and lack of common construction productivity metrics for the progress reporting (Park, Thomas, & Tucker, 2005). Shehata & El-Gohary (2011) have also indicated that besides the productivity decline, the lack of productivity standards is the main problem of the construction industry (Shehata & El-Gohary, 2011).

CII RT-252 (2013) has aimed at standardizing the activities per construction discipline. As an example, piping work hours comprise of the following construction activities: (i) erecting and installing piping, including welding, valves, and in-line specials; (ii) hydro testing; (iii) tie-ins; (iv) material handling; (v) in-line devices; (vi) specialties; (vii) equipment operators; (viii) hangers and supports; and (ix) rework. However, CII excluded the following piping activities from the measurements: (i) non-destructive evaluation, (ii) steam tracing, (iii) stress relieving, (iv) underground piping, (v) offloading pipe as it is received, (vi) commissioning and (vii) field fabrication of large bore piping. Therefore, the piping activities included in the construction activities will comprise for the actual work hours input in the labor productivity measurements also including the rework hours in the actual work hours input (CII RT-252, 2013). Moreover, European Construction Institute (henceforth ECI) has come up with standardized data, defining each piping activity with a corresponding measurement and a unit rate (ECI, 2005). However, it has not been stated to which extent this standardized data has been utilized across the projects in the oil and gas industry and if it has been found successful.

When the construction activities per discipline are chosen and are considered in the actual work hours, the next step is to report output quantities. Shehata & El-Gohary (2011) suggested the following construction metrics for different construction categories: (i) cubic meters for concrete; (ii) tons for steel; (iii) numbers installed for electrical equipment, devices and lighting fixtures and linear meters for electrical conduit and cable; (iv) each unit installed for instrumentation loops and devices, and linear meter for instrumentation cable; (v) linear meter for piping; (vi) equipment metrics per each piece of equipment and (vii) equipment insulation in square meters and piping insulation in linear meters (Shehata & El-Gohary, 2011). CII RT-252 (2013) further suggested reporting quantities in units of measure which are simple, accurate and which facilitate easy application. Detail construction metrics per discipline were also presented by the Construction Owners Association of Alberta Institute (henceforth COAA) and are depicted in appendix A accordingly (COAA, 2009).

CII (1990) provided different methods for quantity measurements. As an example, the quantities can be measured in units of output completed. This method is used for a well-defined scope and will be the most detailed, accurate and objective measurement. The only disadvantage is that it will require a lot of effort during the data collection phase. Other methods for the quantity measurements are represented by percent complete or start/finish percentages. Those methods are relatively simple, however may be inaccurate and misleading with respect to the actual construction progress. After determining the method for the quantity measurements, the decision needs to be made over the frequency of the progress reporting, on a daily basis or periodically (CII Productivity Measurements Task Force, 1990).

Activity model presented in figure 6 shows the percentages of time allocated for different construction activities on site.

## Activity Model

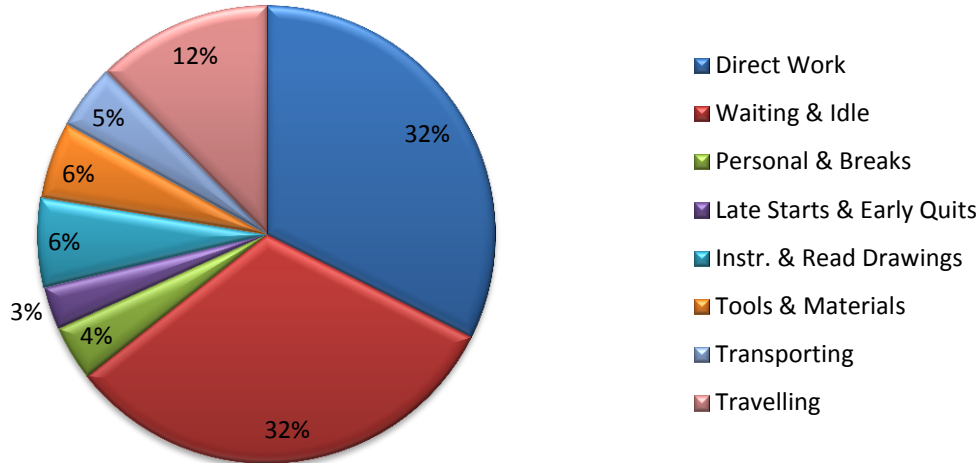


Figure 6 Graphical Representation of Activity Model (Thomas, Maloney, Horner, Smith, Handa, & Sanders, 1990)

The measurement for the actual work hours is depicted in a direct work construction activity. From the presented graph it can be clearly realized that direct work will hardly reach full percentage. Craft members need additional hours to wait for materials to arrive, supervisors may prolong planning activities or simply some rework will be needed for certain corrections and adjustments. The aforementioned factors imply that presented productivity should be expected at the percentage lower than 100 percent, and at the same time considered as a satisfactory percentage. The exact percentage range for the desired labor productivity will depend on the company's benchmarking data.

Thomas et.al (1990) suggested that the actual productive work and thus the direct work activity for all projects is expected to be at 50 percent or lower. He further suggested that the biggest amount of time is wasted on waiting and idle. However, direct work could be enhanced by reducing the waiting time; it does not paint the full picture on the productivity, as there is no information on the actual delivered outputs (Thomas, Maloney, Horner, Smith, Handa, & Sanders, 1990).

### 2.1.3 Construction Productivity evaluation

After determining the input and output requirements for the productivity measurements, the gathered information can be presented in variety of ways. Also, those baseline productivity considerations can be further used for instance for performance evaluation or estimating.

#### 2.1.3.1 Productivity Ratio

While assessing the construction productivity, different units of output (i.e. cubic meters for concrete or linear meters for piping) create challenges in measuring the construction productivity for all of the construction disciplines. For that reason, productivity is frequently assessed by comparing estimated work hours to actual work hours, as presented in the *productivity ratio* equation as follows (CII RT-252, 2013):

$$(2.1.3.1.1) \text{ Productivity Ratio} = \frac{\text{estimated direct work hours}}{\text{actual direct work hours}}$$

(CII RT-252, 2013)

The overall productivity ratio is intended to be higher than 1. Also, the accuracy of the productivity ratio will highly depend on the quality of the initial estimates (CII RT-252, 2013).

### 2.1.3.2 Productivity Index/ Performance Factor

Another representation of productivity measurements can be made using a *productivity index*, also referred to as a *performance factor*. The productivity index is represented by a ratio of planned productivity to an actual productivity and the higher the ratio, the better the index is (CII Productivity Measurements Task Force, 1990).

$$(2.1.3.2.1) \text{ Productivity Index (PI)} = \frac{\text{Planned Productivity}}{\text{Actual Productivity}}$$

(CII Productivity Measurements Task Force, 1990)

### 2.1.3.3 Earned Value Concept

Earned Value Management (henceforth EVM) is a popular Project Management technique used in controlling time and cost progress of the projects. It should give an early indication on the deviations from the planned progress that is initially set up, and thus shed a light on possible future scenarios. Moreover, EVM application should suit all types of projects independently from its size and complexity, in various industries (Fleming & Koppelman, 2000).

There are three different measurements used in describing the Earned Value Management technique and are presented as follows (Ferguson & Kissler, 2002):

**Planned Value** is calculated before starting a project and is considered as a baseline, showing estimated value of work done, at a given time.

$$\text{Planned Value (PV)} = \text{Planned \% of work complete} \times \text{Budget At Completion (BAC)}$$

**Actual Cost** represents a total amount that has been spent for an actual work done, at a given time.

$$\text{Actual Cost (AC)} = \text{cost incurred for actual work at a given time}$$

**Earned Value** measurement shows value of an actual work completed at a given time.

$$\text{Earned Value (EV)} = \text{Actual \% of work complete} \times \text{Budget At Completion (BAC)}$$

In other words, AC shows the total cost that has been spent at a given time, EV represents how much has been actually accomplished at a given time whereas PV is a target value that should have been accomplished at a given time.

With respect to the construction productivity a slightly modified earned value concept is used to calculate the ratio of earned work hours to total earnable hours (CII Productivity Measurements Task



Force, 1990). It gives an overview on the percentage complete from the overall construction activities, following the equations below:

(2.1.3.3.1) *Total Earnable Work Hours*

$$= \sum (\text{Planned Productivity} \times \text{Current Quantity Estimate})$$

(2.1.3.3.2) *Earned Work Hours To Date*

$$= \sum (\text{Planned Productivity} \times \text{Quantities Installed To Date})$$

$$(2.1.3.3.3) \text{ Percent Complete} = \frac{\text{Earned Work Hours To Date} \times 100\%}{\text{Total Earnable Work Hours}}$$

*(CII Productivity Measurements Task Force, 1990)*

Earned value in the equations above is presented in work hours, however could be easily expressed as a cost representation. Furthermore, the earned value measurements can be further used for the schedule and cost progress overview (CII Productivity Measurements Task Force, 1990).

#### **2.1.3.4 Construction Productivity as representation of costs - Profitability**

Construction productivity measurements also contain baseline information for further evaluation of the costs. As it has already been mentioned, input and output factors are usually in different measurement units (i.e. worked hours or quantities). In order to make a comparison, they need to be transferred into the unit that will be applicable to all considered factors, which could be a cost representation. Productivity output is tracked as a physical progress of installed quantities in time. It is essential to consider that those quantities are related to the price that is paid for installing them. In general cost progress is defined as a financial assessment of the value of the work done. Cost progress can be for instance represented by the man-hours priced for delivering certain amount of quantities, as presented in the equation below (Fox, 2008):

$$(2.1.3.4.1) \text{ Physical Progress} = \text{Cost Progress (i. e. actual worked hours priced)}$$

*(Fox, 2008)*

In general, detail physical progress versus the cost progress tracking gives a considerable control to the contractor over the project workflow. Further it is used for accurate reimbursement for the performed work and as a solid basis for successful cooperation with clients (Fox, 2008).

When addressing the costs it becomes necessary to introduce the term profitability. The profitability calculus is presented as a ratio of revenue and cost. Revenue posits in a value of work delivered whereas cost consists of collection of all inputs (i.e. labor, materials, etc.) (Tangen, 2004).

$$(2.1.3.4.2) \text{ Profitability} = \frac{\text{Revenue}}{\text{Cost}}$$

*(Tangen, 2004)*

Construction Productivity representation purely in costs, has also its drawbacks. By presenting overall budget at completion, it becomes subject to fluctuations in prices and inflation. Therefore different projects, from varied regions are hardly comparable due to changes in pricing. Also, historical database on projects performance does not give a good indication on improvements over time, when tracked in costs. Moreover, relation between specific quantities, man-hours and costs, is lost. Thus detail information that could have been used to improve productivity is lacking. Any alterations directed at productivity enhancements should be focused at the source of the actions; allocated quantities and man-hours.

Idealistically, costs could be intertwined in productivity measurements in a way that information on quantities and man-hours is preserved. Tracking of the profitability progress is essential in order to analyze the economic status of the project whereas productivity measurements are very useful in identifying the possible productivity improvements. Given its interchangeable nature a clear link is made between quantities and costs.

Tangen (2004) suggested that the profitability can be expressed as productivity and price recovery combination, as presented in the equation below:

$$(2.1.3.4.3) \textit{ Profitability} = \frac{\textit{Output Quantity} \times \textit{Unit Price}}{\textit{Input Quantity} \times \textit{Unit Cost}}$$

(Tangen, 2004)

#### 2.1.4 Construction Productivity as a measure of efficiency and effectiveness

The literature frequently refers to the construction productivity as a combination of efficiency and effectiveness measurements (Tangen, 2004). However, there is no consensus in the literature whether the effectiveness measurement should be considered within productivity measurements. Some of the efficiency and effectiveness definitions are presented in appendix B.

The effectiveness measurement focuses on how craft is utilized within the construction processes. This could imply how well craft members are organized, taking into account for instance materials/ equipment arrival, tools that are available for the workforce, working hours, breaks, etc. On the other hand, the efficiency measurement concentrates just on the actual work done by workers at a specific time and place (Dozzi & AbouRizk, 1992).

Following the aforementioned descriptions, it is still somehow unclear how those measurements fit into the presented productivity considerations. To further clarify that, closer attention will be given to terms of efficiency and effectiveness.

Firstly, it should be mentioned, that in the literature there are different ways of defining effectiveness and efficiency and those terms are sometimes used interchangeably (Takim & Adnan, 2008).

In the most simplified way, effectiveness means doing the right things whereas efficiency means doing the things right (Johnston, 2017). Efficiency implies performing tasks in a timely manner. When effectiveness is considered, it should bring quality to the performed work (Miksen, 2017). As an example, an engineer can track measurements in a very efficient way, however data input he uses may not be of a value in a broader consideration.

Multiple sources also define efficiency as a ratio of output and input, where the output should be maximized while minimizing the input at the same time (e.g. Watson & Griffith, 2003; Takim & Adnan, 2008). Interestingly, this definition of efficiency corresponds with general productivity measurements (i.e. labor productivity, raw productivity or total factor productivity). Despite that the effectiveness measurements could have a significant impact on the productivity it is not included in the aforementioned productivity measurements. One could even argue if any focus should be given to the effectiveness; increasing quality may have adverse impact on efficiency. In other words, when we improve quality of work it usually becomes more expensive and it takes more time to complete it. Given this consideration, closer attention should be directed at understanding the effectiveness element in productivity.

Effectiveness is described as a strategy for achieving goals and objectives (Sundqvist, Backlund, & Chron er, 2014). Frequently it is referred to quality and value creation (Tangen, 2004). The effectiveness is directed at the evaluation of the outcomes (Shabani, Faramarzi, Saen, & Khodakarami, 2016). The latter can be done by measuring degree to which desired objectives have been achieved in a form of output to goals ratio (Pritchard, 1995).

Diagram depicted below represents relation between input, output and outcome towards the efficiency and effectiveness measurements (Mandl, Dierx, & Ilzkowitz, 2008).

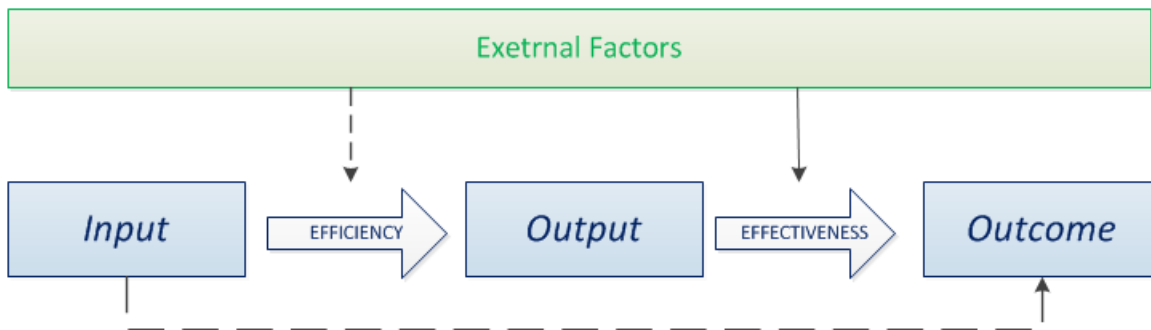


Figure 7 Efficiency and Effectiveness relation to Input, Output and Outcome (Mandl, Dierx, & Ilzkowitz, 2008)

The efficiency measurement is covered in the output to input ratio whereas the effectiveness, as an evaluation of outcome, in an output to goal ratio. Furthermore, there is also a distinction between technical and allocative efficiency. Technical efficiency focuses strictly on maximizing outputs whereas allocative efficiency takes into account economic benefits (Mandl, Dierx, & Ilzkowitz, 2008).

The overall productivity, as a function of efficiency and effectiveness, is presented in the equation as follows:

(2.1.4.1)  $Productivity = Efficiency \times Effectiveness = \frac{Output}{Input} \times \frac{Output}{Goal}$   
 (Mandl, Dierx, & Ilzkowitz, 2008)

The presented effectiveness measurement is exemplified in the *Productivity Ratio* or *Productivity Index* measurements, where the actual output values are set against the desired goal (i.e. planned or estimated) values. Thus, it can be concluded that the combination of both, the efficiency and effectiveness components, is essential towards reaching a comprehensive view on the productivity.

**2.1.5 Key Points**

Overall, all introduced definitions and productivity measurements create a logical sequence that leads to the following chart, presented by Tangen (2004):

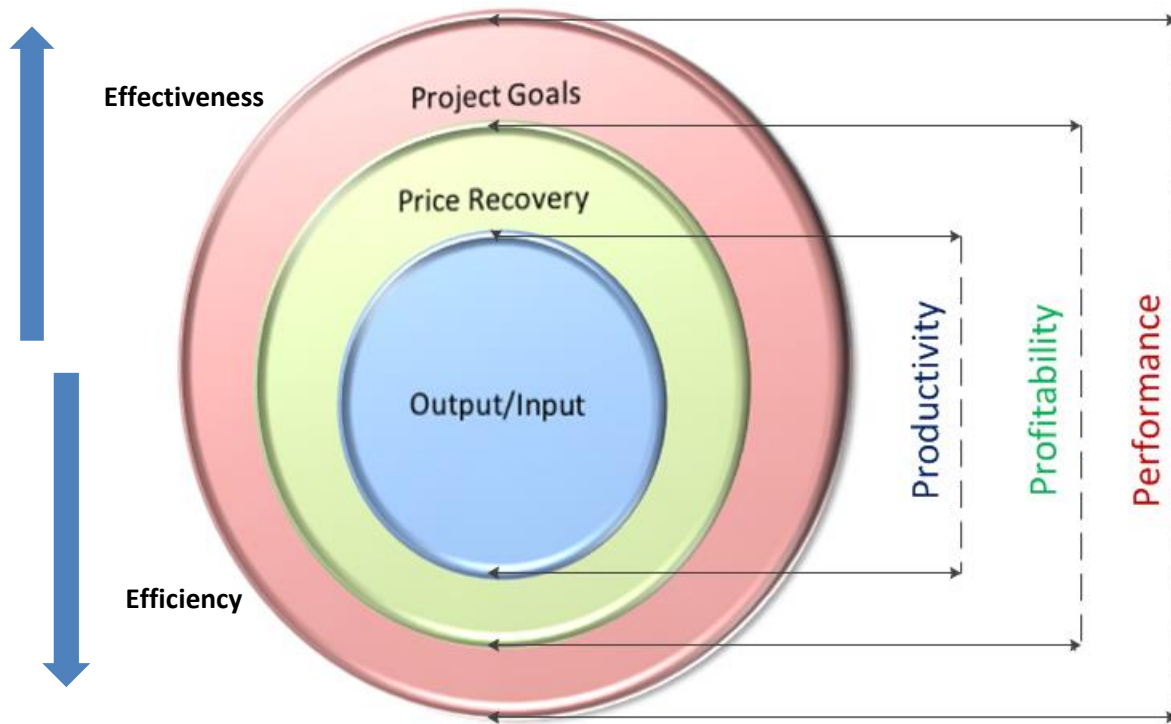


Figure 8 Productivity, Profitability and Performance diagram reproduced from (Tangen, 2004)

Throughout this research study *Productivity* is defined by output to input ratio, where output is represented by the installed quantities. When input is defined by actual work hours it will be the *Labor Productivity*. When it comes to the *Construction Productivity* term it should be treated in a broader perspective towards the *Labor Productivity*. It is also represented by the ratio of output to input, however input will consist of many other factors, depending on the type of the project (i.e. materials or equipment). *Profitability* with respect to the construction productivity is expressed as a revenue of installed quantities to the cost paid for installing them. The efficiency will act at the inputs whereas the effectiveness will drive the output components. Performance is the broadest term representing the overall success of the project (Tangen, 2004).

## **2.2 Identification of factors for productivity loss**

After defining construction productivity it is essential to evaluate what influences it. Existing literature provides multiple research studies on critical factors affecting the construction productivity. Taking into account the amount and variety of different factors, it becomes impractical to consider all of them. Therefore, the intention of this research study is to present the predominant factors described in the literature and thus indicate the main areas of concern for further interviews during the case studies.

10 independent scientific papers on those factors are presented in tables 1 and 2 respectively. The listed articles represent research studies from 1981 to 2015 and depict a comprehensive spectrum on how the productivity factors were assessed in the literature during the past 40 years. All the presented factors were concluded by researchers as the highest impact factors and thus exemplifying the greatest importance while evaluating the construction productivity. Moreover, the main methodology utilized for the identification of factors was done through extensive survey research methodology. As depicted in the tables 1 and 2, the investigated researches vary per number of factors analyzed, criticality of those factors and the researched perspective (i.e. either from the craft or managerial perspective).

The presented researches will serve as a basis for theory development on critical factors affecting productivity from the literature. This framework of critical productivity factors will be developed by identifying repetitive factors in the 10 analyzed researches. The repetitive patterns are marked with different colors and are listed in the supporting legend to the table 2. Furthermore, the selected factors will be grouped into categories of factors and elaborated further in this chapter. The grouping of factors is intended to simplify further descriptions of factors due to the large number of factors analyzed.

Table 1 Factors affecting productivity, literature review. Part 1 (own table).

Factors affecting productivity - literature overview				
Authors	Factors	No. of factors	Methodology	Remarks
1 Borcharding & Garner (1981)	(i) Material availability, (ii) tool availability, (iii) rework, (iv) overcrowded work area, (v) inspection delays, (vi) foreman incompetence, (vii) crew interfacing, (viii) craft turnover and absenteeism and (ix) foremen changes.	9 ranked from the highest impact.	Surveys on around 1300 craftsmen and foremen in the energy sector.	Design lead time and complexity of energy projects were found to impact majority of the listed factors.
2 CIDC (1984)	(i) Weather variability, (ii) material shortages, (iii) lack of experienced design and project management personnel, (iv) large number of changes, (v) ineffective communications, (vi) inadequate planning and scheduling, (vii) lack of sufficient supervisory training, (viii) restrictive union rules, (ix) slow approvals and issue of permits, and (x) lack of management training for supervision, project management.	10 leading factors out of 95 factors analyzed.	Developed through surveys.	None
3 Hsieh (1998)	(i) Delays: unorganized storage area, material handling and disruption, material/tool/equipment unavailability, interference with other crews/congestion, out-of-sequence work, waiting for instruction, waiting for inspection, interruptions due to accident, adverse weather, personal and breaks, late starts and early quits; (ii) ineffective work/rework: boring/ repetitive task, lack of job enrichment, low morale/ lack of motivation, temporary installation, make work, fabrication errors, poor craftsmanship, change order, engineering errors, incorrect technical instructions; (iii) excessive travel: lack of logistics of tools and materials, obstructed walkways, poor housekeeping; (iv) large amount of supportive work: unbalanced crew, unplanned work. Subcontracting as the most undetermined factor affecting productivity.	4 areas identified.	Factors derived from the field work sampling.	Hsieh (1998) identified following critical areas to improve the productivity loss factors: (i) management, (ii) material, (iii) engineering, (iv) labor, (v) equipment.
4 Rojas & Aramvareekul (2003b)	Management skills and scheduling were found to be the most relevant factors affecting labor productivity within mgmt strategies group. Experience of workers and specific activity training were found to have the highest potential of affecting the labor productivity in manpower group. Industry environment (i.e. weather conditions, working conditions and activity interactions) and external conditions (i.e. scope change, information technology) were rated as the least relevant in comparison with the aforementioned management and manpower factors.	Not specified.	Survey on labor productivity, asking 64 participants: general contractors and electrical contractors, consultants and others.	None
5 Liberda, Ruwampura & Jergeas (2003)	(i) Lack of detailed planning, (ii) work experience and skills, (iii) inadequate supervision, (iv) worker motivation, (v) non-availability of materials, (vi) worker attitude and morale, (vii) crew team-spirit, (viii) non-availability of information, (ix) changes in drawings and specifications, (x) non-availability of tools, (xi) non-availability of equipment, (xii) project size and complexity, (xiii) lack of procedures for construction methods, (xiv) changes in contract, (xv) congested work areas.	15 factors with the highest impact, out of the 51 factors identified.	Interviews with 20 industry experts.	Three management factors in top five factors indicating the necessity of effective managerial practices to improve productivity.
6 Klanac & Nelson (2004)	(i) Project characteristics, (ii) site conditions, (iii) project execution, (iv) weather, (v) supervision, (vi) time management, (vii) labor market conditions, (viii) construction equipment and tools.	8	Based on other researches.	Factors which cause variance in construction productivity and are considered during the labor productivity loss claims.

Table 2 Factors affecting productivity, literature review. Part 2 (own table)

Factors affecting productivity - literature overview				
Authors	Factors	No. of factors	Methodology	Remarks
7 Dai, Goodrum & Maloney (2009)	(i) Tools and consumables, (ii) materials, (iii) engineering drawing management, (iv) construction equipment, (v) supervisor direction. Most of the identified factors can be addressed by site management teams.	83 factors, 5 categories with the highest severity factors presented.	Nation-wide survey on 1996 craft.	None
8 Rivas, Borchering, Gonzalez & Alacron (2011)	(i) Material availability, (ii) rework, (iii) equipment and trucks, (iv) tools, (v) interference, (vi) instructions, (vii) design interpretations, (viii) inspections, (ix) absenteeism, (x) overcrowded work areas, (xi) turnover.	Main factors influencing craft productivity.	Questionnaires/ Survey on direct workers and midlevel employees.	None
9 CII (2013)	(i) Adverse weather, (ii) workforce demographics, (iii) project acceleration, (iv) craft density, (v) overstaffing, (vi) overtime, (vii) shift work, (viii) change orders, (ix) turnover, (x) absenteeism, (xi) learning curves, (xii) lighting conditions, (xiii) day of the week, (xiv) equipment availability, (xv) jobsite conditions, (xvi) personnel management, (xvii) project construction phase, (xviii) above grade versus at grade construction, (xix) material availability, (xx) information availability, (xxi) operating plant conditions.	21	Based on other researches.	None
10 Naoum (2015)	(i) Ineffective project planning, (ii) delay caused by design error and variation orders, (iii) communication system, (iv) work environment, (v) constraints on a worker's performance, (vi) design and buildability-related issues, (vii) management/ leadership style, (viii) procurement method, (ix) lack of integration of the management information system for the project, (x) management of material on site, (xi) team/group integration during construction, (xii) experience and training, (xiii) control system on site, (xiv) group coordination, overcrowding on site, (xv) project structure/authority and influence on site, (xvi) specification, (xvii) ineffective site planning leading to program disruption, (xviii) supervision of subordinate, (xix) delay/rework, (xx) site safety, etc.	20 factors presented with the highest impact out of 46 identified.	Surveys with close-ended structured questionnaire, conducted with 19 contract managers and 17 site managers.	Factors with the highest ratings are considered within pre-construction stage.

**Legend:**

- Lack of materials/tools/ equipment/ information
- Site attributes and Congestion on the job site
- Shift work/overtime/schedule acceleration
- Weather
- Changes/rework
- Labor market conditions
- Design processes
- Project Complexity
- Contracting
- Ineffective project and site planning and scheduling
- Management/supervisory skills

Shehata & El-Gohary (2011) present three categories indicating the types of factors affecting construction productivity; Labor Related, Industry Related and Management Related factors (Shehata & El-Gohary, 2011). The aforementioned categories cover all of the critical factors identified from the tables 1 and 2 as productivity loss areas (i.e. listed in the legend of those tables). Thus, the aforementioned framework will be used throughout this research study. The general split of factors into the categories is presented in table 3.

The labor related factors will represent the factors that directly affect craft workers (i.e. waiting for tools or materials). When it comes to the industry related factors, McKinsey institute (2017) has identified three major productivity impact factors from the perspective of the contractor in the construction industry to be (i) misalignment of contractual structures and incentives; (ii) design processes; and (iii) increasing project and site complexities (McKinsey & Company, 2017). Shehata & El-Gohary identified design factor represented by repetition and complexity in the design processes (Shehata & El-Gohary, 2011). As other sources like Borchering & Garner (1982) or CIDC (1984) have also identified design and complexity as productivity impact factors, those will be considered in the industry category. Additionally, Hsieh (1998) claimed subcontracting the construction work as the most undermined but crucial factor affecting construction productivity (Hsieh, 1998). All of the aforementioned factors will be considered under the industry related factors category. Finally, the researchers frequently directed the productivity loss to the management related aspects like scheduling, detail planning, and management skills (Rojas & Aramvareekul, 2003b; CIDC, 1984; Liberda, Ruwanpura, & Jergeas, 2003). Thus, the latter factors will be described under the management related factors category.

Taking the aforementioned considerations into account, the following categories with factors are identified in the table 3, based on the factors presented in the tables 1 and 2:

Table 3 Factors affecting Construction Productivity (own table).

Labor Related Factors	Industry Related Factors	Management Related Factors
<ul style="list-style-type: none"><li>• Lack of materials, tools, equipment, information</li><li>• Site attributes and congestion on the jobsite</li><li>• Shift work and overtime</li><li>• Weather</li><li>• Changes and Rework</li><li>• Labor market conditions</li></ul>	<ul style="list-style-type: none"><li>• Design processes</li><li>• Project complexity</li><li>• Contracting</li></ul>	<ul style="list-style-type: none"><li>• Ineffective project and site planning and scheduling</li><li>• Management skills</li></ul>



Moreover, it should be mentioned that described factors are interdependent and thus one factor may fit into multiple categories. As an example, overtime factor was classified in the labor related factors; however, it could also be under the management related factors, as construction managers will be responsible for managing the construction work time. Furthermore, lack of information classified in the labor factors can also be related to the design processes (i.e. missing engineering deliverables) or management skills (i.e. lack of information from supervisors). To conclude, the main focus should be given to the areas of impact not specific factors and their division.

### **2.2.1 Labor Related Factors**

Labor related factors will directly focus on the craft performance.

#### **2.2.1.1 Lack of materials, tools, equipment, information**

##### *Materials availability*

Management of materials on site has been described as a worldwide problem in construction industry with respect to handling of materials, sorting and marking the materials on site or inefficient distribution, causing its unavailability in the field (Naoum, 2015). The main causes for materials mismanagement were found to be in the lack of timely logistics, materials not available before the work starts and excessive paper work (Rivas, Borcharding, Gonzalez, & Alacron, 2011). Thomas et al. (1998) attributed the following areas affecting the management of materials: (i) unorganized storage area, (ii) housekeeping, (iii) planning delivery of materials, (iv) material availability and (v) material handling and distribution (Thomas, Sanvido, & Sanders, 1989).

##### *Tools and Equipment availability*

Tools and equipment, and especially their unavailability to workers, will likely influence the labor productivity (Klanac & Nelson, 2004). The main causes for the unavailability of tools were found to be: (i) insufficient number of tools, (ii) tools not available when required, (iii) broken tools and (iv) inefficient tool room, located away from the work area (Rivas, Borcharding, Gonzalez, & Alacron, 2011). Furthermore, the unavailability of the right equipment was mainly concerned with the sufficient amount of trucks for loading the aforementioned materials and tools (Rivas, Borcharding, Gonzalez, & Alacron, 2011).

Overall, the unavailability of materials and tools was ranked in multiple sources in top three factors having the biggest impact on the labor productivity (Dai, Goodrum, & Maloney, 2009; Rivas, Borcharding, Gonzalez, & Alacron, 2011; Borcharding & Garner, 1981). Furthermore, Rivas et al. (2011) attributed 59 percent of labor time loss to the materials, tools, equipment and design interpretation factors (Rivas, Borcharding, Gonzalez, & Alacron, 2011).

##### *Information/Instruction availability*

It is needless to say that the craft will not be able to build their deliverables without the right information and instructions on how, when and what to build (CII RT-252, 2013). Thomas et al. (2003) identified that 52 percent of productivity loss relates to the labor workflow, whereas the remaining 42 percent to the workflow of equipment and information (Thomas, Horman, & Chen, 2003).

#### **2.2.1.2 Site conditions and congestion on the job site**

Site conditions refer to the influences like access to the site, overcrowding of labor or safety restrictions (Klanac & Nelson, 2004). Most frequently, previous research studies refer to the overcrowding of labor as a major jobsite factor affecting the productivity (Borcharding & Garner, 1981; Hsieh, 1998; CII RT-252, 2013; Naoum, 2015).

Naoum (2015) described that the congestion on the jobsite will affect productivity and quality of the performed work. This overcrowding was attributed to lack of proper construction planning (Naoum, 2015). CII RT-252 (2013) further explained that density issues usually occur due to the acceleration of the project in order to deliver the planned work in a shorter amount of time. Basically, as the work needs to be complete in a shorter period of time, it usually results in a labor ramp up (CII RT-252, 2013).

In order to facilitate high productivity, it was suggested to allocate around 250 to 300 square feet (i.e. 23 to 28 square meters) of work area per worker. However, 200 square feet (i.e. 19 square meters) per worker was also advised as optimal. Furthermore, modifying the schedule, shifts and carefully addressing the initial work flow planning should help in solving the density issues (CII RT-252, 2013).

#### **2.2.1.3 Changes/rework**

Changes are a common occurrence in construction and are in general caused by changes in scope, not complete design or schedule delays. Those changes usually have an impact on cost and schedule but also may affect the labor productivity by increasing rework (CII RT-252, 2013).

Rivas et al. (2011) indicated that the majority of rework was related to the (i) changes made by the client, (ii) changes due to design errors and (iii) lack of project definition. Furthermore, only 20 percent of the total rework time, was related to the field errors and misunderstandings (Rivas, Borcharding, Gonzalez, & Alacron, 2011).

Hanna et al. (1999) show through research study that estimated hours for change orders where in reality twice larger for the impacted projects. It further implies that the impact of those changes in construction was not fully factored by the contractor and thus resulted in significant losses in labor productivity (Hanna, Russell, Nordheim, & Bruggink, 1999).

Thomas and Napolitan (1995) conducted a quantitative analysis on evaluating the impact of changes on the labor efficiency. They concluded a strong correlation between both, with the negative impact of changes on the labor productivity of around 30 percent in a range from 25 percent to 50 percent (Thomas & Napolitan, 1995).

#### **2.2.1.4 Weather**

Adverse weather conditions may cause a significant drop in the labor productivity due to severity of a seasonal weather like extreme cold, heat or wind (Klanac & Nelson, 2004). During the challenging weather supervisors should ensure that workers have sufficient personal protective equipment to proceed with their work or should even stop any ongoing activities if extreme conditions do not allow performing the works safely (CII RT-252, 2013). Adverse weather can cause up to 30 percent decline in the labor productivity (Thomas, Riley, & Sanvido, 1999).

#### **2.2.1.5 Schedule acceleration:**

Fast-tracked schedule is one of the factors creating a productivity decline. This productivity decline is caused by introducing; (i) additional labor, (ii) overtime work or (iii) additional shift to recover the schedule acceleration. All of those measures will result in a man-hours ramp up and thus additional labor to the initially budgeted one (Awad, Sullivan, & Taylor, 2005). The main reasons for project delays are caused by contractors being behind schedule due to their own mistakes, adverse weather or late material delivery, or clients are asking for earlier completion (CII RT-252, 2013).

On the contrary, prolonged schedule allows for a stable, gradual mobilization of labor. The latter results in a flat efficiency curve, which is maintained throughout the project. When it comes to the process

facilities projects, it is highly unlikely to work under the prolonged schedule conditions. Usually those projects are fast-tracked due to high revenues of running facilities and thus the clients opt for an earlier completion.

The overall impact of overtime, shift work and overmanning on the man-power is presented in figure 9 below:

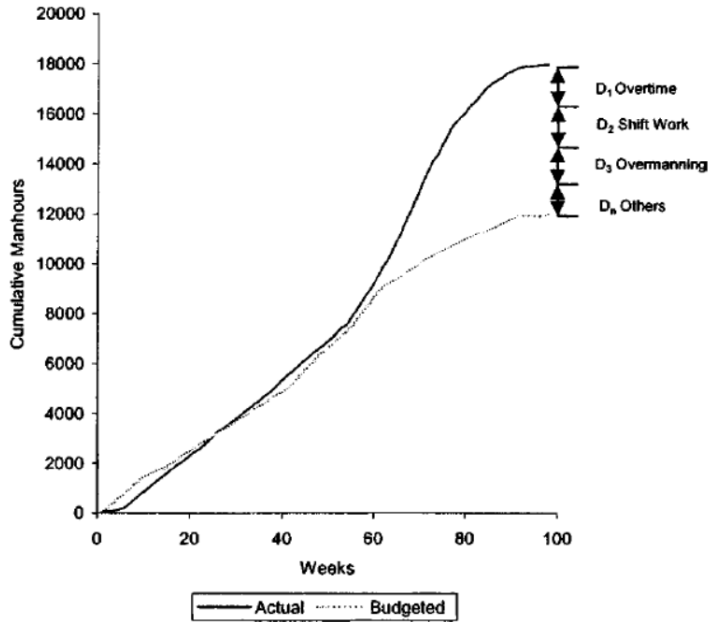


Figure 9 Actual and budgeted cumulative man-hours (Awad, Sullivan, & Taylor, 2005)

Closer attention will be given to the overtime and shift work as the overmanning was briefly described in point 2.2.1.2.

#### Overtime work

Overtime is considered if a workweek exceeds 40 hours per week. The overtime is usually introduced in order to recover a progress decline or due to unexpected issues occurring on site, like unplanned work. Overtime option is preferred over a night shift work option. The shift work needs much more coordination, additional lightning and indirect labor for a night shift (Awad, Sullivan, & Taylor, 2005). Introducing overtime may seem like a good solution however it has its limitations and adverse impact on the labor productivity as depicted in figure 10:

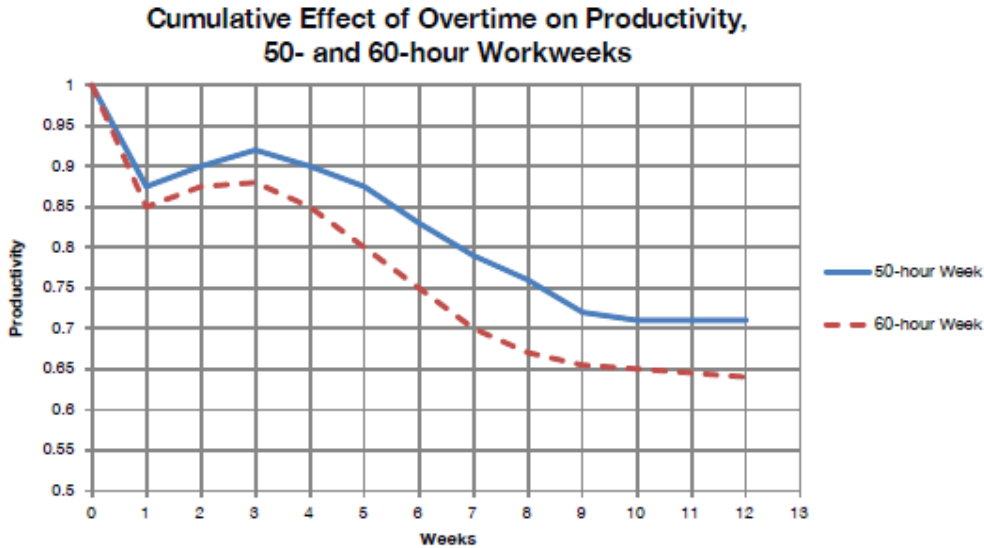


Figure 10 Cumulative effect of overtime on productivity 50 and 60 Hour Workweeks (The Business Roundtable, 1980)

As depicted in the figure above, 60 hours per week schedule may indeed bring positive results to productivity but only up to two, three weeks. After prolonged exposure to overtime, productivity significantly drops. Furthermore, the costs are being continuously increased due to the additional labor without advancing the targeted schedule (CII, 1988).

The aforementioned negative effects of overtime are mainly due to the labor fatigue, low morale which further exemplifies in a human error and thus additional rework needed or occurrence of safety issues. There is also a tendency of labor to stretch their tasks over the worked time (Awad, Sullivan, & Taylor, 2005).

*Shift work*

Shift work is considered when work hours for the same trade are performed by a different group of workers, which follows with the same trade activities after the first group is finished (Hanna, Chang, T., & Lackney, 2008). However, the night shift is costly due to additional administrative labor, management, security and proper lighting needed during the night time. Also, it takes up to 10 to 12 days for labor to adjust to a night shift. As humans are not used to work during the nights their performance is usually less efficient leading to an overall 10 percent productivity loss (Awad S., Chul-Ki, Kenneth T., & Jeffery A., 2008).

Hanna (2008) concluded that the shift work has potential of both; positive and negative impact on the productivity, ranging from an 11 percent gain to a 17 percent loss in the labor productivity (Hanna, Chang, T., & Lackney, 2008).

*Shift work and Overtime as a Management issue*

CII (1988) questioned the negative impact of shift work and overtime on productivity rates. Based on the productivity analysis on 25 different crews, the data findings were inconsistent. The latter implies that some crews did perform worse under overtime and shift work conditions however for some crews no difference has been noted. Furthermore, the negative impact was suggested to lie in the lack of proper management and supporting activities (CII, 1988).

The aforementioned CII (1988) findings introduce the opportunity that, shift work and overtime negative effects, may be overcome at least to a certain extent by addressing the managerial aspects of a proper job organization. This could be accomplished by for instance introducing management overlap between the shifts so all activities can be directed smoothly, with proper understanding of what has been done during the night shift and what needs to be followed up with next day.

#### **2.2.1.6 Labor market conditions**

Labor market conditions are a responsibility of a contractor and those conditions cover the following aspects: (i) size and skills of the local labor pool, (ii) labor rules, (iii) craft turnover and absenteeism, (iv) cultural issues such as holidays and (v) abuse of drugs and alcohol (Klanac & Nelson, 2004). The following aspects have been identified with having the highest impact on the labor productivity:

Experience of workers and specific activity training were found to have the highest potential of affecting the labor productivity in a manpower category. Interestingly the findings showed that the experience was not always correlated with the amount of years worked. The activity training was further associated with the training given to the workers before commencing their activities (Rojas & Aramvareekul, 2003b). Liberda et al. (2003) ranked work experience and skills as a second impact factor affecting the productivity out of the 51 factors analyzed in total (Liberda, Ruwanpura, & Jergeas, 2003).

Borcherding and Garner (1981) identified turnover and absenteeism as the eighth highest impact factor affecting productivity out of 9 major factors identified in total (Borcherding & Garner, 1981). The turnover is defined as gaining and losing employees and was found to have underestimated and considerable impact on labor productivity (CII RT-252, 2013). It was found that sufficient wages and safe working environment can largely influence maintaining the stable workforce and prevent turnover (Eady & Nicholls, 2011). Absenteeism is defined as a voluntary or involuntary absence irrespective of holidays. It usually relates to reasons like time pressure, excessive overtime, illness or boredom at work. Hanna concluded in his research that absenteeism of 0 percent to 5 percent has no impact on labor productivity. However, the absenteeism rates between 6 percent and 10 percent resulted in around 24 percent loss in the labor productivity (Hanna, Menches, Sullivan, & Sargent, 2005).

Another aspect related to work demographics in construction industry was related to aging workforce (CII RT-252, 2013). In construction, workforce over the age of 45 has changed from 32 percent to 50 percent between 1985 and 2010. This widening gap will most probably hamper adoption of new technologies in the construction sector due to aging workforce being accustomed with low-tech jobs (McKinsey & Company, 2017). Furthermore, the construction sector faces hard times in retaining labor at supervisory level; foremen, engineers and project managers. Highly-skilled workforce tends to choose more complex and innovative sectors in order to utilize their talents (National Research Council, 2009). This means that the construction sector will be in a need of re-skilling its workforce, attracting and retaining specialized resources.

#### **2.2.2 Industry Related Factors**

As the labor related factors seem to be closely linked to the productivity issues it would be logical to direct improvement efforts at those factors. However, wider perspective on the construction industry may unfold additional issues impacting the productivity on site. Industry factors are related to the challenges with respect to design processes, complexity of the projects and contracting strategies.

### **2.2.2.1 Design processes**

Design processes were addressed in multiple sources as a high impact factor affecting construction productivity (CIDC, 1984; Hsieh, 1998; Liberda, Ruwanpura, & Jergeas, 2003; Dai, Goodrum, & Maloney, 2009; Rivas, Borcharding, Gonzalez, & Alacron, 2011; Naoum, 2015).

Rivas et al. (2011) identified design interpretation as a seventh impact factor affecting productivity out of 11 categories in total. Design issues were caused by poor quality of engineering drawings and lack of familiarity of engineers with field conditions (Rivas, Borcharding, Gonzalez, & Alacron, 2011).

Dai et al. (2009) explained further that perspective on factors, and especially design factor, varied depending on the construction trade. Pipefitters and electricians, opposed to iron and carpentry workers, rated drawing errors and slow response of engineers to the construction questions as the highest impact factor. Overall the engineering drawing management was rated third after management of tools and materials factors (Dai, Goodrum, & Maloney, 2009).

Naoum (2005) reflected that engineering design has a considerable impact on the productivity and thus high potential for productivity improvements. As designs are becoming more complex, design deliverables are more difficult to be constructed in the field. Naoum ranked delays in the field caused by a design error on the top of the listed factors. He further suggested that the integration of construction and engineering, in order to improve constructability of delivered designs, is crucial in increasing the productivity (Naoum, 2015).

Despite the fact that design affects construction to a large extent, construction discipline has little impact on decision making during the design phase (Dubois & Gadde, 2002). Abu-Shaban (2014) further strengthened the importance of the design factor and suggested that in order to maximize productivity in the field, the productivity needs to be considered already in the design phase (Hamouda & Abu-Shaaban, 2014).

COAA (2009) institute presented interesting correlation between the percentage of complete design and costs of construction phase. It was concluded that the optimal percentage is around 60 percent to 70 percent of complete design in order to ensure the cost effective construction phase as depicted in figure 11. As a comparison, investigated projects by the COAA institute had only around 30 percent complete designs before construction commenced with the works in the field (COAA, 2009).

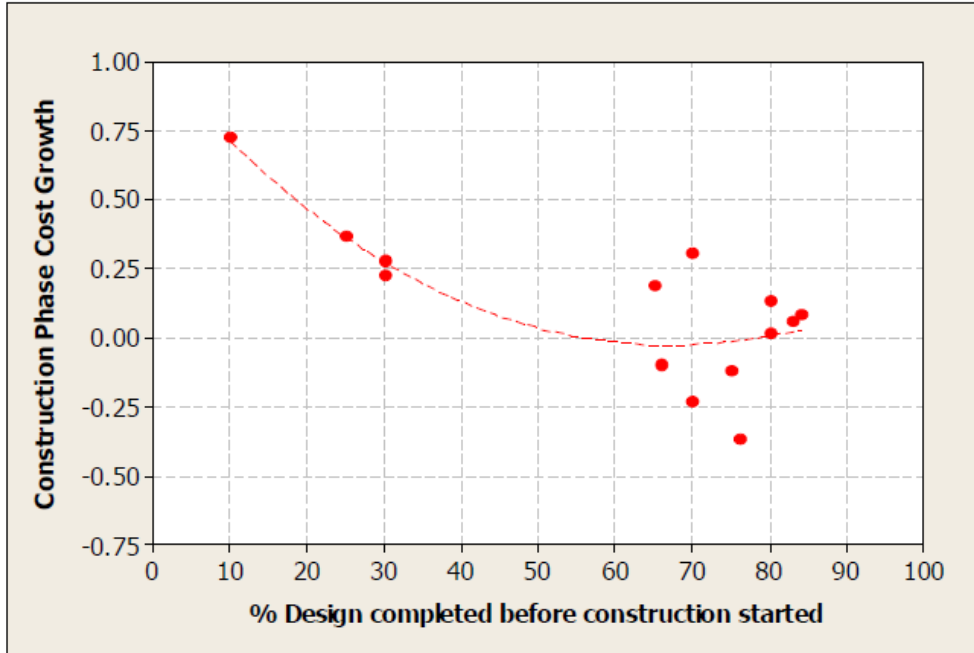


Figure 11 Effect of % Engineering Completed before Construction Started (COAA, 2009)

Furthermore, the lower the percentage of design complete, the costs of construction grow exponentially. The construction costs related to the aforementioned incomplete design could be caused by later design errors and design changes resulting in unplanned construction works or rework.

### 2.2.2.2 Project Characteristics

Project characteristics were considered as an important factor during the labor productivity loss claims. Those characteristics included considerations over the size and complexity of the project, competing projects or construction contracts (Klanac & Nelson, 2004). Liberda et al. (2003) also ranked project size and complexity as a twelfth factor affecting productivity out of 51 factors identified in total (Liberda, Ruwanpura, & Jergeas, 2003). Furthermore, Borcharding and Garner (1981) concluded their findings indicating that design lead time and complexity of projects impacted the majority of identified factors affecting productivity (Borcharding & Garner, 1981). McKinsey Institute besides the already described factors of design processes and complexity has also indicated contracting as a major factor affecting productivity from a perspective of contractor (McKinsey & Company, 2017). Therefore, lastly in the industry related factors, contracting strategies will be briefly described.

#### Complexity

De Ridder (2016) defined complexity of a system as a sum of all relations between elements of this system. The system becomes complex when: (i) number of elements increases, (ii) relations between elements are strong relations, (iii) there is wide variety of the elements in the system and (iv) environment of the system affects the system. Furthermore, the complexity is not a problem when the system operates well. Issues occur, when the system or the element of the system needs to be changed, due to the knock-on effect on the interrelated elements (de Ridder, 2016).

Bosch-Rekvelde (2011) investigated project complexity in the process facilities projects. She categorized complexity into the three following categories creating a TOE framework: (i) Technical Complexity (i.e. scope and content of the project) (ii) Organizational Complexity (i.e. related to the project team) and (iii)

External Complexity (i.e. related to external stakeholders and market conditions). Final findings based on extensive case studies revealed a negative impact of complexity on the project performance, with the highest impact of goals and scope definition (Bosch-Rekveltdt, 2011).

Furthermore, McKinsey research concluded a positive correlation between project size and complexity, which was further mirrored in productivity measurements. Projects with around 1 million worked hours were found to be 15 percent to 20 percent less productive than smaller projects with around 100,000 worked hours. Also, projects executed in brownfield were dampening construction productivity by obstructed and complex work in the existing refineries (McKinsey & Company, 2017).

Gidado (1996) identified two main causes for construction complexity to be: (i) uncertainty and (ii) interdependencies. Uncertainty is generated by and relates to parties employed for a project and to the environment of the project. Interdependencies are however related to tasks and are initiated by bringing all the parts of the project together (Gidado, 1996). The aforementioned definition of uncertainty could refer to the organizational and external complexity described by Bosch-Rekveltdt (2011). Whereas the interdependencies would be exemplified in the technical complexity (Bosch-Rekveltdt, 2011) and further mirror relations described by de Ridder (2016).

Some of the sources of complexity caused by the interdependence and uncertainty are listed in table 4 as follows:

Table 4 Complexity in Construction (Dubois i Gadde, 2002)

Complexity in Construction	
Interdependence	Uncertainty
Number of technologies and interdependencies	Lack of complete activity specification
Rigidity of sequence between various main operations	Unfamiliarity with local resources and local environment
Overlap of stages or elements of construction	Lack of uniformity of materials, work and teams with regard to time and place
	Unpredictability of environment

Despite strong technical interdependencies, construction companies exhibit strong organizational independence. All disciplines work in rather isolated environments and follow decentralized decision making processes. Complexity caused by the interdependence could be solved by enhanced coordination of interrelated tasks, people and machines. Complexity caused by uncertainty could be dealt with by building long term relationships and aligning teams on the projects (Dubois i Gadde, 2002).

#### *Contractual arrangements*

Contractual terms are usually prepared as a result of risk assessment and allocation of those risks among different parties. Both sides, contractor and owner struggle to efficiently manage execution risks during design-build/engineering procurement and construction (henceforth EPC) contracting in the oil and gas industry. One of the main factors creating this difficulty in risk management lies in lump sum versus reimbursable contracting schemes. Lump sum contracting entails that owner pays a fixed amount of money to the contractor and the contractor will be responsible and accountable for managing any unforeseen risks. The latter situation creates both: opportunity and threat for the contractor, depending on how well he will be able to manage his risks. On the other hand, a cost reimbursable contract entails a cost plus contract in which contractor is paid based on his progress. In this contracting scheme the



owner will bear more risks and thus will have more control over the performance of the contractor. (Galloway, 2009.)

McKinsey research suggests that there is a strong correlation between the type of contract; reimbursable or lump-sum and productivity, promoting the second contracting scheme. Whichever party holds the risks, for lump-sum most of the risks are on EPC provider, it will be more focused on raising its productivity. It is also explained that better productivity under lump-sum could be due to the nature of projects, which are usually smaller and easier to handle. Whereas reimbursable scheme implies more complex, bigger projects and thus productivity is negatively affected by rising complexity (McKinsey & Company, 2017). Those assumptions may however be counterintuitive as large engineering projects of oil and gas industry, which entail higher complexity, are also executed under lump-sum conditions (Galloway, 2009).

Detail progress tracking of the construction productivity is mainly suggested for the projects on reimbursable basis. In this type of contracting scheme, both owner and contractor will have high interest in a detail progress in order to evaluate the progress of the contractor accurately (Fox, 2008). However, alongside the freedom of the progress of the contractor tracking during the lump sum contracting, come also the risks that are on the contractor's side. The overall progress that is shown by a contractor to the client may satisfy both parties but the contractor may lack level of details needed to control his actual workflow.

Hsieh (1998) shed a light on another factor affecting productivity which is not typically considered in the research area and could be a missing element, and that is subcontracting. He explained that majority of construction contractors opt for direct-hire, trained workers from unions or labor markets. As an example, direct hire gives more freedom to the contractor over maintaining the workflow in the field. However, the subcontracting of construction work became more popular due to the unstable market conditions (Hsieh, 1998). While subcontracting strategy gives plenty of benefits, when it comes to progress measurements, a lot of confusion and misunderstandings occur, due to for example usage of different unit rates or lack of clear contracts. As a result of that, subcontractors are filing claims against the contractor to recover unfair pricing (ECI, 2005). Furthermore, Hsieh described that employed subcontractors are not oriented on cost savings and usually more workers are employed as a contingency. Therefore, redundant workers were found in the fields, contributing to the lower productivity performance. Also, general contractor does not invest in craft training while subcontracting the construction work, as the subcontracted craft tends to work on different projects and may leave the project at any time (Hsieh, 1998).

### **2.2.3 Management Related Factors**

When it comes to management related factors, the factors identified through the literature were most frequently related to scheduling, planning and management skills (CIDC, 1984; Hsieh, 1998; Rojas & Aramvareekul, 2003b; Liberda, Ruwanpura, & Jergeas, 2003; Klanac & Nelson, 2004; Naoum, 2015).

#### **2.2.3.1 Planning and scheduling**

Naoum (2015) identified ineffective project planning as the most important factor affecting productivity out of 46 factors identified. Before construction commences, managers need to make a lot of decisions with regard to available resources, construction methods, activities and identify the status quo of previous activities. Also, during the pre-construction planning, multiple assumptions and estimates are made, which may not be accurate anymore when construction discipline starts with their activities in the field (Naoum, 2015).

Liberda et al. (2003) also ranked lack of detail planning as the highest impact factor affecting productivity out of 51 factors analyzed in total. He further concluded that owners are reluctant to invest in additional resources during the initial planning phase which immensely affects productivity in the field during construction phase (Liberda, Ruwanpura, & Jergeas, 2003).

Klanac et al. (2004) and Rojas et al. (2003b) also classified scheduling as an important factor affecting productivity within a management category. Scheduling is crucial during sequencing of construction activities. If construction activity is stopped and needs to be rescheduled, it will cause a momentum loss while activities are being reorganized (Rojas & Aramvareekul, 2003b). Furthermore, the contractor is responsible for managing time on site. It sometimes occurs, that owner changes or accelerates the construction schedule. As the schedule acceleration can result in unplanned overtime and thus create a productivity loss to the contractor, the owner may become liable for that loss (Klanac & Nelson, 2004).

### **2.2.3.2 Management skills**

Management and supervisory skills were addressed in all researched papers on productivity, as depicted in the tables 1 and 2. Construction managers are responsible for identifying needed resources, changing construction methods and any modifications to the schedule. Also, responsibility of managing construction workforce lies usually on the contractor (Klanac & Nelson, 2004; Rojas & Aramvareekul, 2003b).

Construction industry and especially on site execution is still mainly focused on managing labor. Managers spend roughly half of their time talking with people (Sunindijo, Hadikusumo, & Ogunlana, 2007). Furthermore, construction projects entail collection of varied organizations and teams for the project durations (Naoum, 2015). This means that relationships with craft, clients, subcontractors, vendors, etc. will also play important role in a successful project delivery.

Following Collin's words in his book "Good to great":

"Those who build great companies understand that the ultimate throttle on growth for any great company is not market or technology or competition or product. It is one thing above all others, the ability to keep the right people" (Collins, 2011).

Naoum (2015) explained that effort of workers depends on their motivation. The latter was found to be highly dependent on the 'work environment' and 'constraints on worker's performance', which were further related to effectiveness of managers (Naoum, 2015).

Projects with high complexity were considered the most successful under management equipped with certain qualities. Those managers scored very high on critical thinking, managing resources and were very influential in bringing high spirits across the project (Muller & Turner, 2009).

Interestingly, CII RT-252 (2013) has shown that effective managerial skills improve productivity but should not only be expected from construction managers. As craft usually has superior technical skills, there were found benefits towards labor productivity, while setting up balanced teams with both technical and management skillset within craft members. However, the more multi-skilled workforce was utilized the less benefits were identified (CII RT-252, 2013).

Lastly, Dai et al. (2009) researched 83 factors affecting productivity and concluded that majority of those identified factors could be solved by management teams on site (Dai, Goodrum, & Maloney, 2009).

### 3 Case Study Preparation

Case study preparation will consist of case study propositions, brief description of the Company A, construction strategies utilized in the Company A and will be further followed with setting criteria for case studies and interviewees. Lastly, interview questions will be formed to conduct case study interviews with construction experts.

#### 3.1 Case study propositions

The literature review has provided insights into the construction productivity definitions, measurements and factors that are affecting the construction productivity. Based on the developed theory, four propositions are formulated that will be further tested via case studies.

Propositions 1 and 2 refer to the inconsistencies in the academic research with respect to the construction productivity definitions and measurements. Proposition 3 suggests that criticality of factors will considerably depend on the project specific considerations. Proposition 4 further implies the hypothesis on initial construction strategy to have a knock on effect and thus the greatest potential of affecting the productivity on site.

*Proposition 1:* There are multiple ways of defining construction productivity presented in the academic research. This confusion over the construction productivity definitions is expected to be mirrored in the analyzed case studies.

*Proposition 2:* There is also no clear standard of measuring the construction productivity in the academic research. Due to the aforementioned, inconsistencies with chosen construction metrics and productivity measurements are expected with regard to progress reporting during the construction phase.

*Proposition 3:* The academic research has aimed at identifying critical factors affecting the construction productivity. Despite number of research papers, there is wide variety with respect to importance of those factors over the productivity. Thus, it is suggested that criticality of factors will highly depend on the project specific considerations and the project context.

*Proposition 4:* Construction is the final phase of the project, when all preceding efforts come into place to construct a process facility. Therefore, it is suggested that initial construction strategy aligned with the client's objectives will have a significant impact on the final productivity on site.

The basis of the aforementioned propositions drives the following research objectives: identification of critical factors within the specific project context in the process industry (proposition 3 and 4) and to gain insights into the construction productivity definitions and measurements that are applied and followed during the on-site execution in the process industry (proposition 1 and 2).

The verification of the introduced propositions through the case studies' interviews will provide groundwork for answering the sub-research questions and the main research question subsequently.

### **3.2 Organizational structure of the Company A**

The second part of this research, case studies, will be developed with cooperation of the Company A. The Company A is one of the largest EPFC (i.e. engineering, procurement, fabrication and construction) and maintenance provider in the world. The researched company is providing those services to the projects being executed worldwide.

This research takes place in the Amsterdam office, where the main focus is placed at the oil and gas industry, life sciences and infrastructure projects. Based on the research outline, the primary study will be done in the construction department examining the process facilities projects of the oil and gas industry.

The preliminary discussions with company's managers have revealed that despite the EPFC orientation and construction driven execution, the projects remain engineering driven. Furthermore, the Amsterdam office has been oriented on the EP (i.e. engineering and procurement) services for the majority of time and has only recently added FC (i.e. fabrication and construction) services to its scope.

Furthermore, the Company A tends to subcontract majority of construction work in Europe, whereas in North America the construction work tends to be a mix of a direct hire and subcontracting. While subcontracting construction work, subcontractors are evaluated based on their progress and paid accordingly. Remuneration scheme varies per Time and Materials (henceforth T&M) and Unit Rate contract with subcontractors. Depending on the numbers of hired subcontractors and layers of them, it might be challenging to supervise and maintain all interfaces with subcontractors. However, for both variations, subcontracting and direct hire, work evaluation is done. The basis for that is defined by a contracting scheme.

The aforementioned situation sets a perfect environment for investigating the actual needs of construction and opens further possibility for improving existing construction productivity procedures in the Company A. Thus, the literature and the company's construction role in the Amsterdam office come together in creating a conducive environment for the research on the construction productivity.

### 3.3 Project specific considerations in the Company A

The initial preparation for case studies comprises of analyzing existing procedures on the construction productivity in the Company A. This information has been obtained from the Global Productivity Lead in the researched company. The aforementioned lead is also a co-author and a member of the Craft Productivity Research Program, Research Team 252 (2013) for the Construction Industry Institute (CII). Thus, the presented productivity guidelines are also resembled and can be found in the aforementioned CII sources. Furthermore, the existing construction strategies will be briefly described, which further represent baseline considerations for all projects in the Company A.

#### 3.3.1 Construction Productivity guidelines

The current construction productivity guidelines in the Company A focus mainly on the craft performance. Firstly, *Activity Survey* is introduced, followed by a *Construction Roadmap* and *Essential Construction guidelines*. The aforementioned productivity considerations are not fully standardized and not fully mandatory procedures in the Company A, and are only followed if requested by a management team. The mandatory procedures comprise of *Construction Checklists* which are not directly related to the productivity, however indirectly take into account factors affecting the construction productivity.

#### *Activity Survey*

The Company A is conducting *Activity Survey* including three craft performance measurements. Each factor measures work from a different aspect, and each is a good metric contributing to an overall understanding of the actual craft performance. The three following measurements comprise for the aforementioned craft performance evaluation:

1. **Activity Level** is defined as a percentage time that craft are performing direct work. It refers to 'Time-on-Tools' performance and is measured as a *Direct Work Rate*. This is the amount of craft time spent actively creating units of output that contribute to the completion of the project, divided by the total craft time. An observation is defined as seeing and recording one crafts person doing one activity, for example, one electrician doing direct work, or one pipe fitter doing preparation work.

$$\text{Direct Work Rate} = \frac{\text{Observations of Direct Work}}{\text{Total Number of Observations}}$$

2. **Direct Productivity** (efficiency/effectiveness) is measured as a *Labor Productivity* and consists of actual units of work completed per hour as a percentage of a standard. Within direct productivity measurements the focus is also given to cost effective balance of methods, materials, training, tools, etc.

$$\text{Labor Productivity} = \frac{\text{Physical Output}}{\text{Work Hours}}$$

There are no specific definitions given to the efficiency and effectiveness terms. The Global Productivity Lead explained that respondents get a better understanding on the construction productivity when it is associated with the efficiency and effectiveness terminology.

3. **Rework** is measured as a percentage of work re-performed which is further a result of being initially performed with errors.

$$\text{Rework Rate} = \frac{\text{Hours of Rework}}{\text{Total Hours of Work}}$$

The Global Construction Productivity Lead further suggested to first focus on increasing the *Activity Level* to the *Target Range* (represented by the Company’s A benchmark of 50 percent), and then explore, evaluate, and implement improvements in the *Direct Productivity* and *Rework* areas.

The *Activity Survey* consists of the following activities: (i) random work sampling technique (i.e. in order to conduct rounds on the construction site, observe craft activities, and categorize observations by craft and an activity type), (ii) measure craft utilization through measuring direct activities (i.e. direct activities are understood as activities that move the job forward), support activities (i.e. planning activities, getting material and equipment, travelling, etc.) and delays (i.e. waiting for information, material, equipment, etc.). The *Activity Survey* results in a comprehensive overview on the craft performance and serves as a basis for further recommendations in the identified concern areas.

*Activity Survey based on the Sample Project in the Company A*

The *Activity Survey* sample project is presented below with the following steps. To start with, random work sampling technique is performed during the sample project by observing the craft members’ activities. Based on those observations, activities are broken down into the direct activities, support and delay activities, as presented in figure 12.

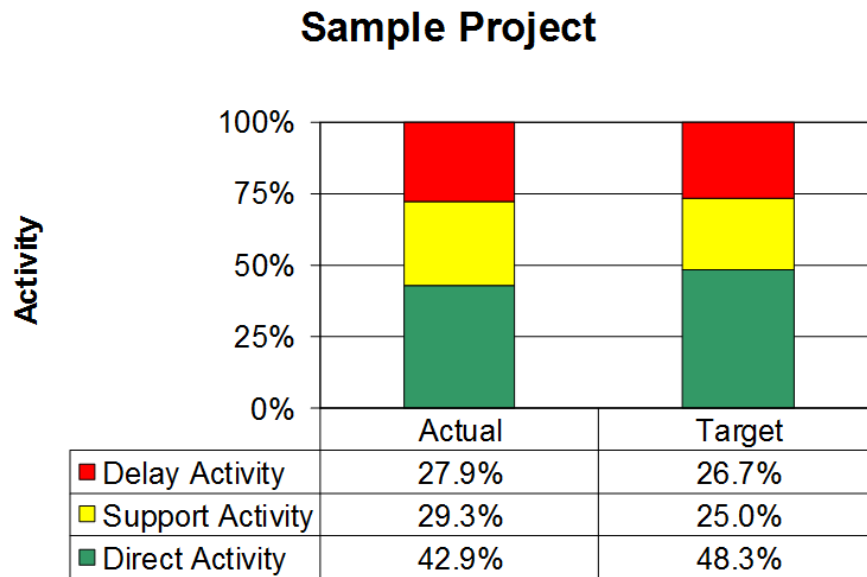


Figure 12 Percentages for actual and target percentages for construction activities (The Company’s A internal documentation)

The current situation on the sample project depicts that the direct activity percentage could be improved from the 42,9 percent to reach the benchmarked 48,3 percent, by reducing the delay and support activities. In order to do that, further detail split of the delay and support activities is shown in figure 13 as follows:

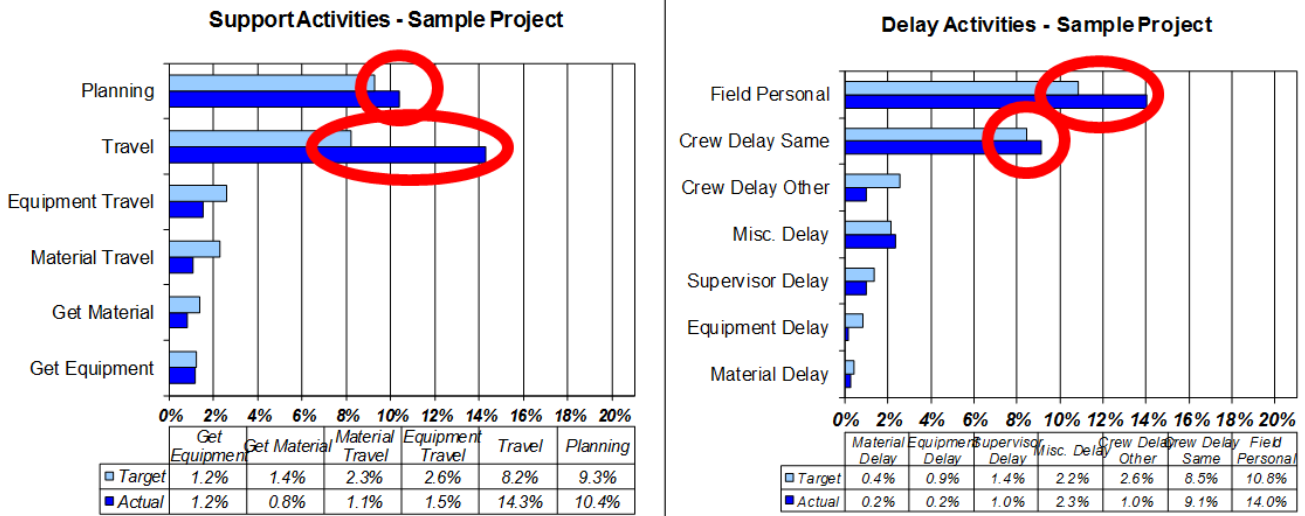


Figure 13 Delay and Support Activities on the Sample Project (The Company’s A internal documentation)

Planning and travel support activities comprise of the highest percentage of all of the support activities. Furthermore, the biggest time and thus productivity loss is also found to be in those areas. Also, for the highest scope delay activities: ‘field personal’ (i.e. personal breaks of craft in the field) and ‘crew delay same’ (i.e. delay caused by and within the same crew) activities created the biggest time loss during the sample project. The aforementioned time loss is further mirrored in a daily analysis presented in figure 14, depicting percentages of the support and direct activities. The remaining percentage represents waiting time.

### Sample Project - Daily Analysis July XXXX

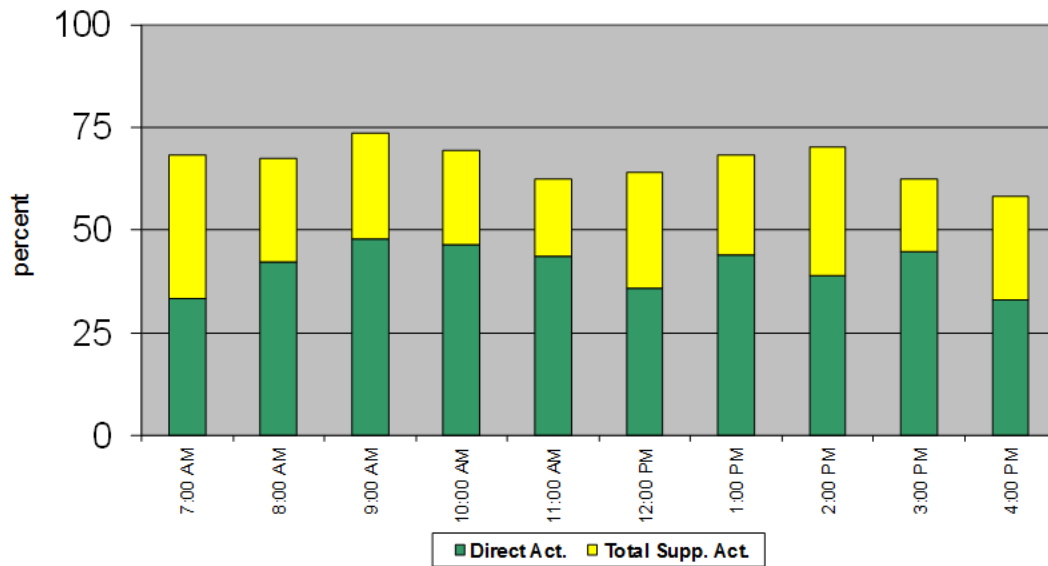


Figure 14 Initial Daily Activity Survey on the Sample Project (The Company’s A internal documentation)

The highest time loss during the day is found to be in the morning around 7 am, during the lunch time around 12 pm, and in the afternoon around 4 pm. This time loss can be easily explained by for example, crew travelling in the morning, prolonging the lunch break and crew getting less productive by the end of the day. After identifying the support and delay activities within a time frame, certain corrective measures can be taken to increase the direct activity.

### Sample Project - Daily Analysis September XXXX

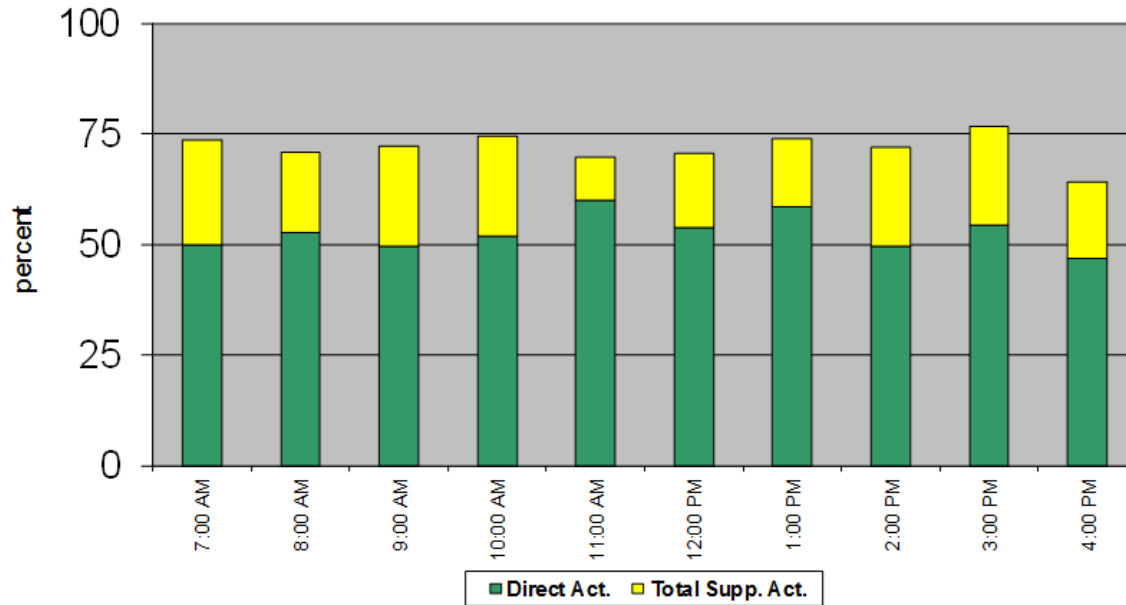


Figure 15 Improved Daily Activity Survey on the Sample Project (The Company's A internal documentation)

After performing the *Activity Survey*, the updated craft performance is depicted in figure 15, showing the direct activity exceeding the desired 50 percent throughout the whole day analysis.

The *Activity Survey* was performed for all craft disciplines and per each unit on the sample project and is further depicted in appendix C. As an example, the direct activity on the interconnecting pipe racks was much lower in comparison with other units presented in the appendix C. That could be explained by much more difficult accessibility of the pipe racks in comparison with the remaining units. This example shows, that the desired percentage for the direct activity may not always be possible to reach, depending on the complexity of the construction activities. However, the main focus should always be directed at increasing the direct activity despite of the targeted percentage.

### Construction Roadmap – BPPII

In addition, the Company A uses the Best Productivity Practices Implementation Index for Industrial Projects (henceforth BPPII) as the basis for a comprehensive productivity improvement roadmap. BPPII research team 252 has developed a planning tool in Excel which addresses the following categories: (i) materials management, (ii) equipment logistics, (iii) craft information systems, (iv) human resources management, (v) construction methods and (vi) environment, safety and health (RT-252, 2013). Each category is tested on the level of implementation of the best practices and mainly evaluates the level of



automation of the construction processes. The BPPII should be applied at the end of Front-End planning phase and should be a part of a project execution strategy (RT-252, 2013).

### *Essential Construction Guidelines (Site Practices that Enhance Craft Performance)*

Construction guidelines presented below were gathered by the Global Productivity Lead in the Company A throughout his in depth construction experience on several projects in the researched company. The latter are presented as follows:

1. Bring craft on site only when unobstructed work is ready to be done – not before.
2. Implement Advanced Work Packaging / Work Face Planning principles:
  - Ensure materials, tools and equipment, design and information, and craft with appropriate skills are available.
  - Ensure pre-requisite work is complete.
3. Time Management:
  - Reduce and eliminate the number of unnecessary breaks and work interruption periods per shift.
  - 10 hours work day as the most efficient working scheme, however dependent on the legal working hours' norms.
  - Keep foremen and supervisors with their crews in the field – “set the example, model the behavior”.
  - Determine and follow appropriate line out and clean up periods at beginning and end of shift.
  - Positive work ethics in craft through management and supervisors.
4. Site Logistics
  - Effective location of temporary facilities.
  - Prepare for and maintain effective site access by road and by foot.
  - Minimize bussing.
  - Obtain Performance Engineering support.
5. Plan for Activity Analysis Cycles at appropriate times.
6. Validate level of safety watch appropriate for specific site and type of work.
7. Validate appropriate Supervisor and Superintendent Ratios.

### *Construction Checklists*

Overall guidelines regarding external factors affecting productivity are considered through the *Construction Checklists* in the Company A. The latter consists of the overall considerations over the following items: (i) materials, (ii) equipment, (iii) site attributes, (iv) site preparation, (v) loading and unloading, (vi) access and parking, (vii) meteorological data, (viii) transportation considerations, (ix) constructability, (x) client's representation, (xi) opportunities for a modular component, (xii) subcontractors, (xiii) local customs, conditions and regulations, (xiv) codes and building permits, and (xv) local labor (the Company's A internal documentation).

The aforementioned categories are considered during a Front-End Engineering and Design (henceforth FEED) phase and are a mandatory construction deliverable. Those items are considered qualitatively in a form of questionnaire that is further signed by a construction manager and reviewed by other disciplines' managers, mainly the engineering manager.

### 3.3.2 Construction Strategies

Furthermore, the current global guidelines in the Company A imply application of Advanced Work Packaging (henceforth AWP) technique and maximization of Modularization in the construction execution. The aforementioned construction strategies create a specific context of the researched projects and may have an impact on the construction productivity during the onsite execution. Therefore, those strategies will be taken into account in the research considerations and should be regarded as potential factors affecting productivity.

The aforementioned construction strategies in the Company A have been consulted with the Global AWP Lead for the Advanced Work Packaging strategy and with the Global Modularization Lead for the Modularization strategy respectively.

#### 3.3.2.1 Advanced Work Packaging

The main goal of the Advanced Work Packaging (henceforth AWP) strategy is to integrate processes in order to increase the overall construction performance. The AWP strategy is applied early in the project definition and is continued until commissioning phase, as depicted in the flow chart below. Despite that the AWP is considered a construction strategy, its implementation starts early in the Stage 1 with close cooperation of engineering and construction disciplines. Furthermore, during the Stage 2 engineering creates engineering work packages, which should support construction deliverables and construction schedule. Finally, in the Stage 3, construction prepares the installation work packages which are created based on a two week look-a-head and are delivered to a foreman accordingly (CII Research Team, 2013a).

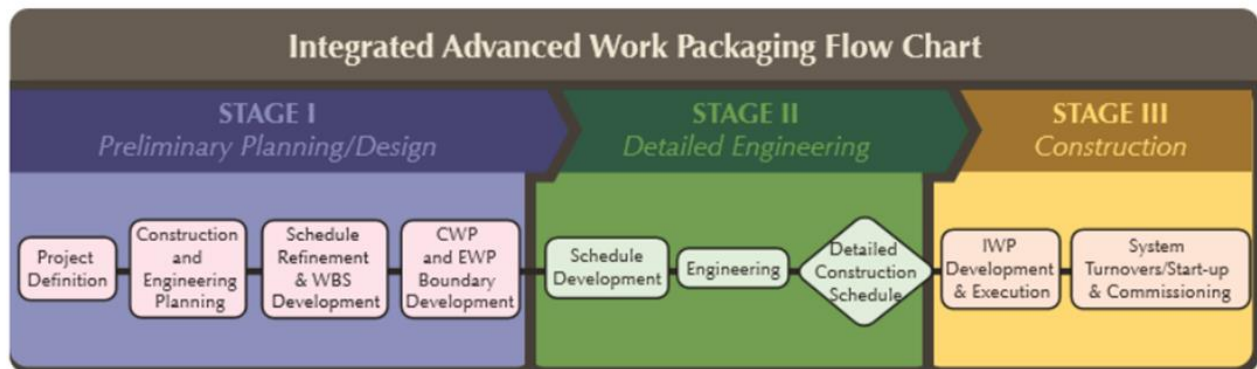


Figure 16 Integrated Advanced Work Packaging Flow Chart (CII Research Team, 2013a)

Overall, the AWP strategy aims at dividing construction work into manageable packages following a predefined work breakdown structure. To start with, Construction Work Areas (henceforth CWAs) are defined representing all disciplines without underground, cables and trays. CWAs consist of different construction disciplines and each discipline is creating a separate Construction Work Package (henceforth CWP) (Geoff, 2009). Further on, Engineering Work Packages (henceforth EWPs) consist of all the information that is needed to create a single CWP and that is (i) scope of work, (ii) drawings, (iii) installation and (iv) material specifications (CII Research Team, 2013a). Lastly, Installation Work

Packages (henceforth IWPs) are dissected from the CWP and delivered to craft to execute the work. The process of creating IWPs from the CWPs with the supportive information of the EWPs is called Work Face Planning and is depicted in figure 17 (CII Research Team, 2013a). The visual representation of CWA, CWP and IWP with further explanation is presented in appendix D.

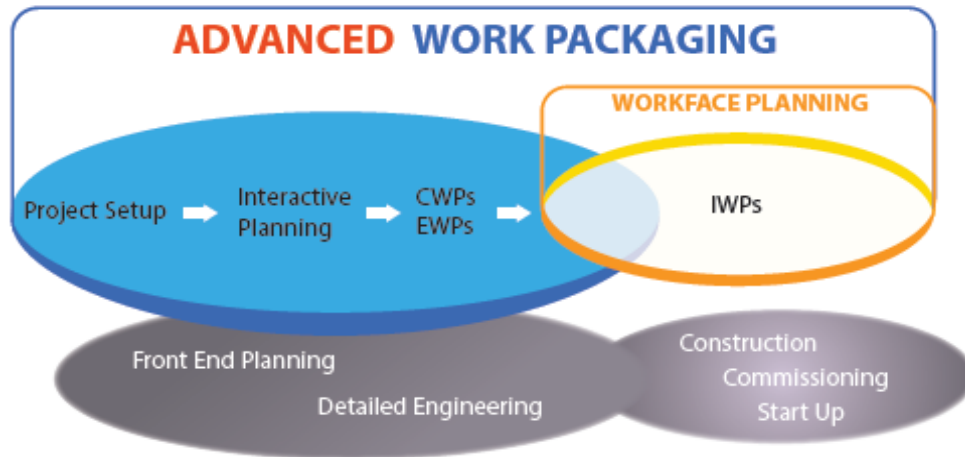


Figure 17 Work Face Planning in Advanced Work Packaging (CII Research Team, 2013a)

Each IWP consists of a short description of work, estimated duration of the work, allocation of man-hours needed to execute the work and ensures that all the required materials, equipment and tools are available for the worker at the right time. Thus, the IWP is a constraint free construction deliverable so the construction work can be executed without any disruptions by craft in the field. Each IWP should not be longer than two weeks of work (CII Research Team, 2013a). Example of the IWP is presented in appendix E.

After defining construction work packages, next step is to identify sequence of construction work. Construction work fronts should be organized based on the predefined work breakdown structure. Moreover, the planning of the construction work fronts should be supported by engineering deliverables approved by construction and ensured materials availability (Bakker & Kleijn, 2014).

The IWPs creation represents the means for the planning and sequencing of the construction work on site and further during commissioning and start up phases. Furthermore, complete IWPs form a basis for reporting construction progress and help in having control over the construction progress on site. Both, the planning and the sequence of the IWPs need to be firstly approved by a superintendent, a subcontractor and a foreman, before it can be released to craft (CII Research Team, 2013b).

Haggard (2009) describes certain quantitative benefits of the AWP application in a form of: (i) superior safety performance of 0,21 Total Recordable Incident Rate (henceforth TRIR), (ii) increased productivity of 11 percent, (iii) 10 percent cost savings, (iv) reduction in re-work on site to less than 0,5 percent (Haggard, 2009).

Overall the AWP and especially the Work Face Planning during the construction phase facilitate work preparation, coordination and execution on site.

### 3.3.2.2 Modularization

Another strategy, modularization, has recently emerged across varied industries like shipping, pharmaceutical and has been ever successful there. The application of modular solutions allows to reach the following benefits: (i) significant compression of schedule (i.e. especially beneficial during the process facilities projects, where clients want to get their products into the market sooner), (ii) material and labor cost reductions (i.e. established through economies of scale and optimizing supply chain), (iii) higher quality (i.e. due to the controlled environment of the fabrication yards), (iv) innovations improvements (i.e. due to automation of processes resulting in lower production cost), (v) reduces congestion on site and improves safety (e.g. due to reduced working on heights, etc.) (CII, Construction Research Team, 2011).

The aforementioned benefits are usually accomplished by transferring man hours from the jobsite to the off-site fabrication yards. This way the whole unit can be constructed under controlled conditions independently from the adverse weather conditions, site access and height constraints, and availability of skilled labor (CII, Construction Research Team, 2012).

To further explain, a module is a section of a plant that is being fabricated, assembled and tested away from the actual project site. Percentage modularized represents the amount of work hours that have been transferred from the job site to the fabrication shops, as a part of the initially estimated site-based work hours (CII, RT-283, 2012).

The Company A describes a module as a minor or a major section of a plant that can be used to construct a more complex structure. Modularization process is considered to be anything that moves work away from the job site to the fabrication yard (The Company A internal documentation).

There are different types of modularization, depending on the level of modularized units. The Company A presents an overall modular generations' split as depicted in table 5. Zero generation comprises for the standard stick built construction, where majority of work is performed on the job site with exception of some pipes that are pre-fabricated offsite. Pre-fabrication stands for fabrication of typically single craft component into a fabricated item whereas pre-assembly stands for a partial assembly of typically multi-disciplined components into an assembly (The Company A internal documentation). On the other side of the spectrum are third generation modules which exemplify high level of modularization, with most of the pipe racks and equipment modularized (The Company A internal documentation).

Table 5 Levels of modularization (The Company's A internal documentation)

Generation	Description	Remarks
0G (Zero Generation)	Stick built	No modularization, but steel and some pipe pre-fabricated offsite.
1G (First Generation)	Piperack Modules	Pre-assembled units with multiple modules.
2G (Second Generation)	Equipment Modules	Some equipment, including dressed vessels.
3G (Third Generation)	High Level of Modularization	Majority of equipment and bulk materials on module. Significant shift of labor from field to a module yard.

Despite multiple benefits of modules it is essential to address how the modularization strategy will affect the onsite execution. As most of the projects executed in the Company A are a hybrid of both construction execution strategies; standard stick built construction and modularization, it becomes essential to explain the main differences between both construction execution types.

The graphical representation of the main difference between the stick built and the modularization strategies over the project life cycle is depicted in figure 18 below. During the stick built construction, equipment and materials are directly delivered to the job site and then fabricated and assembled on the construction site. However, during the modular solution, equipment and materials are firstly delivered to the fabrication yard, fabricated and assembled there, and then modules are delivered to the job site (The Company A internal documentation).

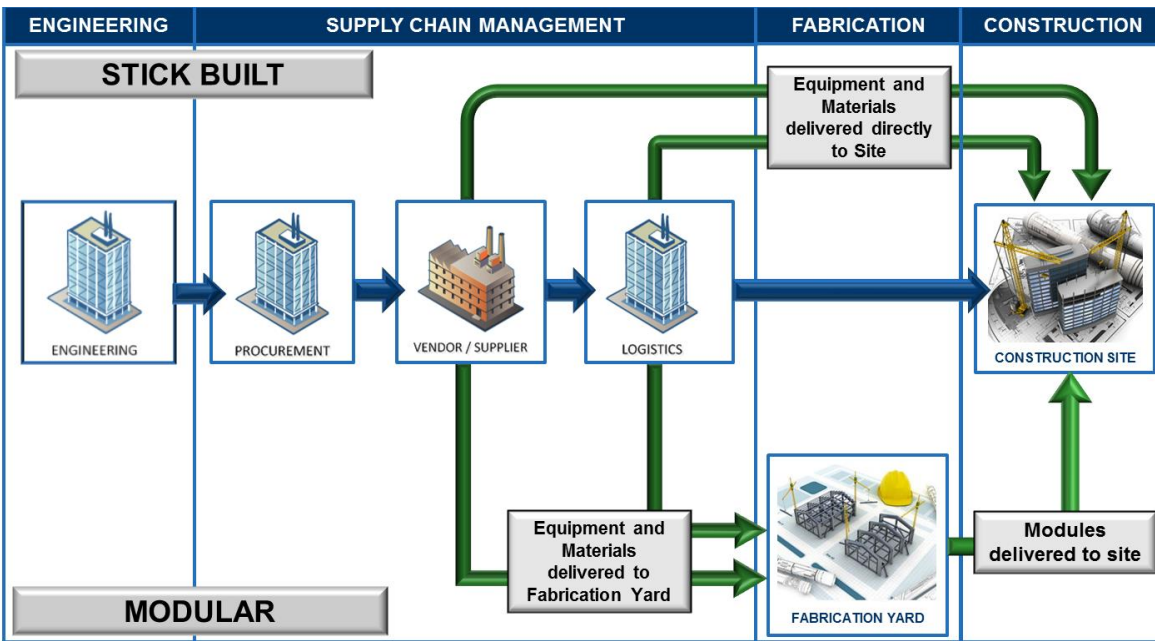


Figure 18 Stick built and Modular Execution, comparison (The Company's A internal documentation)

Furthermore, engineering and procurement programs need to be accelerated in order to facilitate timely assembly at the fabrication yard. The modular component further increases logistics and supply chain complexity. Due to multiple remote work locations the transportation considerations (i.e. quality of roads, bridges, site access, weight management etc.) become of a significant importance in order to ensure successful delivery of modules (The Company A internal documentation).

While examining the level of modularization a standard Company's A procedure is to perform a density analysis. In general, higher labor density positively impacts productivity, till it reaches a saturation point. After that, productivity will decline. It is hard to estimate the accurate density as each construction project is unique. The Company A recommends maintaining a minimum of 200 square feet per worker (i.e. 19 square meters per worker) to a maximum of 400 square feet per worker (i.e. 37 square meters per worker), where the optimal density is around 300 square feet per worker (i.e. 28 square meters per worker). This will allow reaching desired productivity which is represented by 50 percent of a direct activity. It needs to be noted that those indications will vary per project size, complexity and contracting strategy. An example of density analysis is further presented in appendix F. (The Company A internal documentation.)

Furthermore, off-site fabrication has been found to increase labor productivity. As an example, productivity off-site increased by 2,32 percent yearly, whereas productivity on site increased by 1,43 percent due to prefabrication and mechanization (Eastman & Sacks, 2008).

CII RT-283 (2012) has identified critical factors affecting modularization and has ranked them as follows, starting with the highest importance: (i) module envelope limitations (i.e. evaluation of transportation possibilities), (ii) alignment on drivers among critical stakeholders, (iii) owner's planning resources and processes, especially front-end planning, (iv) timely design freeze, (v) early completion recognition, (vi) preliminary module definition, (vii) owner-furnished/ long-lead equipment specification, (viii) cost savings recognition, (ix) contractor leadership, (x) contractor experience, (xi) module fabrication capability, (xii) investment in early studies, (xiii) heavy lift, site transport capabilities, (xiv) vendor involvement, (xv) O&M provisions, (xvi) transport infrastructure, (xvii) owner delay avoidance, (xviii) data for optimization, (xix) continuity through project phases, (xx) management of execution risks and (xxi) transport delay avoidance (CII, RT-283, 2012).

Most of the aforementioned factors play a crucial role in the beginning phases of the project (CII, RT-283, 2012). As those factors will affect modularization processes, they may also indirectly affect final productivity on the job site and thus should be taken into consideration during the case study analysis.

### 3.4 Selection criteria for case studies

There will be five projects analyzed in order to disclose what has affected the construction productivity on site and how the productivity was tackled during the construction phase. The main goal of the case studies is to analyze the construction productivity within its specific project context of chosen site strategies and interrelations between external factors affecting productivity in the process industry. The number of business cases is limited to five due to the time constraints of this research study. However, this projects' sample will enable analyzing the in depth complexities during construction phase and allow drawing sufficient conclusions within the specific research area of process facilities from the construction perspective.

In order to create a comparable sample for a further analysis, the criteria below are developed and followed during the selection phase of case studies:

1. As for the type of the evaluated projects, only EPFC process facilities projects will be taken into account. This means that complexities of performed activities on the job site will be similar and thus the construction productivity considerations should be comparable.
2. All examined projects are executed under the Advanced Work Packaging strategy and have a modular component of around 40 percent to 70 percent. Both construction strategies create a specific context of the analyzed case studies.
3. All case studies are conducted analyzing the construction perspective to evaluate main challenges with respect to the construction productivity and what is needed in order to facilitate the onsite execution.
4. Large projects will be taken into account with a scope of around 1 billion euros or more.
5. Projects will be chosen irrespectively of a lump-sum or reimbursable contracting scheme. Despite major differences and impact of those contracting schemes, it is assumed that the onsite productivity considerations should be the same under both contracting schemes.
6. General practice of the Company A in Europe is to subcontract construction work. The researched company is utilizing subcontractors to execute the work on site and provides its own

managers and supervisors to organize the work and oversee the progress. However, projects executed in North America are usually a mix of direct hire construction and subcontracting. The aforementioned aspect will be also considered during the factors' evaluation.

7. As the Company A is delivering projects globally, with work sharing across the offices, all projects are executed within a multicultural and diverse environment. Furthermore, even employees, who are located in certain offices, work on the variety of projects globally. Thus, a cultural background and specific project location will not be a part of this research study consideration.
8. All of the projects chosen for case studies should be either recently finalized or in a completion phase during the undertaken interviews, in order to gather complete information from the onsite experience.

It should also be mentioned that the core value of the Company A is safety. Welfare, well-being of the employees and their safety is a primary consideration during all projects. As an example, lunch facilities are provided with tv screens, green plants, etc. in order to create a conducive and comfortable environment for all workers. There are also several safety bonuses in a form of small gifts or special dinners, which are granted individually or to the whole team, based on the craft safety performance on site. The aforementioned measures are taken to maintain motivated and satisfied personnel. Thus, no recommendations can be made with regard to impact of craft wellbeing on the productivity as it is a stable requirement in the investigated company.

The aforementioned criteria and considerations represent a comparable sample of case studies with regard to the project type, scope, implemented construction strategies and duration of the on-site activities. All projects are executed by the Company A – EPFC provider, under the same procedures and standards.

### **3.5 Selection criteria for interviewees**

Each case study will be analyzed through conducting semi-structured, in depth interviews with construction experts in the Company A. For each case two comprehensive interviews are conducted which amounts to ten interviews in total. The selection criteria for the interviewees are defined as follows:

1. The construction experts chosen for the interviews should have a significant role in the analyzed projects with respect to organizing, leading, supervising or reporting activities on the job site during the construction phase.
2. The construction experts should be involved in the analyzed projects preferably from the beginning in order to understand the initial considerations and then relate it to the factors that have affected the productivity on site.
3. The construction experts should be permanent employees of the Company A with experience of at least five years in construction so it is ensured that they are familiar with specific procedures of the Company A with respect to the productivity considerations. Furthermore, it should be the experience within the process facilities projects of the oil and gas industry.
4. The construction experts come from varied nationalities; mainly from North America, the UK and The Netherlands offices of the Company A. They are all engaged in different projects around the world and hence all have a global perspective.
5. All of the experts apart from construction expertise will be further specialized within certain construction areas, for example modularization, advanced work packaging or field engineering.

All of those differences will be considered in the evaluation of the interviews in order to avoid their professional bias.

The following construction roles have been identified based on the *Construction Roles and Responsibilities* guidelines in the Company A and are depicted in figure 19 below. Each construction role describes main responsibilities and hierarchy in decision making during the projects.

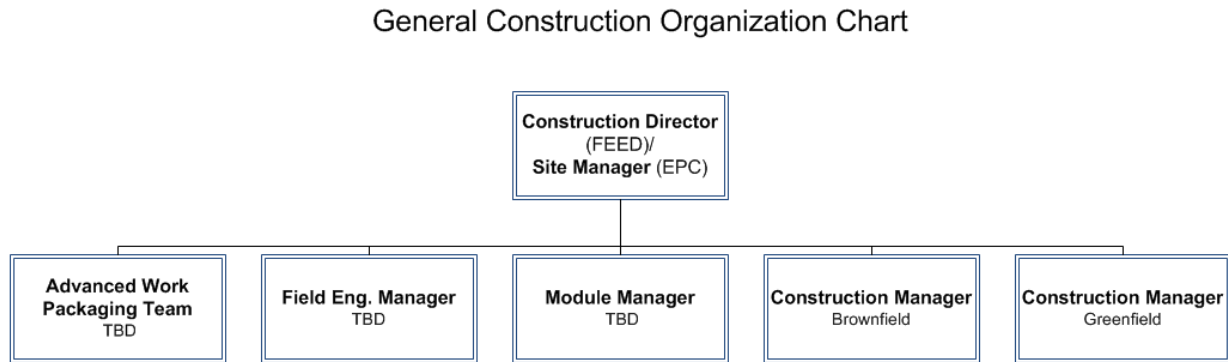


Figure 19 General Construction Organization Chart in the Company A (own figure)

The most important role from construction perspective is held by a Site Manager/Construction Director. However, its description has changed recently, in late 2017, and the new one reinforces the role and responsibility of the Site Manager. As both definitions are presented below, the previous and the latest one, it should be kept in mind that the construction experts during the interviews still base their comments on the previous Site Manager role description. However, this change indicates the recognized need for reinforcing the construction influence. To further explain, the Site Manager is often called a Construction Director as the name for this role depends on the phase of the project. This role is held by the same person, during the FEED phase it is called the Construction Director, however, when the construction commences to the field this role is called the Site Manager.

*Site Manager (previous version)* - (often called a Construction Director) – Reports to the Project Manager (unless a construction-only project) and is responsible for managing and executing construction, fabrication, modularization, turnover, startup, and/or operations and maintenance activities in accordance with the Prime Contract.

*Site Manager' (latest version)* - (often called a Construction Director) – Reports to the Project Manager (unless a construction-only project) and is responsible for managing and executing construction, fabrication, modularization, turnover, startup, and/or operations and maintenance activities in accordance with the Prime Contract. **The Site Manager is entirely responsible for all activities on site. This includes financial responsibility for all construction components such as construction indirects, temporary facilities, site staffing, estimate placement rates, and crew mix wage.**

The remaining roles of construction experts represent the next level and thus report to the Site Manager and are further described as follows:

*Module Manager* - Reports to the Site Manager and is responsible for managing and executing the modularization and fabrication scope of the project.



*Construction Management* - The Construction Management team will plan and organize construction activities with contractors to ensure all work conforms to specifications and drawings and meets the construction milestone dates. Construction Management will also instruct the workforce or contractors to take corrective actions when problems occur during the construction execution. Construction Managers report to the Site Manager and are usually responsible for a certain scope of the project.

*Site/Field Engineering* - The Site/Field Engineering Manager and the site engineering team will resolve technical problems, propose field solutions, liaise with the design engineering team, issue field procedures, ensure quality of the construction meets design and environmental requirements, coordinate deficiency lists and corrective actions and manage all vendor representatives on site. The Site Engineering team will include discipline engineers, document control personnel, and a CAD technician. The Site Engineering Manager reports to the Site Manager.

*Advanced Work Packaging Team* is responsible for the following activities:

*Planning:*

The site Construction Planning group will receive the engineering work packages from Project Document and Data Management (henceforth PDDM) and create Installation Work Packages (henceforth IWP) under the direction of the Workface Planning Manager/Lead. The Construction Packagers will create the IWP in accordance with the procedures and Job Bulletins created by the Construction Planners during FEED and Detailed Design phase. The Construction Packagers will provide the craft the scorecard (i.e. rules of credit). The Construction Packagers will continue to work with engineering to plan and package late engineering changes and Request for Information (henceforth RFI)/Field Change Notification (henceforth FCN) and include within individual IWPs.

*Reporting:*

The site Construction Planning group will receive the scorecard updates daily from the field and will generate a standard set of progress reports. One set of progress reports will go to Construction Management to assist in managing the actual work. Another set of reports will go to site Project Controls to provide overall progress for reporting back to Project Management. Finally, the planning group will provide a standard report to the schedulers to update the level 4 schedule.

*Scheduling:*

The site planning group will provide the construction schedulers a standard report in order to update the Level 4 schedule. The level 4 schedule is regularly updated (weekly) and published to provide certainty for mechanically completion.

*Construction Quality:*

The Quality Manager will develop and issue a project specific construction Quality Manual that contractors will use to prepare quality plans for their scopes of work. The quality program will be aligned with commissioning procedures.

However, it should be mentioned that the construction experts on the investigated projects had usually more than one role. For example Construction Manager was also a Deputy Safety Manager at the same time. Furthermore, despite the certain title on the project, experts' responsibilities were cross-functional within the aforementioned construction roles.

The diversity of the interviewees' background and construction specializations will give a reliable sample for analysis that will not be biased by any specific construction expertise. Furthermore, the anonymity of the interviewees will be ensured.

### **3.6 Interview questions and analysis**

Information gathered during the theory development and initial analysis of the project specific context within the Company A form basis for the interview questions which are presented in appendix G.

Before the case study interviews, presentations, plot layouts and other available materials on the studied projects will be analyzed in order to understand the project specific considerations. The Company A will provide productivity measurements on the investigated projects and will make available any procedures and regulations related to the onsite execution forms.

In pursuance of conducting fruitful interviews, several guidelines will be followed. The semi-structured approach was chosen to conduct interviews, where the context of the answers is expected to play a crucial role. Thus, interview questions will have an open character, letting the interviewees explain the complex nature of the researched items (Trull, 1964).

There are two interview sessions planned for each expert: first one, to conduct the actual interview, and a second one to confirm the outcomes. The time allocated for the first interview is 90 minutes and the time allocated for the follow up session is 30 minutes. Furthermore, all interviewees will receive interview questions with supplementary definitions a week prior to the interview. Also, a brief description of the research study and goals will be provided beforehand. Possible drawbacks of the interview sessions lie in the sample set; two interviews per case study and five case studies in total. However, the latter sample constraint results from the time allocated to execute this research study.

Gathered feedback from the interviews with experts will set a basis for the pattern matching analysis followed by the cross-case analysis. The latter will be further verified by an extensive discussion with the Global Productivity Lead in the Company A and executive construction representatives.

## **4 Case study analysis**

Case study analysis will comprise of the summary of each case study, cross case analysis, validation of propositions and reflection. Detail description of the case studies is presented in appendix H.

### **4.1 Summaries of case studies**

Summaries of case studies are focused on the main findings with respect to construction productivity. Only main roles of the interviewees are mentioned in those summaries. For the detail description of responsibilities of interviewees and specific challenges during the investigated projects refer to the appendix H.

4.1.1 Case Study A

Table 6 Case Study A – Summary (own table)

<b>Case Study A - Summary</b>	
<p><i>Project Details:</i> Process Facilities of around 2bln \$ in North America. <i>Contracting:</i> reimbursable, mix of subcontracting and direct hire. <i>Construction Strategies:</i> AWP, 60-70% Modular (3rd generation), 30% Stick Built. <i>Interviewees:</i> Senior Construction Director and Deputy Construction Engineering Manager.</p>	
1	<p><b>Construction Productivity definitions and measurements:</b></p> <ul style="list-style-type: none"> <li>» Quantities per work hours (where work hours are related to costs).</li> <li>» Experts not fully agreed with % split for piping activities during progress reporting.</li> <li>» Construction metrics chosen based on the managers' preferences.</li> <li>» Inconsistencies in progress reporting for different units.</li> <li>» Suggested to report progress against estimates, not always followed.</li> <li>» Productivity will be as good as the initial estimates.</li> </ul>
2	<p><b>Advanced Work Packaging:</b></p> <ul style="list-style-type: none"> <li>» Profound impact on labor productivity (time-on-tool performance 15% higher than the Company's A benchmark).</li> <li>» Experts recommended to start AWP early in the engineering phase and to set up a proper breakdown structure supporting construction.</li> </ul>
3	<p><b>Modularization:</b></p> <ul style="list-style-type: none"> <li>» Reduction of bulks of papers needed to support AWP (recommended standardizing documents).</li> <li>» Increased efficiency, safety and certainty of outcomes. Dependent on proper logistics.</li> <li>» Modules prematurely shipped due to unseasonable weather and road conditions.</li> <li>» Main driver for modules cost effectiveness.</li> </ul>
4	<p><b>Labor Related Factors:</b></p> <ul style="list-style-type: none"> <li>» 3 shorter breaks were reduced to 2 longer breaks in order to reduce workers walking time.</li> <li>» Night shift introduced to accelerate part of the scope to meet the schedule.</li> <li>» Relocation of temporary facilities due to the operating facility nearby. It caused additional time wasted on walking from the temporary facilities to the jobsite location.</li> <li>» More than 10 working hours a day was not considered effective anymore.</li> <li>» Client provided internal and external bussing to avoid traffic conditions.</li> </ul>
5	<p><b>Industry Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Much higher productivity on direct hire scope of work.</li> <li>» Issues with multiple layers of subcontractors, congestion on the jobsite due to multiple subcontractors, some subcontractors are dictated by the client. The Company A needs to rely on the progress reported by subcontractors.</li> <li>» Much lower productivity on one facility due to complexities of performed activities. This facility was also not initially the Company's A scope and was transferred by the client at a later notice.</li> </ul>
6	<p><b>Management Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Management team influencing productivity, driving projects based on procurement and engineering needs. However, changes in engineering will have a massive impact on construction.</li> <li>» Experts recommended that Construction Director should be equal to Project Director during decision making in construction phase. More focus on red flags raised by construction.</li> <li>» Client dictated systems schedule causing disruptions to construction work fronts. Importance of prioritized activities.</li> </ul>

4.1.2 Case Study B

Table 7 Case Study B – Summary (own table)

<b>Case Study B - Summary</b>	
<p><i>Project Details:</i> Substations, coolers, preassembled racks of around 1 bln € in Europe. <i>Contracting:</i> reimbursable, construction work was subcontracted. <i>Construction Strategies:</i> AWP, 40% Modular, 60% Stick Built. <i>Interviewees:</i> Construction Area Manager and Piping Supervisor.</p>	
1	<p>Construction Productivity definitions and measurements:</p> <ul style="list-style-type: none"> <li>» Quantities per work hours. Tracking budgeted against actual and earned man-hours.</li> <li>» No available standards on the most suitable metrics for progress reporting. Multiple ways of presenting progress, usually decided by managers.</li> <li>» After sending progress to project controls, construction has no input on how the overall progress is presented.</li> <li>» Time-on-tools performance successful for majority of subcontractors besides one local subcontractor.</li> </ul>
2	<p>Advanced Work Packaging:</p> <ul style="list-style-type: none"> <li>» Benefits to work planning, increasing productivity, maintaining control over cost and schedule.</li> <li>» Challenge in starting in FEED and convincing clients and engineers over this construction strategy.</li> <li>» Engineers are not used to work to a level of detail needed by AWP.</li> <li>» Packages should be prioritized and aligned with construction sequence.</li> </ul>
3	<p>Modularization:</p> <ul style="list-style-type: none"> <li>» Increased productivity by decreased densities on site.</li> <li>» Little damage to modules during shipping, no major changes while incorporating modules on site.</li> <li>» Estimates do not cover additional man-hours needed to incorporate modules on site.</li> </ul>
4	<p>Labor Related Factors:</p> <ul style="list-style-type: none"> <li>» Due to construction nature, it is more realistic to work around 50 hours per week.</li> <li>» Night shift: introduced to meet the schedule (helped in planning activities for the following day) and avoid high densities.</li> <li>» Overtime should be introduced only when deemed necessary. Negative impact of prolonged overtime.</li> <li>» People as the most valuable asset of the Company A.</li> <li>» Laydown area located away from the site due to space constraints.</li> <li>» Temporary facilities away from the jobsite due to operating facilities. Increased walking time resolved by providing small resting containers on the job site.</li> </ul>
5	<p>Industry Related Factors:</p> <ul style="list-style-type: none"> <li>» Subcontractors were underreporting their progress. The Company A was performing random spot checks to evaluate subcontractors' work.</li> <li>» Subcontractors mobilized from abroad were more productive than local craft (being away from home facilitated work focus).</li> <li>» Engineering team was not finished before construction started. Construction not incorporated enough to engineering discipline.</li> </ul>
6	<p>Management Related Factors:</p> <ul style="list-style-type: none"> <li>» Client requested late change of a sewage system. This change was not fully factored in to initially planned work.</li> <li>» Client was driving majority of execution decisions. Construction should be involved in a bidding phase.</li> </ul>

4.1.3 Case Study C

Table 8 Case Study C – Summary (own table)

<b>Case Study C - Summary</b>	
<p><i>Project Details:</i> Boiler units, tank farms, control building, cooling towers, interconnecting pipe racks of around 1 bln \$ in North America. <i>Contracting:</i> reimbursable, fully subcontracted. <i>Construction Strategies:</i> AWP, 60% Modular, 40% Stick Built. <i>Interviewees:</i> Construction Area Manager and Construction Manager.</p>	
1	<p><b>Construction Productivity definitions and measurements:</b></p> <ul style="list-style-type: none"> <li>» Quantities per work hours. Tracking earned and actual man-hours.</li> <li>» Specific standards used for construction metrics (steel types, weld numbers, work at elevation, etc.).</li> <li>» Client influenced % for activity split per construction discipline. Client's unit rates were used.</li> <li>» Issues with change management. Quantities not correctly loaded to utilized tools. Recommended to check more frequently situation in the field to what is loaded in tools.</li> </ul>
2	<p><b>Advanced Work Packaging:</b></p> <ul style="list-style-type: none"> <li>» Benefits to work planning and sequencing, increasing productivity.</li> <li>» Not implemented from the beginning of the project.</li> <li>» Closely cooperated with subcontractors.</li> </ul>
3	<p><b>Modularization:</b></p> <ul style="list-style-type: none"> <li>» Firstly 3rd generation modules planned with full modular pipe racks. Later Senior level management wanted to reduce a modular component and massively change construction strategy.</li> </ul>
4	<p><b>Labor Related Factors:</b></p> <ul style="list-style-type: none"> <li>» The highest productivity on 10 hours work day.</li> <li>» Night shift introduced to reduce congestion in one unit. Specific construction activities like X-ray benefit from a night shift.</li> <li>» Overtime introduced to recover damages due to hurricanes.</li> <li>» Site attributes were effectively considered and good temporary facilities set up was done.</li> <li>» Issues with sequencing of materials (3rd party's scope). Company A took over materials' responsibility. Issues with materials were attributed to wide variety in types and sizes of materials, exemplifying standardization needs.</li> </ul>
5	<p><b>Industry Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Difficulties in convincing clients over standardization of materials.</li> <li>» Progress reported by subcontractors. Crucial aspect in loading utilized tools with the right data.</li> <li>» Construction started with not complete design (client's decision based on lack of engineering hours).</li> <li>» Experts highlighted importance of design standardization.</li> </ul>
6	<p><b>Management Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Importance of construction influence in home office.</li> <li>» Communication styles between younger and older generation.</li> <li>» Client seized investments in AWP. The strategy was brought back however causing difficulties with convincing subcontractors to a different strategy.</li> <li>» After contacting 3rd party, client wanted to significantly reduce a modular component despite the 3rd generation modules planned initially (decision based on costs). After the in depth explanations from the Company A, modules were reintroduced, however not to a full extend, as initially planned.</li> </ul>

4.1.4 Case Study D

Table 9 Case Study D – Summary (own table)

<b>Case Study D - Summary</b>	
<p><i>Project Details:</i> Multiple process units, utilities and infrastructure of around 2 bln \$ in Middle East. Joint venture. <i>Contracting:</i> lump sum, fully subcontracted. <i>Construction Strategies:</i> AWP, 60% Modular, 40% Stick Built. <i>Interviewees:</i> Modular Manager and Project Manager for temporary facilities.</p>	
1	<p><b>Construction Productivity definitions and measurements:</b></p> <ul style="list-style-type: none"> <li>» Quantities per man set against estimated values.</li> <li>» Activity split per discipline, activities performed with and against gravity.</li> <li>» Complex construction metrics, inconsistencies in their usage.</li> <li>» Multiple existing standards on productivity but not in a centralized and standardized form.</li> <li>» Available tools are not suitable for all construction activities.</li> <li>» Construction is not fully integrated with other departments, for example from cost perspective. Construction progress should be set against expenditure at least on a monthly basis.</li> <li>» Focus on activities that consume the greatest scope, starting with piping discipline.</li> <li>» AWP not fully implemented.</li> </ul>
2	<p><b>Advanced Work Packaging:</b></p> <ul style="list-style-type: none"> <li>» IWP with limited coverage on materials. Not all elements on isometrics were available for workers. Availability of right drawings and materials as a predominant factor affecting productivity.</li> </ul>
3	<p><b>Modularization:</b></p> <ul style="list-style-type: none"> <li>» Project D was initially designed as fully stick built project, and was later changed to a partially modular project. Strategic and technical directions did not fully match.</li> <li>» Modular component shifts engineering and procurement to finish their deliverables earlier.</li> <li>» The key is to establish material, labor, fabrication and logistics costs.</li> <li>» Avoid duplication of activities performed in fabrication yards and on site.</li> </ul>
4	<p><b>Labor Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Night shift and overtime introduced to recover schedule delays. More cost effective than penalties for late completion.</li> <li>» Abundant site boundaries allowed for a convenient set up of temporary facilities and man camp, ensuring proper logistics.</li> </ul>
5	<p><b>Industry Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Subcontractors did not planned their work to the level of detail required by AWP.</li> <li>» The Company A needs to rely on information provided by subcontractors.</li> <li>» Experts suggested prioritized delivery of materials to the site.</li> <li>» Standardization of design processes. Less variability in materials and elements.</li> <li>» Importance of cost effective design and commercial awareness of engineers supporting construction.</li> <li>» Difficulties with interfaces between joint venture partners and subcontractors.</li> </ul>
6	<p><b>Management Related Factors:</b></p> <ul style="list-style-type: none"> <li>» Construction acts more as a client in comparison with project managers who drive engineering and procurement deliverables. Experts recommended more integration between disciplines.</li> <li>» Business oriented managers with limited construction experience are not fully able to convince the clients over the right strategies.</li> </ul>

4.1.5 Case Study E

Table 10 Case Study E – Summary (own table)

<b>Case Study E - Summary</b>	
<p><i>Project Details:</i> Process units of around 1 bln \$ in North America. Schedule was extended due to the client's planning change. <i>Contracting:</i> reimbursable, fully subcontracted. <i>Construction Strategies:</i> AWP, 70% Modular, 30% Stick Built. <i>Interviewees:</i> Two Construction Managers.</p>	
1	<p>Construction Productivity definitions and measurements:</p> <ul style="list-style-type: none"> <li>» Input in a form of hours spent in order to deliver certain quantity.</li> <li>» Wide variety in construction activities and ways of assessing them. Different factors per region.</li> <li>» Existing tools for progress reporting are not properly set up.</li> <li>» Construction estimates are not done to enough detail.</li> <li>» Productivity measurements used for cost representation and form basis for choosing most suitable strategy.</li> <li>» AWP immensely helped in maintaining proper material and labor logistics on site.</li> <li>» AWP should be applied early in a FEED phase to utilize its full potential.</li> <li>» Daily meetings and close cooperation with subcontractors while preparing construction work fronts.</li> </ul>
2	<p>Advanced Work Packaging:</p> <ul style="list-style-type: none"> <li>» Modular component enables construction activities to be done under controlled conditions.</li> <li>» Other disciplines need to support this strategy and get involved earlier than during the standard stick built construction.</li> </ul>
3	<p>Modularization:</p> <ul style="list-style-type: none"> <li>» Detail planning enabled good incorporation of modules. Construction works were performed in parallel.</li> <li>» Weekly and daily meetings with procurement helped in aligning material logistics.</li> </ul>
4	<p>Labor Related Factors:</p> <ul style="list-style-type: none"> <li>» Night shift was introduced for 2 subcontractors. The night shift was very beneficial to support construction workflow and benchmarked productivity was reached during night shift.</li> <li>» Good temporary facilities set up, close to the site, convenient parking.</li> <li>» Questionnaires provided to workers to evaluate their satisfaction with temporary facilities set up.</li> </ul>
5	<p>Industry Related Factors:</p> <ul style="list-style-type: none"> <li>» Construction hours are included in initial budget. Based on those budgeted hours construction work is subcontracted.</li> <li>» Confusion with reporting progress between subcontractors and the Company A.</li> <li>» The most devastating thing to productivity is to start construction with not complete engineering. The engineering discipline needs to deliver their deliverables earlier on the modular execution.</li> <li>» Most challenges identified with engineering discipline.</li> </ul>
6	<p>Management Related Factors:</p> <ul style="list-style-type: none"> <li>» Integrated Management Team environment in which in which clients, contractor and subcontractors are jointly making decisions under alliance contract.</li> <li>» Main driver on the project E to ensure high quality input data to create high quality outputs.</li> </ul>



## 4.2 Consistent feedback across case studies

This section represents a consistent feedback given during the case studies, gathered from all the experts. Due to the repetitiveness of given answers it is presented in a separate section in order to avoid repeating the same feedback per each case study.

### *Construction Productivity definitions and measurements*

For all of the case studies, experts have not chosen the productivity measurement as a combination of efficiency and effectiveness measurements. They have expressed their familiarity especially with respect to the efficiency measurement and its connection to the productivity measurement. When it comes to the effectiveness measurement, the goals and estimates were considered during the productivity measurements, however were not reflected using the 'effectiveness' terminology.

### *Safety*

For all of the case studies, experts have expressed that safety is a primary value in the Company A and helped in reaching higher productivity. Every day on the site starts with a tool box meeting to discuss the safety issues that have occurred on the site and raise the safety awareness. If there are no incidents and safety is a strong part of the working culture the productivity rises up.

### **4.3 Cross-case analysis**

The description of each case study gives an overview on the specific challenges that have occurred on site with respect to the construction productivity. Taking into account the context created by the current state of the productivity procedures in the Company A, project specific considerations and the multiple factors affecting productivity, the difficulties and inconsistencies in assessing the construction productivity seem reasonable. The main observation is that the success in evaluating the construction productivity may be considerably linked to the prior understanding of productivity and understanding of construction strategies which further affect the productivity. Thus, the criticality of considered factors will also vary on each project, depending on the project specific context. The matching patterns across all case studies form the basis for deriving conclusions on the factors affecting construction productivity and their relation to the project's context. The matching pattern is considered positive if the same occurrence is found within at least two case studies. Furthermore, patterns which are contradictory but for predictable reasons will be considered as a matching pattern. These patterns are categorized in a comprehensive analysis and contribute to a determination of the final findings. The cross-case analysis is presented in table 11 and is further evaluated in this section.

Table 11 Cross-Case analysis (own table)

Cross-Case Analysis							
Item:		Patterns:	Case A	Case B	Case C	Case D	Case E
1	Productivity definitions and measurements	Construction Productivity is measured by the worked hours needed to install a certain quantity. Materials and equipment are considered separately.	x	x	x	x	x
2		Productivity measurements against the estimates may affect positively or negatively the final productivity measurements.	x	x		x	x
3		Construction Productivity is not considered with the specific usage of efficiency and effectiveness terminology.	x	x	x	x	x
4		Complexities of the construction activities per construction discipline.	x	x	x	x	
5		Inconsistent use of construction metrics within and across the projects.	x	x	x	x	
6		Incorrect data input into utilized construction tools (i.e. software).			x	x	x
7	Labor Related Factors	Overtime and shift work, despite a negative impact on the labor productivity, were found to have multiple benefits, which may override that labor productivity decrease.	x	x	x	x	x
8		Temporary facilities, site attributes and access points despite having a considerable impact on the labor productivity were considered in detail and any constraints were mitigated in the most effective way.	x	x	x	x	x
9	Industry Related Factors	Direct hire construction may facilitate high productivity rates due to direct control over the workforce. Whereas, subcontracting strategy was found to create difficulties in assessing the reliable progress state.	x	x		x	x
10		Design processes, especially under the AWP strategy and Modularization, have high potential of impacting the productivity on site.	x	x	x	x	x
11		Complexities of the projects and specific construction activities have influenced the productivity on site.	x	x	x	x	x
12	Management Related Factors	Construction role during the FEED and EP phase in the management team was found to significantly impact major decision making and have influenced the workflow planning on site.	x		x	x	
13		The client's influence in driving the major decisions without the thorough understanding of construction expertise can determine to a great extent the final construction productivity.	x	x	x	x	
14	Construction Strategies	Advanced Work Packaging strategy has immensely helped in increasing the construction productivity on site.	x	x	x	x	x
15		The modular component has supported the on-site execution by decreasing the on-site densities and by enabling parallel construction works.	x	x	x		x
16		Productivity measurements and main decisions were closely related to costs.	x		x	x	x

1. *Construction Productivity is measured by the worked hours needed to install a certain quantity. Materials and equipment are considered separately.*

In all case studies the construction productivity was measured as the labor productivity, tracking the input in a form of actual worked hours allocated to deliver an output in a form of quantities as described by Park et al. (2005). Furthermore, this measurement corresponds with the efficiency measurement introduced during the literature review by Mandl et al. (2008). For all cases materials and equipment were considered irrespectively of the productivity measurements.

It should also be mentioned that for the case studies B and C, experts further highlighted the importance of tracking burnt man-hours against earned man-hours. The burnt man-hours define the actual worked hours whereas the earned man-hours represent hours that have been gained with respect to delivered quantities. Those measurements depict to some extent measurements presented in the point 2.1.3.3 on earned value concept.

Whether the productivity measurements were presented as a percentage of the total or a ratio of the quantities to the man-hours, it will be only a matter of the final representation of results without changing the baseline considerations.

2. *Productivity measurements against the estimates may affect positively or negatively the final productivity measurements.*

During four out of five case studies in total, experts mentioned that the productivity measurements are further set against the initially estimated values. Those values reflect either estimated man-hours or planned quantities in time. During the Case A experts further suggested that the productivity will be as good as the initial estimate. The latter means that if the values are estimated correctly, the productivity measurements compared with the estimated values, will give an accurate representation of how well the work is being executed on site.

As an example, during the project A, construction works on one facility were found to be much less productive with respect to the works executed at the remaining facilities. The latter slack in the productivity has been blamed on the complexities with regard to the specific construction activities. However, if those complexities would have been taken into account during the estimates, the productivity measurements could have reflected a satisfactory craft performance in the end. Therefore, the productivity measurements which were not reported against the estimated values may have been done so due to the poor quality of the initial estimates. CII RT-252 (2013) also expressed the questionable accuracy of estimates while making comparisons with the actual values. Furthermore, as another example, during the project B estimates did not cover man-hours needed for incorporating modules on site. This means that additional man-hours needed to be spent on site however they were not budgeted in the estimate. During the case E, experts revealed that estimates are not made to enough detail to support construction progress.

3. *Construction Productivity is not considered with the specific usage of efficiency and effectiveness terminology.*

During all of the interviews, experts have not chosen the productivity as the combination of efficiency and effectiveness measurements. According to their perceptions, efficiency measurement was closer related to the productivity than the effectiveness measurement. Despite the terminology and specific meaning given to the efficiency and effectiveness measurements, both were considered to some extent

during the productivity measurements. Firstly, labor productivity was exemplified in the efficiency measurement, whereas comparison against the initial estimates presented in point 2, resembled the effectiveness measurement. As the effectiveness has been defined as output to goal ratio by Pritchard (1995), the aforementioned goal can be reflected in the estimated values. The lesser usage of the effectiveness measurement could be also explained by the difficulty in making the accurate estimates. Those occurring difficulties will be further explained in the following points on construction metrics.

4. *Complexities of the construction activities per construction discipline.*

Case studies A, B, C and D revealed the complexities of varied construction disciplines and several activities that they comprise of. During the case study A, experts expressed difficulty in a proper allocation of percentages among different piping activities. During the case study B, experts revealed importance of a proper percentage allocation between activities completed in the fabrication yards and on site. During the case C experts expressed the importance of factoring steel depending on light, medium and heavy steel, where light steel will require more man-hours due to the additional connections. During the cases C and D, experts also said to consider construction activities depending on whether they are performed with or against the gravity, with a greater factor for the latter activities. Furthermore, during the case D, experts described variety of construction activities for concrete. They also explained the scope of work for different construction disciplines during the process facilities projects, highlighting the highest scope for a piping discipline.

The aforementioned complexities are a result of lacking common standards over the split of activities per discipline for the process facilities projects.

5. *Inconsistent use of construction metrics within and across the projects.*

Case studies A, B, C and D revealed the confusion over the used construction metrics. During the project A, for one facility welds were progressed against the numbers, whereas for the remaining facilities against the weld inches and per a weld type. Also, during the project B, experts expressed that there were no standards available for the preferable metrics. The construction metrics were usually chosen based on the manager's experience and their preference over the available standards. During the case C experts expressed their preference to progress number of welds as differentiation by the weld types was perceived as too much detail work. The experts on the project D also confirmed the inconsistency in the used metrics and expressed complexity over those metrics. However, no specific examples were given with regard to the project D.

Based on the aforementioned considerations, certain questions arise on which metrics are the most suitable for reporting progress and to which level of detail they should be considered. Those questions combined with the inconsistencies described in the preceding points, constitute the need for a standardized construction data. This finding corresponds with the research done by Shehata & El-Gohary (2011) in which he claimed that lack of the productivity standards is the biggest problem of the construction industry, alongside the productivity decline.

6. *Incorrect data input into utilized construction tools (i.e. software).*

Another challenge with construction metrics is resembled in the accuracy of construction data input into the utilized tools. During the project C output quantities were not properly loaded into the utilized tools. During the case D, experts revealed that not all of the construction activities were supported by the available tools. Furthermore, during the project E tools were not properly set up. The aforementioned

examples show that despite construction software can significantly help with productivity measurements it will highly depend on a quality of data input, which should further mirror the actual situation on site.

7. *Prolonged overtime and shift work, despite a negative impact on the labor productivity, were found to have multiple benefits, which may override that labor productivity decrease.*

All of the investigated projects have introduced some form of the overtime or/and an additional work shift. Despite, the literature has revealed multiple proves of adverse effect of prolonged overtime and additional shift on the productivity (CII, 1988), the case studies have shown a different perspective to that matter. For the cases A, D and E, there was introduced overtime in order to recover and stay on the targeted schedule. Expert D1 also explained that the penalties for late completion may override the costs related to overtime and the productivity decrease. Expert C2 also added the overtime was necessary in order to make up for the lack of construction works during the adverse weather conditions. Furthermore, Expert B1 explained that most of the workers are mobilized from abroad for the specific project and thus their main driver is to work hard and earn money. As a result, those workers do not mind working overtime when they are away from their family lives. Additionally, during the project C, night shift helped in reducing the congestion on site. For both projects B and C, night shift helped in preparing construction activities for the next day. Moreover, very specific activities like X-ray were much more beneficial to be executed during the night shift, with the limited exposure to people.

The aforementioned examples show that the overtime and the night shift factors, despite having a negative impact on the productivity may be overridden by the schedule and cost factors. Also, specific construction activities done during the night shift helped in preparing the work fronts for the next day. Overall, properly managed overtime and night shift, for short periods of time may be highly beneficial in supporting the construction deliverables as indicated by (CII, 1988).

8. *Temporary facilities, site attributes and access points despite having a considerable impact on the labor productivity were considered in detail and any constraints were mitigated in the most effective way.*

For all of the analyzed case studies any site constraints were mitigated in the best possible way. During the case A, temporary offices needed to be relocated further from the construction site due to the blast zone created by the operating facility. Furthermore, in order to reduce traffic to the construction site, the client provided busses coming in and out the construction site. Also, during the case B temporary offices were moved away from the site due to the blast zone area. In that case, the Company A provided additional containers for short breaks on the actual construction site, in order to reduce walking time from the site offices to the job site. During the project B due to the space constraints laydown area needed to be allocated away from the site. The latter constraint was however taken into account and proper logistics mitigated any issues that could occur with bringing in materials.

During the cases C, D and E temporary facilities and site attributes were well considered without major challenges reported by the experts. Only during the case C some issues occurred in the laydown area with respect to logistics of materials. However, this disruption was resolved by the company A through taking over responsibilities of a third party which was responsible for maintaining this laydown area.

The project D was developed in the remote location in the Middle East and thus abundant site boundaries were allocated to this project. This freedom of space immensely helped in setting up all the facilities, warehousing and laydown areas in the most effective way.

Moreover, it should be mentioned that during the project E craft received questionnaires in order to evaluate their satisfaction with the temporary facilities set up.

Overall, the lack of major challenges being reported in this category may have multiple explanations. Firstly, existing procedures in the Company A address temporary facilities, site attributes, access roads in a detailed way. Also, those procedures are a mandatory construction deliverable during the FEED phase. Secondly, the scope of the process facilities projects usually exceeds billion euros. This big scope of projects and complexity that comes with it require proper consideration over the logistics of bringing in people, materials and equipment in and out of the construction site. The latter logistic is also highly supported by the AWP application as a baseline construction strategy on all projects. Moreover, the standards set by clients are very high. Based on the aforementioned, proper temporary facilities set up becomes a must for the Company A, not only to satisfy the client's requirements but also to ensure smooth workflow during the execution phase. Lastly, most of the interviewed construction experts are holding managerial positions. As it has been already derived from the literature, main productivity factors from the managerial perspective were identified in the planning activities (Naoum, 2015). Thus, even if a craft worker would identify *waiting for tools* as a productivity factor, from the managerial perspective the same situation could be identified as a *lack of proper workflow planning* factor. In the end, the same situation can be seen from different perspectives depending on the position held by the interviewee during the project.

9. *Direct hire construction may facilitate high productivity rates due to direct control over the workforce. Whereas, subcontracting strategy was found to create difficulties in assessing the reliable progress state.*

The analyzed case studies were either fully subcontracted or a mix of direct hire construction and subcontracting. For the case studies A, B and D, experts reflected certain difficulties with respect to progress reporting while working with the subcontractors. During the case studies A and B experts highlighted that the Company A is relying on the information provided by the subcontractors and that despite the multiple checks, the company A is still aware that the subcontractors may underreport their progress. The concerns with the quality of progress reports submitted by the subcontractors were also expressed in the ECI (2005) study. On the other hand, the direct hire scope of work was easier to manage due to the direct control over the workers. Moreover, the Company's A construction strategies could be fully utilized during the direct hire. The importance of following the Company's A procedures was mirrored in the case D, where subcontractors did not develop their work plan to enough detail to support the AWP strategy.

For the remaining cases C and E no major difficulties while working with subcontractors were recognized.

10. *Design processes, especially under the AWP strategy and Modularization, have high potential of impacting the productivity on site.*

During all of the case studies experts have tackled the importance of design processes. On the projects B, C and E experts have expressed the need for finished detail engineering before construction work can commence. During the case B engineering deliverables came in late to the field whereas during the case C engineering has not finished their deliverables as they run out of hours allocated for them. Expert E1 added that starting construction with not complete engineering design is devastating to the productivity as it becomes much harder to make any changes already in the field. The impact of incomplete

engineering on construction and importance of design processes in productivity was also described in COAA research (COAA, 2009).

Furthermore, both construction strategies, Modularization and Advanced Work Packaging, require the engineering discipline to work in a different manner and strengthen even more the importance of the design processes. The experts on the case studies A and B explained that the AWP strategy requires engineering to work to much more detail than normally and to start creating the packages early in design phase. Those packages need to further support construction packages and construction schedule and sequence. The aforementioned comments align with the literature information, where engineering work packages contain all the information needed to support creation of construction work packages (CII Research Team, 2013a).

Moreover, during the cases C and D interviewees C2 and D1 expressed the importance of standardizing the engineering designs in order to reduce the engineering hours and commence faster with construction. During the project C, foundations and tanks were designed from scratch delaying the final engineering deliverables. However, those designs could have been derived from previous projects. Expert D1 explained that standardization of design will be even more important during the modularization and will highly support the modular component. The standardization through decreasing variability of elements in design facilitates smooth procurement and fabrication processes. The repetitive materials in bulks are much easier to be obtained and will further enable a continuous cooperation with suppliers as those suppliers can anticipate future orders. The aforementioned modular considerations show that even if engineering will slightly overdesign but this design will have standardized components, it will highly facilitate the upcoming procurement, fabrication and construction processes.

Construction work packages, as a part of the AWP strategy, will also benefit from the standardization as during the project D those packages had limited coverage on materials. Despite all the engineering information included in the work package if the materials were not ordered the craft was not able to proceed with work.

However, the difficulties with shifting engineering to finish their designs earlier, standardize designs and thus reduce the engineering time may be exemplified in an engineering payment scheme of being paid by the hour. Thus, the engineers may be reluctant to reduce their working time.

*11. Complexities of the projects and specific construction activities have influenced the productivity on site.*

The cases A and D revealed specific complexities that occurred during those projects. During the case A the differences in complexities of construction activities impacted the final productivity measurements and were not fully factored into the productivity estimates. The example during the case A reflects *technological complexity* described by Bosh-Rekveltdt (2011), which relates to the complexity of scope and content of the project.

During the project D, big scope and a lot of interfaces between joint venture partners and multiple subcontractors created issues with work transfers. The latter complexities reflect *organizational complexity* described by Bosh-Rekveltdt (2011), which relates to the complexities of the project team.



Furthermore, during all case studies, close interrelations between construction and engineering, procurement and project controls disciplines became highly visible. Moreover, the construction strategies were setting direction for the aforementioned disciplines, influencing design and procurement processes. Thus, all disciplines were highly correlated in a project's sequence. The sequence and prioritized schedule were also further mirrored in construction activities. All of the aforementioned interrelations are clear exemplification of complexity described by Dubois and Gadde (2002) as a 'rigid sequence' and 'overlap of construction stages'.

*12. Construction role during the FEED and EP phase in the management team was found to significantly impact major decision making and have influenced the workflow planning on site.*

Limited construction role during initial phases of the projects was especially exemplified in the cases A and D. For both cases experts explained that project managers usually have an engineering background and thus drive the projects based on the engineering needs. However, any overruns in the engineering will have a relative cost for engineering in comparison with the later impact and changes in the construction phase. This considerable impact of any changes in construction is also represented in the high TIC of 40% for construction discipline and only 15% TIC for the engineering discipline (CLMA, 2017).

During the cases A, C and D experts suggested that the construction discipline should be involved in the home office during the design phase and should influence engineering to further support the construction phase. Furthermore, experts suggested that during the construction phase decision making power of a construction director should be equal to a project director's one.

The aforementioned limited construction role during the pre-construction phases does not surprise as it has been presented that the Company A is mainly driven by the engineering discipline. Moreover, the latest changes in the descriptions of roles and responsibilities of Construction Director/Site Manager in the Company A, were elaborated to strengthen the position of the Site Manager and his accountability. The evidence coming out from those case studies and specific issues in design in point 10 strengthen the essential role of construction and the importance of its involvement in the initial phases of the project. This finding corresponds with the research done by Naoum (2015) in which he concluded, that majority of the highest impact factors affecting productivity are still in the pre-construction phases.

*13. The client's influence in driving the major decisions without the thorough understanding of construction expertise can determine to a great extent the final construction productivity.*

Client's expectations and his considerable influence in the major construction decisions have been found to play crucial role during the projects A, B, C and D, greatly impacting the construction phase.

As an example, during the case A the client dictated to prematurely move to systems when the previous, higher priority construction activities were still not complete. Experts on the project A explained that any change and thus rework in the previous not completed activities, would be much more difficult than the changes in the construction activities related to the systems. Thus, it would be much more beneficial to wait and delay the systems activities.

During the project B, the client decided to change the depth of a sewage system to the greater depth which needed to be followed by additional surveys and a lot of underground work. That change caused a lot of disruptions to other construction activities on site and its impact was not fully taken into account.

During the project C major changes were made with respect to the AWP and Modularization strategy due to the client's requests. The project C was reimbursable and the client did not have full conviction over the chosen AWP strategy. Thus, the client has decided to cancel further investments in the AWP still during the FEED phase. Later on due to adverse effect on the project performance the AWP strategy was brought back to the project when construction was already in the field. However, this strategy transfer was very difficult due to the lack of the engineering and procurement data needed to support the AWP strategy breakdown structure and additionally unplanned AWP specialists needed to be urgently mobilized to the site. Also, during the project C the client has resigned from the initially planned third generation modularization due to the costs associated with that strategy. However, all of the design, logistics, temporary facilities, etc. were planned under the full modular strategy. The significant reduction of the modular component to the majority on a stick built portion would force the project to plan everything again from the scratch. In the end, the client, after considering the impact of that change, agreed on increasing the modular component, however still not to its initial considerations.

The impact of changes initiated by the clients is also reflected in previous research studies. Rivas et al. (2011) concluded that 80 percent of rework on site is due to changes made mostly by the clients, followed with design changes and lack of project definition (Rivas, Borcharding, Gonzalez, & Alacron, 2011). Additionally, Hanna (1999) reflected that changes on site with respect to estimated work hours usually result with twice as much work hours for impacted projects (Hanna, Russell, Nordheim, & Bruggink, 1999).

Moreover, during the project B, client has dictated the set-up of temporary facilities with little involvement of the Company's A construction team. In the end, the Company A has set up additional break spots on the site in order to reduce the worker's walking time.

Lastly, expert D1 has further recognized a strong link between working with clients and limited construction role described in the preceding point. Managers should be able to convince the clients over the best construction strategy. Expert C1 explained this should be done based on firm and credible data early on in the FEED phase of the project. Any deviations from set construction direction should be further minimized. Clients should also be aware that the lowest cost for the shortest schedule is usually not possible. The latter is especially exemplified during the case C, where the full modular plan significantly helped in reducing the schedule, however was planned at the cost expense.

*14. Advanced Work Packaging strategy has immensely helped in increasing the construction productivity on site.*

During all of the investigated case studies experts have expressed multiple benefits towards the AWP implementation on the projects. On the project A, time-on-tools performance was found to be 15% higher than the Company's A benchmark due to the AWP application. Expert on the project B expressed that it helped with planning the work flow, increased productivity and helped in maintaining control over the cost and schedule. Experts from the projects C and E added that AWP helped in sequencing the construction activities and opening multiple work fronts, improving the overall logistics on site.

Despite multiple benefits there have been realized certain conditions that need to be met in order to facilitate this strategy. To start with, AWP needs to be applied still in the FEED phase and needs to be supported by other disciplines. Engineering discipline needs to work much earlier to the higher level of detail on the engineering work packages in order to support construction break down structure, schedule and sequence. Construction work packages despite relying heavily on the engineering

deliverables also need to be supported by procurement to ensure that all the right materials will be available at the right times. Furthermore, working with subcontractors will require more effort from the EPC contractor to align subcontractors into the Company's A AWP planning team and plan the work fronts together. On the other hand, direct hire approach will facilitate the AWP application as the contractor can independently organize the work fronts. Based on the experience from the presented case studies, the biggest challenge with AWP strategy lied not only with convincing the engineering discipline over this strategy, but also the client, as described in preceding points on the client's involvement and design processes.

*15. The modular component has supported the on-site execution by decreasing the on-site densities and by enabling parallel construction works.*

During the case studies A, B and E experts expressed that the modularization helped with transferring man hours from the job site to the fabrication yard, where work could be performed under controlled conditions irrespectively of the weather. Also, the off-site fabrication allowed for the parallel civil works on the site, significantly reducing the schedule. During the cases D and E experts explained how modular strategy is affecting other disciplines, where engineering and procurement need to finish faster with their deliverables due to the introduction of the fabrication yard. The main challenge during the cases C and D lied in setting and freezing the modular strategy during decision making process. In order to facilitate modularization, strategic decisions need to be made faster so detail design and procurement can start earlier than during the full stick built construction.

The aforementioned challenges are aligned with the factors affecting modularization identified by CII RT-283 (2012) as follows: alignment on drivers among stakeholders, front-end planning or timely design freeze.

*16. Productivity measurements and main decisions were closely related to costs.*

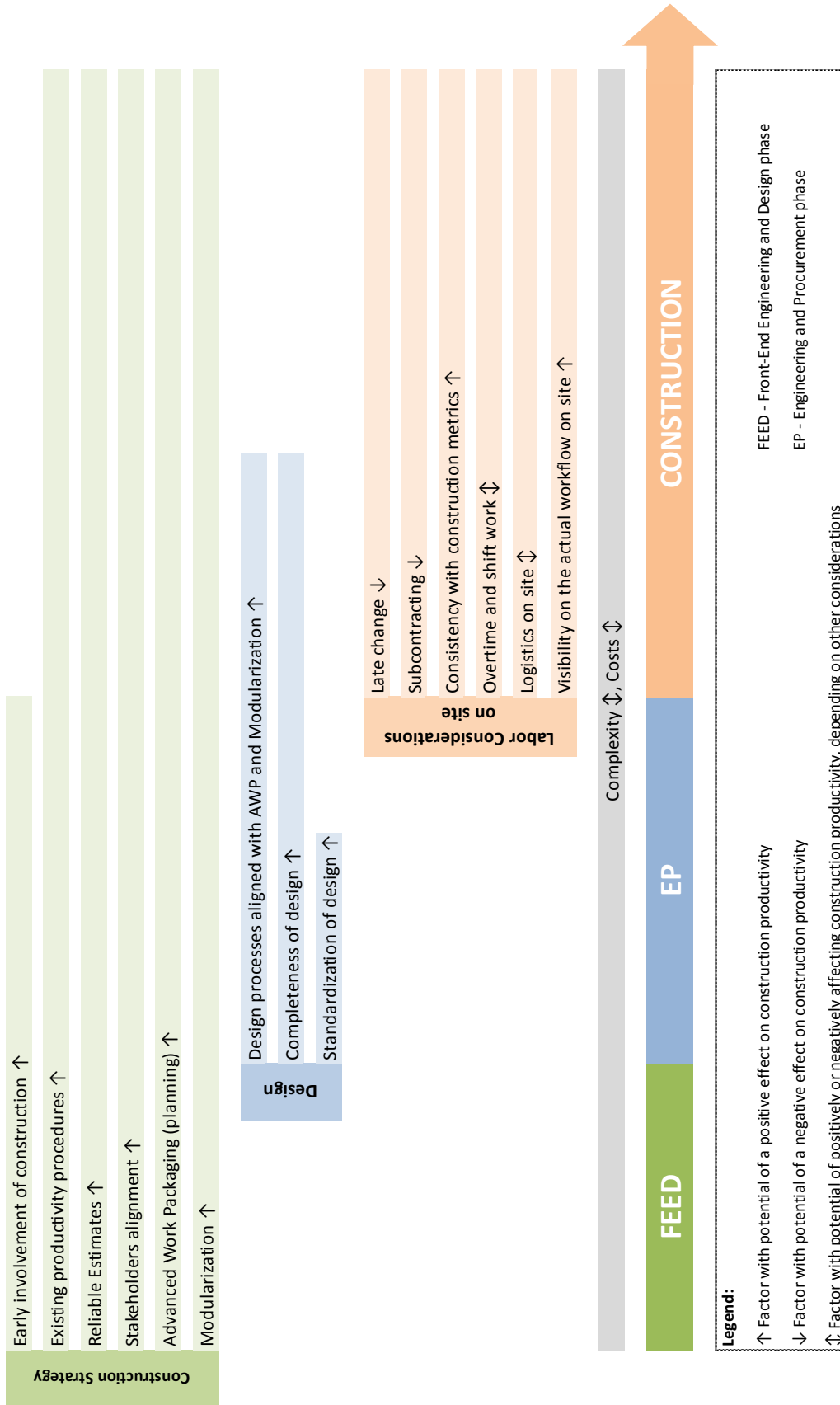
During the investigated projects productivity measurements were further delivered to a Project Controls department and utilized for an overall progress and a cost representation. During the project D experts recommended that the construction progress should be set against the expenditure at least on a monthly basis. Furthermore, the night shift or overtime were frequently chosen to stay on schedule and avoid penalties for late completion. Construction strategies (i.e. modularization and AWP) despite multiple benefits were also preferred due to their cost effectiveness. The main part of deciding over the modular component was to estimate materials, labor, fabrication and logistics cost in order to choose the most effective option. Moreover, frequent comment related to not sufficiently standardized design processes was also related to importance of commercial awareness among engineers. Overall, cost aspect was considered throughout all the project phases and played important role in decision making, impacting further productivity on site.

#### **4.3.1 Factors affecting construction productivity derived from the cross-case analysis**

Based on the matching patterns identified through the cross-case analysis, specific and consistent factors affecting construction productivity can be further derived from the case studies. Moreover, the relevance of those factors varied per different phases of the project. The overall split of factors during the project timeline is depicted in figure 20. Arrows up or down next to each factor indicate the potential of a positive or negative impact of those factors on construction productivity.

Figure 20 Factors affecting construction productivity derived from case studies (own figure)

**FACTORS AFFECTING CONSTRUCTION PRODUCTIVITY DERIVED FROM CASE STUDIES**



### *Factors identified in FEED phase*

Factors affecting construction productivity were already identified in the initial phases of the project during the front-end engineering and design phase (henceforth FEED). Those factors were mostly related to *construction strategies (i.e. Advanced Work Packaging and Modularization)* and *existing productivity methods*. The aforementioned strategies and methods were found highly beneficial towards the construction productivity, however, were not fully applied or followed during the investigated projects. The issues identified with choosing and maintaining the pre-set construction strategies could be rooted in the limited construction role in the Company A during the pre-construction phases. It may be a preconception that construction works start later in the project and thus there is no need for allocating a considerable amount of work hours for construction team from the very beginning. Also, the case studies have shown that project directors and project managers drive the majority of decisions based on the engineering deliverables with limited construction involvement. This finding is further supported by the latest changes in the described responsibilities in the Company A, where the definitions of site manager strengthened its role to drive and be accountable for construction phase. Although this change is very supportive towards increasing the construction role in the field, the case studies have also revealed the importance of involving construction during the early project phases. Therefore, those construction strategies and methods need to be facilitated by *early construction involvement* and *alignment across key stakeholders (i.e. clients, project team and, subcontractors)*. Construction representatives poses the expertise and experience necessary to decide on the most effective execution and to further convince the other stakeholders over those strategies. The crucial importance also lied in the *reliability of the initial estimates* factor which sets a baseline for further comparisons of actual productivity measurements. During the case studies, productivity measurements depended on how well estimates mirrored the actual conditions on site. Moreover, factors related to the construction strategies had a considerable impact throughout the remaining phases of the project as well. All of the aforementioned factors had potential of positively affecting the construction productivity.

### *Factors identified in EP phase*

Furthermore, during the engineering and procurement phase (henceforth EP) a strong focus was given to *design processes*. The applied Advanced Work Packaging strategy is directed at the craft performance to ensure all the needed information, materials and tools are ready for craft at specific times. Although, the AWP strategy undoubtedly helped with increasing the labor productivity on site, it created additional challenges for example with regard to design processes. The design processes under the AWP strategy require higher level of design details and support of construction work packages structure and sequence. The other crucial factor was mirrored in necessity of high percentage of *design complete* before construction commences with works on site. Moreover, both construction strategies (i.e. Modularization and AWP) required a considerable effort from engineering and procurements disciplines to finish their deliverables faster than if those strategies would have not been applied. Furthermore, *standardization* of design was important in order to reduce variability of elements and to further support procurement and fabrication processes. Also, construction activities needed to be facilitated by a timely procurement to ensure that the right materials will be brought to the site or to the fabrications yards at the right times. All of the listed factors during the EP phase had potential of positively impacting productivity on site, if properly considered.

### *Factors identified in Construction phase*

During the construction phase critical factors were found to be associated with *subcontracting* and *late changes to the project*. Both factors had high potential of negatively impacting the construction productivity. The late changes were mainly initiated by clients and reflected changes in the main strategies and scope changes. The other changes were contributed to not complete design and thus rework was needed due to those design changes. The majority of construction works in the Company A was subcontracted, the planning of work packages and logistics of bringing modules on site needed to be closely aligned with the subcontractors. The direct hire construction was more beneficial towards the productivity due to much easier control over the onsite activities and the progress. The subcontractors, on the other hand, maintain their own productivity measurements and Construction Managers of the Company A needed to rely only on what has been reported to them. The Construction Managers, despite performing casual spot checks on the subcontractor's performance, did not have full visibility on the actual workflow and on the reported progress.

Moreover, *site logistics* and *overtime and shift work* factors had a relative impact on the productivity, depending on other considerations. Those factors were in detail considered and resolved by the Company A (i.e. any constraints were mitigated in the best possible way). The overtime and shift work, despite slightly lower productivity, have highly supported construction activities on site and helped in opening the work fronts for the next day. Thus, it could be concluded that those factors contributed to the overall construction productivity. The benefits of night shifts were found in the specific construction activities which were easier to perform at nights. Furthermore, sometimes the overtime was cheaper than the penalties that would be paid for a late delivery. Moreover, most workers, being mobilized from abroad did not mind working overtime.

Finally, the highest potential for improving the construction productivity was found in a *consistent construction metrics for progress reporting* and *enhancing the visibility on the actual workflow* through a proper data input into utilized tools and strategies (e.g. AWP or utilized software). During all of the investigated projects different standards were used for the productivity measurements. Furthermore, the data input into the utilized tools did not reflect the actual situation on site or simply the less preferred metrics were used, further hampering the actual measurements.

### *Cost and Complexity factors*

Case study methodology has increased visibility on a *complexity* factor within the investigated projects. The complexity was especially related to strong interdependencies between project phases, construction strategies and activities. Any change to construction strategy or scope of the project resulted in a chain effect on construction sequence and had a negative impact on final productivity on site. As an example, a switch from an initially planned modular construction to a stick built construction required reconsiderations of the initial designs, onsite logistics and labor markets. If the complex system operates as initially planned it does not create any constraints in the construction execution. However, change of one element creates difficulties for all the interrelated elements.

Furthermore, throughout the investigated projects main decisions were based on the cost effectiveness of those decisions, revealing the importance of a *cost* factor. The cost influence started already while deciding on the construction strategy (e.g. modularization component reduces labor, materials and equipment costs) and during the estimating processes. The cost factor was sometimes overriding the other productivity factors (i.e. overtime and night shift factors to avoid further penalties for late

completion). Frequently, clients were reducing the modular component or were resigning from the AWP strategy due to the cost associated with those strategies.

As the complexity and cost factors can become visible throughout all phases of the projects those factors are not indicated within a specific phase of the project. Furthermore, those factors are closely related to and underlie the remaining factors. Their impact on the construction productivity is relative. Complexity only becomes an issue due to the certain changes. Furthermore, cost reduction can have a positive impact on productivity, for example due to the modular solution. However, introducing overtime to avoid penalties for late completion (i.e. cost reduction) will result in a negative impact on the productivity.

#### 4.3.2 Key points

Based on the cross-case analysis and factors identified, three interdependent areas which affect the construction productivity are formed as follows: (i) initial construction strategy, (ii) design and (iii) labor considerations on site.

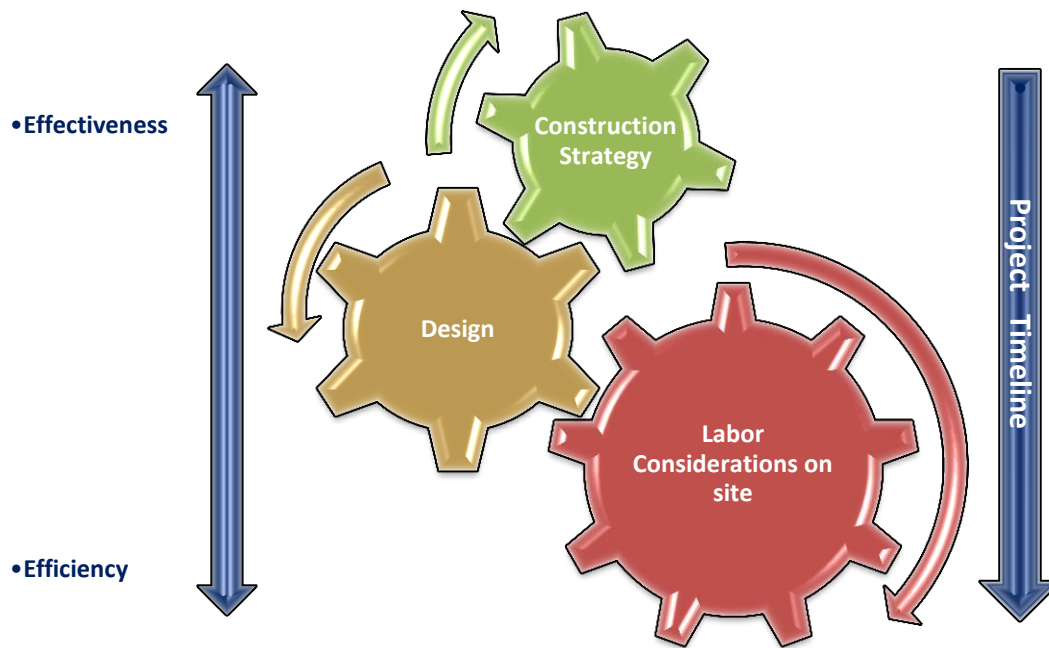


Figure 21 Areas affecting construction productivity (own figure)

To start with, construction strategy is defined early in the FEED by a construction team. During that time the main decisions are made over the extent of a modular component and whether to apply Advanced Work Packaging strategy, depending on the project's drivers. Conviction towards the chosen strategy is necessary from both sides: the client and contractors. During the investigated projects the alignment over the main strategy was missing. Furthermore, main goals are set providing initial estimates related to construction activities, needed quantities, man-hours and thus the overall productivity estimations. The latter considerations related to the project's goals are mostly exemplified in the effectiveness measurement which addresses the output to goals ratio. Still during the FEED phase, based on the chosen construction strategy, temporary facilities, site attributes, logistics and other factors related to



the on-site execution are considered accordingly. The construction team is well acquainted with those procedures and considers in detail the labor related factors.

However, setting up the construction strategy will take relatively the least amount of effort and time it will set a concrete direction for engineering and procurement disciplines. The chosen construction strategy will have an impact on all the following phases due to the interdependence of disciplines and activities. Thus, any changes to the main construction strategy have big potential of affecting construction productivity on site due to a knock-on effect on the following phases. Under the clear construction strategy engineering can start working in a timely manner on the design which will support construction phase later on.

Finally, under a consistent construction strategy supported by the engineering and procurement disciplines, the construction can commence with activities in the field. In the field, work should be coordinated with the subcontractors on a weekly or daily basis, depending on the planned construction activities. The effective sequence of construction activities and craft workflow is ensured by the AWP strategy and AWP onsite planning team. During the construction works the main focus is placed at the efficiency measurement of evaluating delivered quantities and spent man-hours. Those efforts directed at output and input measurements in the field will take the highest amount of time in comparison with the previous stages. Depending on the quality of initially made estimates the productivity measurements including the estimated values, may not always be an accurate representation of the actual productivity results. However, the focus should always be directed at increasing the direct activity irrespectively of the estimated values.

#### **4.4 Validation of propositions and quality of research design**

The propositions introduced based on the literature review are hereby verified with the findings from the analyzed case studies.

*Proposition 1: There are multiple ways of defining construction productivity presented in the academic research. This confusion over the construction productivity definitions is expected to be mirrored in the analyzed case studies.*

The analyzed case studies have shown that the construction productivity is mostly assessed as the labor productivity. For the labor productivity, mainly the efficiency measurement is tracked based on the input man-hours and output quantities. Sometimes the latter figures are set against the estimated values, however, it was done just on some of the investigated case studies. The construction productivity as a combination of efficiency and effectiveness measurement was not chosen by the interviewed experts, even though the actual productivity measurements were reflecting the efficiency and effectiveness measurements. Despite the familiarity of all experts with the efficiency and effectiveness measurements, this terminology was not specifically used while measuring the productivity.

*Proposition 2: There is also no clear standard over measuring the construction productivity in academic research. Due to the aforementioned, inconsistencies with chosen construction metrics and productivity measurements are expected with regard to progress reporting during the construction phase.*

The investigated case studies have revealed and confirmed the complexities of construction metrics. On different projects, varied standards were used for the construction productivity measurements. Mostly, they were decided by the Construction Managers and were followed accordingly. It has occurred that

even during the same project the quantities were reported in different metrics. The interviewed experts were also not aligned on the level of detail that should be reported during the construction phase.

*Proposition 3: The academic research has aimed at identifying critical factors affecting the construction productivity. Despite number of research papers, there is wide variety with respect to importance of those factors over the productivity. Thus, it is suggested that criticality of factors will highly depend on the project specific considerations and the project context.*

The analyzed case studies have been embedded in a specific project's context. This context was mainly created by the applied Advanced Work Packaging strategy and the Modularization component in chosen case studies. Both strategies have impacted not only the construction considerations but also other disciplines related to the construction discipline. Furthermore, the initial productivity considerations in the Company's A procedures revealed the current state of productivity understanding and were a starting point for the productivity evaluation. Also, the existing construction checklists have considered majority of the labor related factors and needed to be completed by a construction team as a mandatory deliverable. The aforementioned considerations were reflected in the final evaluation of the construction productivity.

*Proposition 4: Construction is the final phase of the project, when all preceding efforts come into place to construct a process facility. Therefore it is suggested that initial Construction Strategy aligned with the Client's objectives will have a significant impact on the final productivity on-site.*

The case studies have shown multiple examples in which clients influenced major strategy changes during the projects. Those changes were not only made towards the initially chosen construction strategy but also to the scope of the projects. Those changes caused massive disruption to the initially planned logistics, construction activities, sequence of work, etc. and were not fully factored to the overall impact on remaining construction activities.

#### *Additional comments from executives in the Company A*

The presented findings have been addressed by the Global Productivity Lead and two other construction executives in the Company A, providing further comments to the validation of the presented propositions.

The Global Productivity Lead has reflected on the accuracy of the construction estimates. He explained that the most credible productivity measurement is time-on-tools performance. Following the time-on-tools measurement, increasing the direct activity will give the best indication for increasing the labor productivity, as estimates may not always be reliable. Furthermore, he agreed on the need for standardizing construction metrics across the projects in order to enable better comparisons.

Moreover, the executives highlighted that it is difficult to obtain productivity data from subcontractors, especially when the contracting scheme is based on a unit rate. On the unit rate basis, there is no full visibility on a ratio of direct and indirect man-hours comprised for the work complete. They further suggested ensuring through contracting the way in which productivity measurements will be obtained from the subcontractors.

Furthermore, attention was given to lack of major challenges with respect to the labor related factors. The executives confirmed that the chosen sample of the projects had indeed a relatively convenient site

layout and a good temporary facilities plan. However, they confirmed it is not a standard on all projects and that sometimes site attributes can have a huge bearing on the productivity performance.

The executives have also reflected on the survey methodology used for identifying the factors affecting productivity in the literature. They explained that due to confidentiality of the analyzed productivity data, most companies will not facilitate in depth case study researches. In order to perform the latter, companies turn to the Independent Project Analysis (IPA) company to privately run the in depth analysis. Furthermore, the IPA benchmarks the productivity data in a confidential way.

## 5 Conclusions and Recommendations

### 5.1 Discussion and Conclusion

This research study has investigated the construction productivity performance in the process industry. It has been done by extensive literature review on the critical factors that are affecting productivity on site and on the construction productivity itself. Furthermore, the theoretical framework based on the literature review was tested against the findings from the case studies. The main research question *What are the critical factors affecting construction productivity from a site execution perspective in the process industry?* has been thoroughly answered in both phases of the research study, indicating additional areas of concern.

The answers to the following **sub-research questions** enabled creating a comprehensive answer to the main research question. The sub-research questions are answered, comparing simultaneously the findings from the literature and the case studies.

- *What is construction productivity?*

Both in the literature and from the case studies the Construction Productivity was actually referred to as the Construction Labor Productivity and thus the main focus was on the craft performance. The main question in the literature was whether to consider efficiency and effectiveness measurements or just the efficiency measurement with respect to the productivity. The findings from the case studies spark slightly different question, on whether it is fully feasible to consider both of those measurements due to the difficulties with making fully accurate estimates.

- *What are the ways of measuring construction productivity?*

The main finding resulting from the case studies is the inconsistent use of construction metrics within and across the projects and nonstandard productivity measurements. Multiple construction disciplines require different construction metrics which further need to be factored depending on the working region, construction activity type, complexity, works at grade or at height, etc. The case studies have shown that during each project different standards have been used to assess the productivity measurements. Also, the main focus was on the efficiency measurement, tracking output quantities and input man-hours. The effectiveness measurement of output to goals ratio was not assessed specifically, however, for some reports the productivity was set against the estimates. Taking into account the complexity of construction metrics it does not surprise that those initial estimates which are made early, when some information can be still missing, may not reflect the accurate nature of the construction activities later in the field.

This variety in ways of measuring productivity does not imply that any of them is better than the other. However, in order to make comparisons within and across the projects, the consistency in used productivity data is required. Moreover, taking into consideration the complexity in evaluating the productivity data it becomes questionable whether the reported productivity trends in the literature across the construction sector are indeed accurate.

- *What are the critical factors affecting construction productivity in the literature?*

The critical factors affecting productivity were widely considered in the literature and were tackled mostly through surveys. The latter methodology helped in assessing multiple factors on the numbers of projects. However, due to the large amount of projects and large amount of survey participants, it was impractical to investigate each project taking into account the surrounding contextual situation. Those

surveys were assessed from the craft and managerial perspectives. The critical factors affecting productivity in the literature were categorized into the following groups of factors: Labor (e.g. tools/material availability, congestion, shift work and overtime, changes or weather), Industry (i.e. design processes, project complexity and contracting) and Management (i.e. ineffective planning, scheduling and management skills) related factors in the table 3, based on a comprehensive analysis in the tables 1 and 2.

- *How are industry experts viewing productivity and its factors?*

This research study focused on five projects and investigated the productivity factors based on the in depth case study methodology. The case study methodology shed a light not only on the factors which affected productivity on the projects but also on the interdependencies between those factors and further challenges with respect to assessing and reporting the accurate productivity measurements on site.

The main factors which affected the construction productivity on the investigated case studies have been categorized in three interdependent areas: (i) construction strategy, (ii) design and (iii) labor related considerations. In each category several critical productivity factors were identified also being represented at a certain point in time (i.e. during the FEED, EP and Construction phase of the project). Despite that the majority of interview questions focused on the labor related factors, the main challenges were reported with regard to the inconsistencies in construction strategies, measurements and during the design processes.

During the FEED phase the critical factors were identified in setting up the main construction strategy (i.e. AWP and Modularization) and ensuring alignment over those strategies from all relevant stakeholders. Also, the understanding over the existing productivity procedures was found to positively impact the productivity, depending further on its mandatory or optional nature. Moreover, during the FEED phase first estimates will be established guiding baseline considerations for progress reporting in the field. The aforementioned factors needed to be further facilitated by early involvement of construction discipline.

During the EP phase of the project, design processes factor has been found crucial especially under the chosen AWP and modularization strategies. Both construction strategies were found to facilitate the productivity on site, however, the engineering and procurement disciplines needed to start and finish their deliverables earlier, also supporting those strategies in a different manner. The criticality of complete designs before construction works had huge bearing on the final productivity on site. The last factor related to the design processes, standardization of designs, was found to positively impact the final productivity on site.

During the Construction phase the main factors negatively impacting the productivity were identified in inconsistent construction metrics and progress reporting, lack of visibility on the actual workflow, changes to the project and while working with subcontractors. Overtime and shift work factors were found to be highly beneficial to the overall construction productivity, if properly managed. The logistics factor despite having a huge bearing on the productivity was mitigated in the best possible way.

Overall, the investigated process facilities projects with a scope exceeding one billion were found complex due to the multiple subcontractors involved, interdependencies between construction activities, different disciplines and project phases. Furthermore, all the aforementioned factors were further resembled in the cost effectiveness factor.

- *To which extent do critical factors in the literature match with the factors identified from the examined projects?*

The factors identified in the literature are definitely exemplified in the analyzed case studies, as depicted during the cross-case analysis (i.e. multiple factors identified in the literature were mirrored during the case studies). However, the case study approach resulted in much more visible interdependencies between the analyzed factors.

The context of the investigated projects has been found to play a crucial role in the construction productivity assessment. Especially, the initial understanding of the productivity and ways of evaluating it set a starting point for identification of factors affecting productivity. Also, specific construction strategies applied by the Company A further create the context in which productivity is being assessed. Those strategies set a direction not only on how the construction works will be executed in the field but also affect other disciplines in a major way. Overall, the construction strategies despite multiple benefits to the field productivity need to be firstly aligned with the client, engineering and procurement disciplines and subcontractors, to exploit their full potential on site.

The case studies have shown the importance of criticality of factors at different project stages (i.e. FEED, EP and Construction phase of the project) exemplified by three interdependent areas with factors depicted in the figures 20 and 21. Early construction involvement and alignment across stakeholders were found to be crucial in facilitating the productivity on site early on. Further alignment of engineering and procurement disciplines with the chosen strategy will facilitate the construction works in the field. Finally, when the aforementioned conditions are met the planned construction works under the AWP planning team, can be smoothly executed on site with close cooperation with subcontractors. Thus, the effectiveness measurement of doing the right things not only drives the project's strategy and logistics on site but also ensures high efficiency during the onsite execution.

## **5.2 Reflection**

Case study methodology was found very successful in identifying critical factors affecting construction productivity by painting a picture with all interrelations between the identified factors. The latter helped in understanding productivity and will enable drawing a comprehensive solution to the complex problem of the construction productivity. The favor over a survey methodology in the previous researches was most likely attributed to a possibility of analyzing large amount projects in a timely manner. Also, the confidentiality and sensitivity of productivity data during construction projects may hamper the adoption of a detail case study methodology. Nevertheless, the case studies reflected multiple productivity factors described in the literature and gave further understanding to the complex interplay of those factors and the impact on construction productivity caused by combination of majority of them.

The lack of consensus on whether the construction productivity is rising or declining is further strengthened through this research study. Productivity measurements varied not only between different projects but also within the same project but for different work areas. The case studies provided insights into the complexity of construction metrics with respect to variety in assessment of inputs and outputs. Taking those differences into account it would be hard to compare productivity performance across the investigated projects. Furthermore, those comparisons would be even more questionable for historical and recent projects. Thus, due to the inconsistent data it becomes impossible to derive accurately rising or declining productivity trends in the Company A and maybe further in the industry. Moreover, any comparisons should be made between specific construction trades taking into account the details of productivity assessment, contracting strategies and even construction strategies. As an example, the higher productivity performance can be expected on the projects under the AWP strategy. Therefore, the context of the productivity measurements plays a crucial role in the accurate productivity assessments. It could be even concluded that the most important thing is not to identify the productivity trends but to carefully analyze what influences it. The understanding of those mechanisms will result in a confidence over the presented productivity analysis.

The impact of factors on construction productivity largely depends on the context of those projects. The key in rising productivity seems to lie in carrying out a consistent strategy and ensuring undisrupted work flow. Any changes to scope, strategy should be largely avoided as it is difficult to fully factor the consequences of those changes in to interrelated processes. Therefore, despite that productivity comes into focus during the last project phase it needs to be kept in mind from the very beginning during the FEED phase. The link between last phase (i.e. construction) needs and the first phase (i.e. FEED) planning towards meeting the construction needs, seems to be missing during the investigated projects. Thus, planning with the end (i.e. construction) in mind would definitely improve final productivity performance.

Lastly, the poor performance of projects in the oil and gas industry could be partially explained by the factors identified through this research study. The poor construction productivity definitely largely contributes to the cost overruns and schedule delays. Thus, any efforts directed at the construction productivity improvements will be highly beneficial to accomplishing the overall project goals.

## 5.3 Recommendations

Recommendations presented in this section are developed for the Company A, however, will also be applicable to other companies in the same construction sector. Other EPC contractors in the oil and gas industry, especially under the similar project set up of utilized construction strategies, will have the highest opportunity to benefit from the findings and recommendations of this research study. Furthermore, due to the specific context of investigated case studies, certain limitations will be drawn accordingly. In the end, combining the literature review and findings from the analyzed cases, recommendations for further research will be presented.

### 5.3.1 Recommendations to the Company A

Recommendations to the Company A are divided into two categories: short term recommendations, focused on the immediate application and long term recommendations which will require a considerable effort and time in their implementation. Both, short and long term recommendations will create a comprehensive set of proposed solutions.

#### 5.3.1.1 Short term recommendations

##### *Productivity measurements as mandatory procedures*

The most important recommendation is to include productivity measurements in the procedures as a mandatory construction deliverable. At this point, those measurements should focus on the craft performance by maintaining an overview on the actual work hours and delivered quantities. Before the construction works commences, the construction managers should decide on the used metrics for different construction disciplines and align them across the project. The main focus is advised to be placed at quantities as this will be the most reliable measurement. When it comes to the actual work hours, several geographical, labor related factors will be applied, making comparisons of hours more complicated. Also, decisions over the activity split comprised for the direct work hours will require significant efforts.

As Advanced Work Packaging is a baseline strategy for the Company A, it is suggested to align the construction metrics already during the work breakdown structure creation. Installation work packages under the AWP strategy contain all the information (i.e. start and finish date, work hours and description of work) needed to report construction progress. Thus, the aligned construction metrics should be already introduced during the creation of Engineering and Construction Work Packages. In the end, the IWPs can serve as a progress reporting document.

Moreover, the productivity measurements should be a part of a progress reporting and should be delivered to the project controls department in a consistent way to enable further comparisons. Those construction metrics and consistent construction reporting should be also aligned and agreed with the client and with the subcontractors.

##### *Enhanced collaboration between engineering and construction*

The special attention should be given to collaboration of construction and engineering disciplines. It is suggested to introduce a rotational scheme for construction members to work closely in the home office with engineering, and for engineers to work closely with construction discipline in the field. This way both disciplines will get to know each other's needs and will be more able to support one another. Ideally, this close cooperation will facilitate early design and timely completion further supporting the construction work packages and the modular component. In order to further facilitate the productivity



on site, engineering deliverables and especially the engineering work packages under the AWP strategy, should be aligned with the construction schedule and support the construction prioritized deliverables.

#### *Enhancing the construction role in the Company A during the pre-construction phases*

The construction productivity will definitely benefit from enhancing the construction role within the company during the pre-construction phases. All the initial considerations should be done with the end, that is, construction phase, in mind. Construction team should also have a proactive attitude in communicating their needs and aligning those needs with the client and other disciplines. During the initial phases of the projects it becomes essential to determine the best, fit for purpose construction strategy, considering the level of modularization and the level of Advanced Work Packaging. Each discipline and especially the client need to be familiarized with how the construction strategies work and what their implications on the other disciplines are. Those initial considerations should involve project managers, construction experts on AWP and modularization, engineering and procurement representatives in order to align the main parties on the most desirable construction path. Setting up and preserving a good understanding of construction needs and what is needed to support the chosen strategies can be a powerful safeguard for the future cooperation during the remaining phases of the project and will definitely facilitate the final productivity on site. Furthermore, construction representatives should be involved in creating the initial estimates which will reflect more accurately the actual situation in the field.

#### *Restricted use of overtime*

As the occurring issues regarding the temporary facilities set up were resolved by the construction team satisfying the client's expectations, it gives a clear message that the current procedures and expertise of construction team is more than satisfactory in dealing with those issues. Although the overtime is being frequently introduced, it is done to make up for example for the unsatisfactory weather conditions. Despite of the justifications and arising necessity for overtime, it is suggested that the overtime is applied only when really needed and not for longer than two weeks continuously.

#### *Integrating subcontractors to the Company's A planning team*

The majority of construction work is performed by subcontractors. While working with subcontractors it becomes slightly more difficult to have full visibility on the progress on site. Thus, the AWP strategy despite being highly beneficial towards the productivity will require more coordination with subcontractors to plan and execute the work. It is suggested that the contractor applies more of a direct control approach. The contractor should act as a mentor and guide the subcontractors throughout the AWP processes. It is also recommended that the contractor would provide WFP facilitators to the subcontractor's teams to align the planning activities. That would take away the uncertainty and initial investment from the side of subcontractors. This additional guidance should result in a consistent reporting of progress and provide clear visibility on the work being executed at site. The daily meetings and alignment sessions with subcontractors will also facilitate the modular component, especially during the integration of the modules on site.

### **5.3.1.2 Long term recommendations**

#### *Standardized use of construction metrics globally*

It is advised that the best way of improving the construction productivity would be to start with measuring and reporting the productivity in a consistent way. For that reason, the construction metrics and measurements should be aligned across the projects in the Company A. This standardized way of

the productivity measurements would not only improve the visibility on the actual craft performance but would also enable to compare this performance within the project and across different projects. When the status quo on productivity is accurately reflecting the situation on site, any further improvements can be introduced.

Construction representatives from different regions should decide on the following aspects. Firstly, available standards on metrics should be revised examining the level of detail needed in the productivity measurements. As an example, during the case studies some experts suggested to progress welds against the number of welds in order to reduce complexity of the productivity measurements. However, another expert claimed a greater level of detail is needed with regard to the weld type, how long it takes to make that weld and further suggested to measure welds in diameter inches. Those considerations should be done with cooperation of the project controls department, which is in the end responsible for presenting the overall progress. Thus, the chosen construction metrics and the way of reporting them should facilitate the project controls' data reporting. Furthermore, when the construction metrics are chosen for different construction disciplines, those metrics should be further factored depending if the construction work is performed at grade or at height. Also, those metrics should be factored against different geographical regions, depending for instance on the weather conditions.

Secondly, when the consensus is made on the construction metrics, different construction activities per each construction discipline should be identified accordingly. The last step in facilitating the consistent productivity measurements would be to create construction templates with respect to the productivity measurements per construction discipline and use them globally. Also, it is further suggested to start those considerations with the piping construction discipline as it comprises the largest scope of construction disciplines in the process industry and thus standardizing the piping discipline will bring the highest benefits to the construction productivity measurements.

Furthermore, as described in the short term recommendations, construction progress reporting should be aligned with the AWP process and carried out through the IWPs documents. This standardized productivity data will be gathered in a database and will enable making more accurate estimates for the future projects. The more data will be analyzed the better estimates will be made. Those better estimates will facilitate more accurate comparisons with the actual productivity measurements on site. Ideally both efficiency and effectiveness measurements will be feasible to be included in the overall construction productivity measurements.

#### *Design processes supporting AWP and Modularization*

Both construction strategies AWP and Modularization were found to be highly beneficial towards increasing the construction productivity on site. Therefore any support given to main challenges that occurred with those strategies will have a positive impact on the construction productivity on site.

Modularization would definitely benefit from standardization of design processes. This would be accomplished by reducing the variability of design elements. There would be available few categories of elements to choose from, depending on different loads, material properties, etc. This reduction in the variability of design elements would result in a slight overdesign however the overall benefits would yield much higher results. The engineering discipline would finish faster the design, enabling procurement to order repetitive materials in a timely manner, ensuring they will arrive to the fabrication yard when needed. The company A could also establish continuous relationships with its supplier, who can further anticipate required materials.

The AWP strategy is also putting a lot of additional effort on the design processes. Engineers need to develop the engineering work packages which include all the data needed to support the construction work packages. It is suggested to develop EWP and CWP jointly by construction and engineering disciplines. This integration of packages in the AWP work process would facilitate further integration of construction and engineering disciplines, supporting solution presented in the short term recommendations.

### 5.3.1.3 Comprehensive proposition

Combining short and long term recommendations would ideally lead to the flow process presented below.

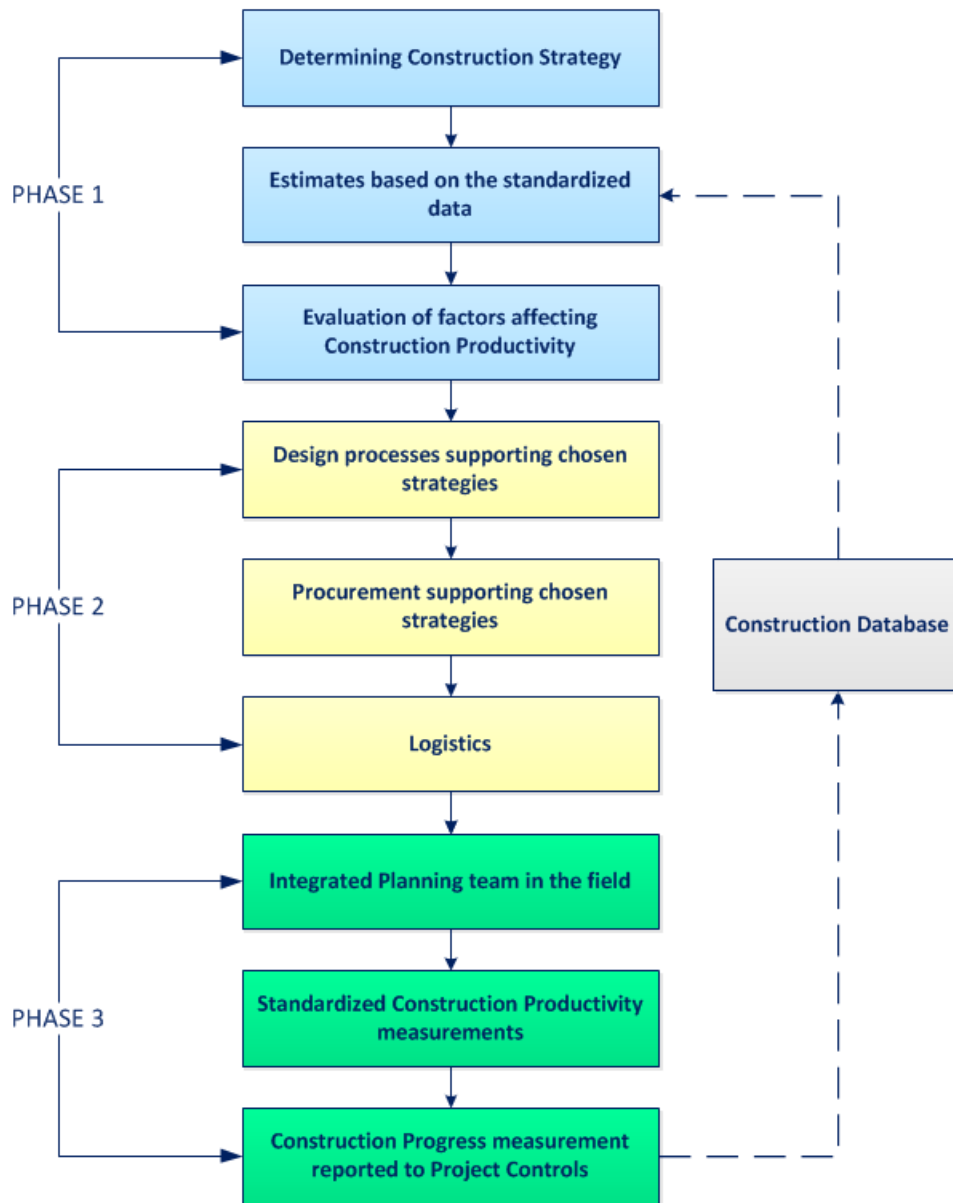


Figure 22 Phases of a project supporting construction flow process aimed at improving the productivity (own figure)

The main goal of this process is to start with determining the main construction strategy in the phase 1 based on the available data from previous projects. At this point, initial estimates should be made in order to evaluate which construction strategy will be the most suitable for the specific project. Those considerations should include the level of modularization and initial productivity estimates. Also, depending on the specific project's context, factors affecting productivity should be considered accordingly.

After choosing the best construction option, based on a solid data, engineering and procurement disciplines can start working under the pre-set construction direction. Those design processes should support the AWP strategy and the Modular component and should be aligned with construction deliverables. The integration of construction in those processes will facilitate timely completion of engineering and procurement processes.

The last phase 3, will consider the actual construction phase in the field. At this point, engineering should be at least 70 percent complete, and procurement should ensure, all the needed materials are ordered, supporting construction sequence. As the AWP strategy is a standard procedure in the Company A, and the majority of construction work is being subcontracted, this set up is considered as the most probable scenario. At the construction site, integrated planning team should be set up; including the Company's A workface planners integrated with the subcontractors' representatives. The installation work packages should be dissected from the integrated engineering work packages and construction work packages by the workface planners and jointly planned the workflow with the subcontractors. This integrated planning team will ensure that craft can commence with their work without any disruptions: (i) all the needed materials and tools should be ready for workers at the right times, (ii) any interfaces between subcontractors should be resolved. The construction progress will be further reported by the subcontractors on a daily basis, based on the standardized construction metrics and using the standardized construction templates. The progress reports provided by the subcontractors should be evaluated by the Company's A construction team on a weekly basis. In the end, the productivity reports from all construction disciplines should be transferred to the project controls department and stored in a construction productivity database. The more productivity measurements input to the database the easier it will be to make accurate estimates.

### *Challenges*

The main challenge with standardizing the productivity measurements is expected to be connected with the sensitivity of this data. The productivity measurements contain powerful information on the field progress and the project's performance, thus becoming a confidential property of the Company A. The Company A should evaluate how transparent the processes of estimating, calculating, evaluating and reporting the productivity will be and who will be responsible for them. Another challenge will be in convincing the clients and the subcontractors over the standardized metrics set by the Company A. Each company has their own way of working and their own preferences in reporting the progress.

### **5.3.2 Research Limitations**

This research investigated the construction productivity in the Company A. For that reason, specific context of the analyzed company and context of the chosen case studies implies multiple research limitations:

1. The investigated case studies were done from the perspective of the EPC contractor. Only process facilities projects of around 1 billion euros scope were evaluated with respect to the

construction productivity. Studies done in other construction sectors, for much smaller or much larger projects, could reveal different productivity challenges.

2. Furthermore, the cases studies were analyzed only from the construction perspective and interviews were conducted with the construction management team. The Company A is usually subcontracting the construction scope of work and provides Construction Director, Construction Managers and Construction Engineers to coordinate the craft workflow on site. Only permanent employees of the Company A were interviewed, who are familiar with the specific procedures and have experience of at least 5 years in the Company A and in construction. As a result, the construction productivity considerations lack craftsmen perspective. The interviews made with craft workers would probably shed light on different challenges.
3. The Company's A procedures implied the AWP strategy application and maximization of a modular component during for the process facilities projects. Those construction strategies create a specific set up in which the productivity was evaluated. This is why the findings and the recommendations of this research may be applicable to other companies in the same sector, which also have similar construction approach.
4. Furthermore, the current productivity considerations in the Company A set additional limitation of this research study. The construction productivity measurements were not set up as a mandatory deliverable. Progress has been reported on each project, however under different standards, also using different construction metrics. The other companies may have different procedures and thus would lead to different outcomes of this study.
5. The productivity measurements reflect the project's performance and thus contain potentially confidential and sensitive information. For that reason it is expected that not all of the relevant information with regard to the productivity measurement was disclosed during the case studies.
6. The Company A is successfully executing projects globally and thus has a worldwide recognition among the most demanding clients. Therefore, there were limited issues identified with regard to the factors described in the labor related factors. The Company A, executing the projects on such a large scope has specialized expertise in identifying and mitigating any occurring challenges on site.

### **5.3.3 Recommendations for further research**

Based on the research findings, recommendations to the Company A and identified limitations, several areas for further research are identified:

1. The literature has investigated range of different factors affecting productivity, making it almost impractical to analyze all of them. It is suggested that all of the factors have potential of being critical depending on how productivity is understood, how it is tackled by the companies, which construction strategies are applied, and what will be the geographical project's context. However, it is suggested to analyze the criticality of factors affecting productivity at different points in time on the project's timeline also including its context.
2. The factors affecting productivity were analyzed only from the managerial perspective. It is suggested to develop a research on the process facilities from the craft perspective and set it further against the managerial one.
3. This research study has only addressed the construction perspective. However, a lot of challenges have been identified in design processes and while cooperating with clients. Thus in order to develop a comprehensive view on the construction productivity in the process industry it is suggested to develop the same case studies including the client's and engineering perspectives.

4. It is suggested to evaluate the impact of cost awareness, modularization and AWP strategy on design processes. Also, it is further suggested to investigate the possibilities of incorporating those findings as a coursework during the construction management studies.

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## Appendices

### Appendix A Construction Productivity Metrics Categories and Breakouts

Table 12 Construction Productivity Metrics Categories and Breakouts (COAA, 2009)

<p><b><u>Concrete</u></b></p> <ul style="list-style-type: none"> <li>- <b>Total Concrete</b> <ul style="list-style-type: none"> <li>o <b>Slabs (CM)</b> <ul style="list-style-type: none"> <li>• On-Grade (CM)</li> <li>• Elevated Slabs/On Deck (CM)</li> <li>• Area Paving (CM)</li> </ul> </li> <li>o <b>Foundations (CM)</b> <ul style="list-style-type: none"> <li>• &lt; 4 CM</li> <li>• 4 – 15 CM</li> <li>• 15 –38 CM</li> <li>• ≥ 38 CM</li> </ul> </li> <li>o <b>Concrete Structures (CM)</b></li> </ul> </li> </ul> <p><b><u>Structural Steel</u></b></p> <ul style="list-style-type: none"> <li>- <b>Total Structural Steel (MT)</b> <ul style="list-style-type: none"> <li>o Structural Steel (MT)</li> <li>o Pipe Racks &amp; Utility Bridges (MT)</li> <li>o Miscellaneous Steel (MT)</li> </ul> </li> </ul> <p><b><u>Instrumentation</u></b></p> <ul style="list-style-type: none"> <li>- <b>Loops (Count)</b></li> <li>- <b>Devices (Count)</b></li> </ul> <p><b><u>Piping</u></b></p> <ul style="list-style-type: none"> <li>- <b>Small Bore (2-1/2" &amp; Smaller) (LM)</b> <ul style="list-style-type: none"> <li>o Carbon Steel (LM)</li> <li>o Stainless Steel (LM)</li> <li>o Chrome (LM)</li> <li>o Other Alloys (LM)</li> <li>o Non Metallic (LM)</li> </ul> </li> <li>- <b>Inside Battery Limits (ISBL) (LM)</b> <ul style="list-style-type: none"> <li><b>Large Bore (3" &amp; Larger) (LM)</b> <ul style="list-style-type: none"> <li>o Carbon Steel (LM)</li> <li>o Stainless Steel (LM)</li> <li>o Chrome (LM)</li> <li>o Other Alloys (LM)</li> <li>o Non Metallic (LM)</li> </ul> </li> </ul> </li> <li>- <b>Outside Battery Limits (OSBL) (LM)</b> <ul style="list-style-type: none"> <li><b>Large Bore (3" &amp; Larger) (LM)</b> <ul style="list-style-type: none"> <li>o Carbon Steel (LM)</li> <li>o Stainless Steel (LM)</li> <li>o Chrome (LM)</li> <li>o Other Alloys (LM)</li> <li>o Non Metallic (LM)</li> </ul> </li> </ul> </li> <li>- <b>Heat Tracing Tubing (LM)</b></li> </ul>	<p><b><u>Electrical</u></b></p> <ul style="list-style-type: none"> <li>- <b>Total Electrical Equipment (Each)</b> <ul style="list-style-type: none"> <li>o Panels and Small Devices (Each)</li> <li>o Electrical Equipment below 1kV (Each)</li> <li>o Electrical Equipment over 1kV (Each)</li> </ul> </li> <li>- <b>Conduit (LM)</b> <ul style="list-style-type: none"> <li>o Exposed or Above Ground Conduit (LM)</li> <li>o Underground, Duct Bank or Embedded Conduit (LM)</li> </ul> </li> <li>- <b>Cable Tray (LM)</b></li> <li>- <b>Wire and Cable (LM)</b> <ul style="list-style-type: none"> <li>o Control Cable (LM)</li> <li>o Power and Control Cable below 1kV (LM)</li> <li>o Power Cable above 1kV (LM)</li> </ul> </li> <li>- <b>Transmission Line (LM)</b> <ul style="list-style-type: none"> <li>o High Voltage above 25kV (LM)</li> </ul> </li> <li>- <b>Other Electrical Metrics</b> <ul style="list-style-type: none"> <li>o Lighting (Each)</li> <li>o Grounding (LM)</li> <li>o Electrical Heat Tracing (LM)</li> </ul> </li> </ul> <p><b><u>Equipment</u></b></p> <ul style="list-style-type: none"> <li>- <b>Pressure Vessels (Field Fab.&amp; Erected) (Each), (MT)</b></li> <li>- <b>Atmospheric Tanks (Shop Fabricated) (Each), (MT)</b></li> <li>- <b>Atmospheric Tanks (Field Fabricated) (Each), (MT)</b></li> <li>- <b>Heat Transfer Equipment (Each), (MT)</b></li> <li>- <b>Boiler &amp; Fired Heaters (Each), (MT)</b></li> <li>- <b>Rotating Equipment (Each), (HP)</b></li> <li>- <b>Material Handling Equipment (Each), (MT)</b></li> <li>- <b>Power Generation Equipment (Each), (kW)</b></li> <li>- <b>Other Process Equipment (Each), (MT)</b></li> <li>- <b>Modules &amp; Pre-assembled Skids (Each), (MT)</b></li> </ul> <p><b><u>Insulation</u></b></p> <ul style="list-style-type: none"> <li>- <b>Equipment</b> <ul style="list-style-type: none"> <li>o Insulation Equipment (SM)</li> </ul> </li> <li>- <b>Piping</b> <ul style="list-style-type: none"> <li>o Insulation Piping (ELM)</li> </ul> </li> </ul> <p><b><u>Module Installation</u></b></p> <ul style="list-style-type: none"> <li>- <b>Pipe Racks (MT)</b></li> <li>- <b>Process Equipment Modules (MT)</b></li> <li>- <b>Building (SM)</b></li> </ul> <p><b><u>Scaffolding</u></b></p> <ul style="list-style-type: none"> <li>- <b>Scaffolding Work-Hours/ Total Direct Hours</b></li> </ul> <p><b><u>Construction Work-Hours</u></b></p> <ul style="list-style-type: none"> <li>- <b>Construction Indirect/ Direct Work-Hours</b></li> </ul>
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## Appendix B Effectiveness and efficiency definitions

Table 13 Efficiency and Effectiveness definitions (own table)

Effectiveness and Efficiency definitions				
Item	Title	Authors	EFFECTIVENESS	EFFICIENCY
1	What Is the Difference Between Efficiency and Effectiveness in Business?	Miksen Chris, 2017	"Effectiveness of the workforce has enoarmous impact on the <b>quality</b> ."	"Efficiency in the workplace is the <b>time</b> it takes to do something."
2	How Effectiveness & Efficiency Relate to Productivity?	Johnston Kevin, 2017	"Effectiveness is doing the right things."	"Efficiency is doing the things right."
3	Analysis of Effectiveness Measures of Construction Project Success in Malaysia	Roshana Takim, Hamimah Adnan, 2008	"Effectiveness is directed to the achievement of <b>goals or objectives</b> ."	"Efficiency is broadly understood as the <b>maximisation of output for a given level of input</b> or resources."
4	What is project efficiency and effectiveness?	Erik Sundqvista, Fredrik Backlunda, Diana Chronéera, 2014	"Effectiveness is not defined but refers to the improvement in managing projects with the goal to <b>improve delivery</b> on time and budget."	"Meets all internal requirements for cost, margins, asset utilization..."
5	Construction Management Principles and Practice	Alan Griffith, Paul Watson, 2003	"...choosing the most appropriate objectives and the most efficient methods of achieving the stated objectives."	"...the ratio of <b>output to input</b> ."
6	Demystifying Productivity and Performance	Stefan Tangen, 2005	"...creation of <b>value</b> ." / "...degree to which desired results are achieved."	"...utilisation of resources (inputs)."
7	Simultaneous evaluation of efficiency, input effectiveness and output effectiveness	Amir Shabani, Gholam Reza Faramarzi, Reza Farzipoor Saen, Mohsen Khodakarami, 2016	"... <b>evaluation of the results</b> of the performance." / "...how well company is performing to meet their goals." / "Input and output effectiveness is measured given their determined targets."	"...maximum generation of outputs with minimum amount of inputs."
8	Productivity Improvement: Efficiency Approach vs Effectiveness Approach	Chiang Kao, Liang-Hsuan Chen, Tai-Yue Wang, Shyanjaw Kuo, 1995	"...requires extra input in a form of equipment or labor."	"...production activity converts inputs to outputs." / "...internal cooperation without consuming extra goods."
9	Productivity through Effectiveness and Efficiency in a banking industry	Parastoo Roghanian, Amran Rasli, Hamed Gheysari, 2012	"...measures firm's ability to reach prearranged <b>objectives and goals</b> ." / "...relation between input or output to outcome."	"...achieve outputs with minimum inputs levels."
10	Productivity Measurement and Improvement	Robert D. Pritchard, 1995	"... <b>output to goals</b> ."	"...output to input."

**Appendix C Activity Survey in the Company A. Productivity per unit and per construction discipline.**

**Sample Project - Productivity per Craft discipline**

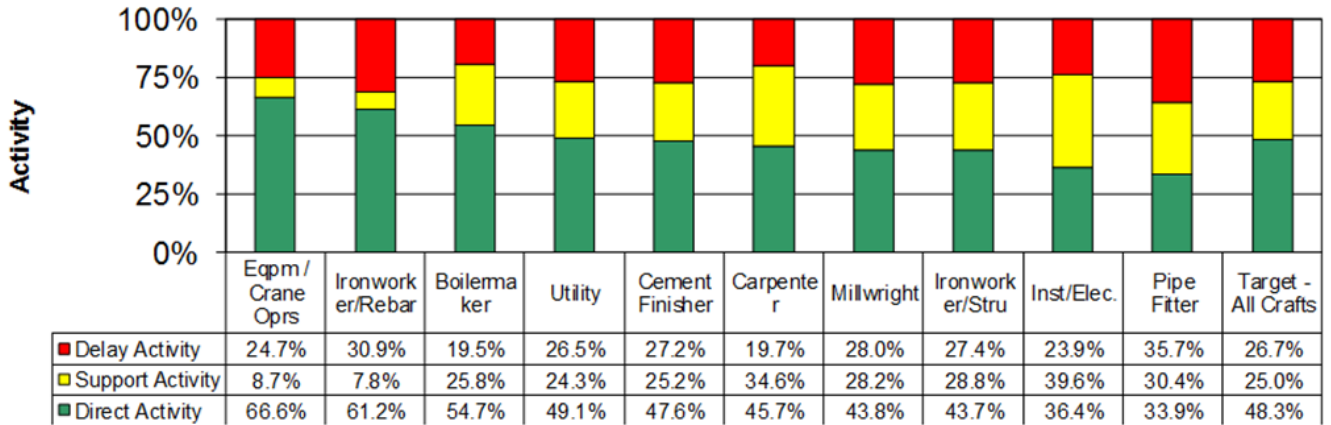


Figure 23 Productivity per Craft discipline on the Sample Project (The Company's A internal documentation)

**Sample Project - Productivity per Unit**

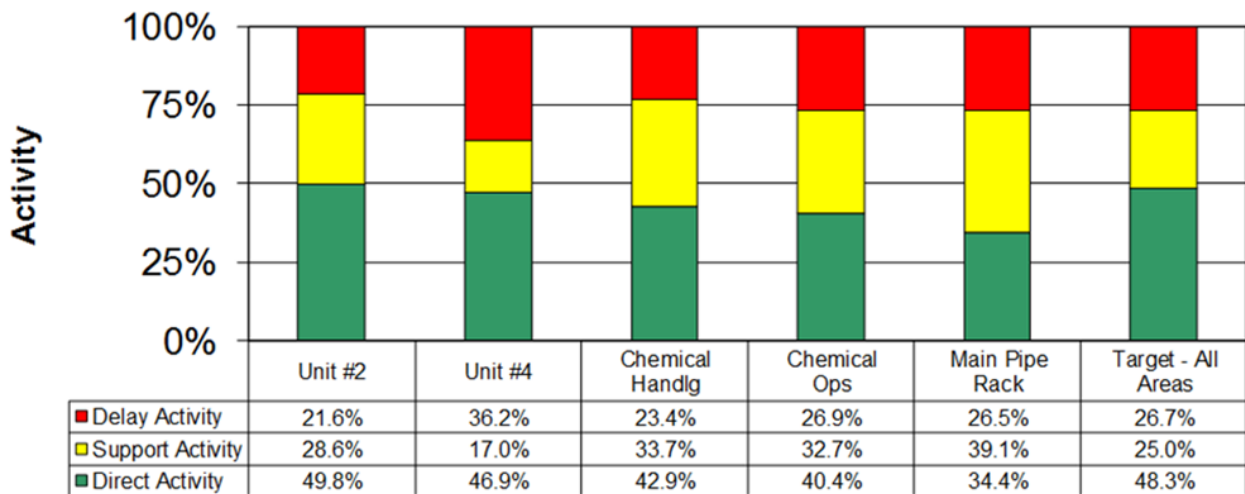


Figure 24 Productivity per unit on the Sample Project (The Company's A internal documentation)

## Appendix D Visual representation of CWA, CWP, IWP

### **Construction Work Area (CWA)**

The construction assigned for CWA should be less than 100,000 hours and is described as a level 2 schedule (Geoff, 2009). The example of CWA is presented in figure below:

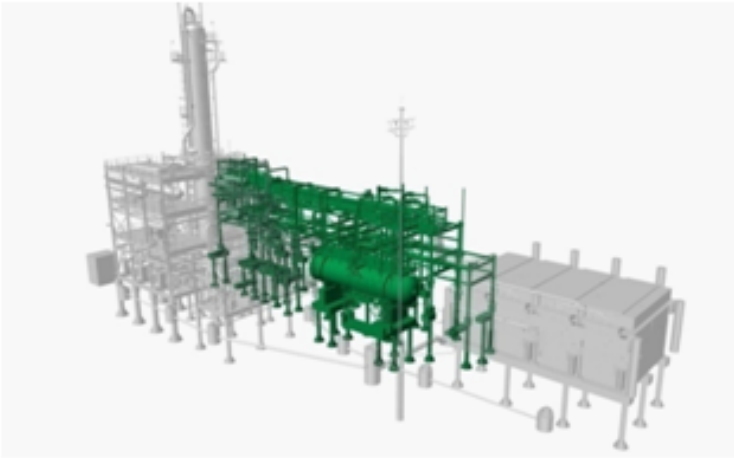


Figure 25 Construction Work Area (Geoff, 2009)

### **Construction Work Package (CWP)**

Each CWP is further divided into a series of IWPs by the Workface Planners (Geoff, 2009).

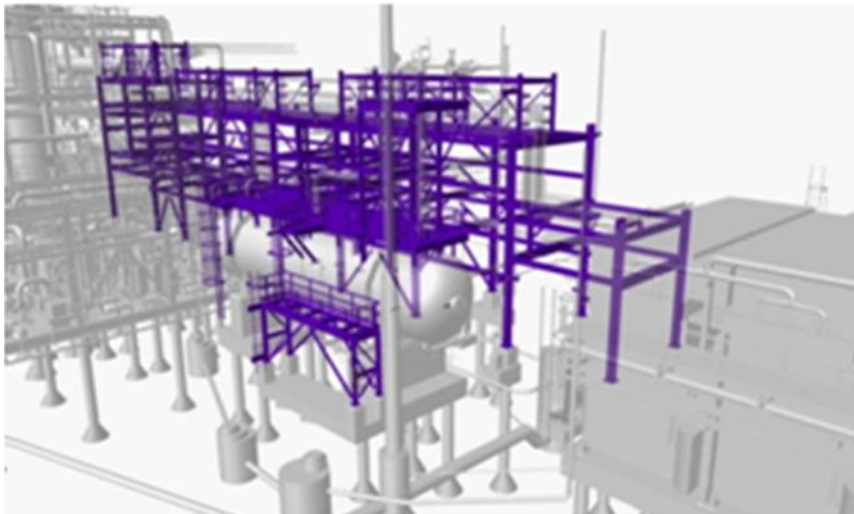


Figure 26 CWP for structural steel is presented (Geoff, 2009)

**Installation Work package - IWP (or FIWP for Field Engineering Work package)**

IWP is derived from the CWP and presented in the whole drawing. Each IWP is a single level 5 activity. All components that create the IWP need to be delivered before any work is started (CII Research Team, 2013a).

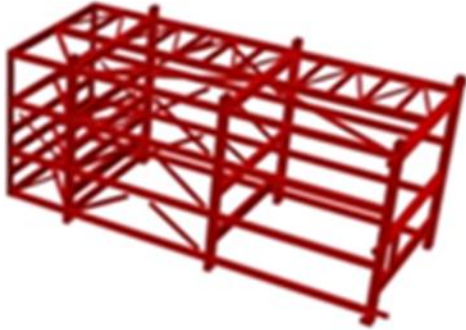


Figure 27 Installation Work package (The Company's A internal documentation)

Appendix E Installation Work package, example from the Company A.

<b>STORK WORK PACKAGE N.</b>	<b>329</b>
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Planned Start: 17-Oct	Planned Finish: 17-Oct	Planned MH: <input type="text"/>
Actual Start: <input type="text"/>	Actual Finish: <input type="text"/>	Actual MH: <input type="text"/>

Module: <b>PAR09, PAR10</b>	Area: 4
-----------------------------	---------

<b>Works Description:</b>
<p>Stork to Torque the following valves stem bushing / body:                  PAR09 - R2R601-BV/R2R604-BV                  PAR10 - R2R401-BV/R2R404-BV/R2R501-BV</p> <p>Torque wrench to be provided by Stork which is capable of supporting attached requirements.</p> <p>Upon completion please return this package to Fluor Planning department</p>

<b>Drawings:</b>					
Drawing Description	Drawing #	Rev	Drawing Description	Drawing #	Rev
P-60-0055-01	ISO	F1			
P-60-2717-01	ISO	F1			
P-60-0019-01	ISO	F2			

<b>Specifications:</b>	<b>Equipment:</b>	
Specification #	Description	
See Attached	Table 4.5	
See Attached	Valve no. to Iso no.	

<b>Other:</b>
<p>Fluor personnel Ricardo Luis Olivera &amp; Juan Fernandez to organise Velan valve representative to witness Torquing the valves</p>

Figure 28 Installation Work Package document (The Company's A internal documentation)



### Appendix F Density analysis on sample project in the Company A.

Density analysis presented below identifies concern areas with high densities marked in red. Furthermore, diagram below depicts those concern areas as a stick built portion marked in red. After, modularizing those concern areas, the workforce in the field is reduced and marked up in green on the diagram, representing a total workforce/ month.

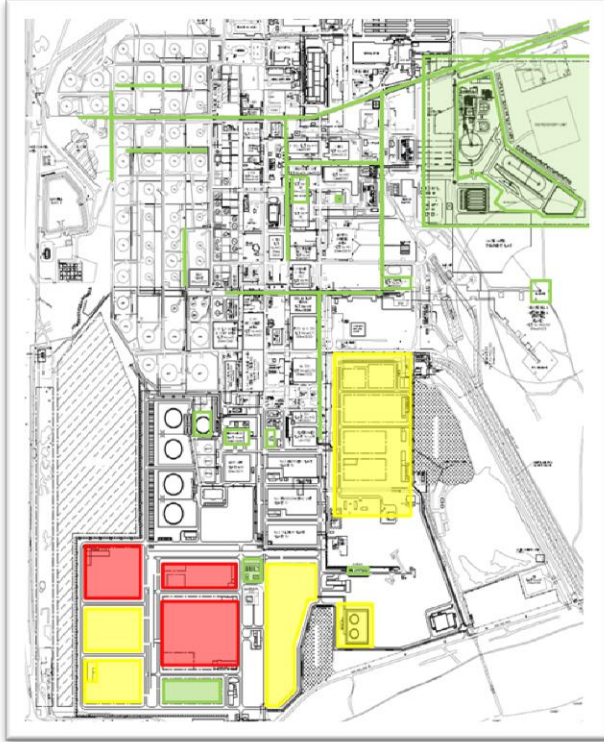


Figure 29 Density Analysis on the Sample Project (The Company's A internal documentation)

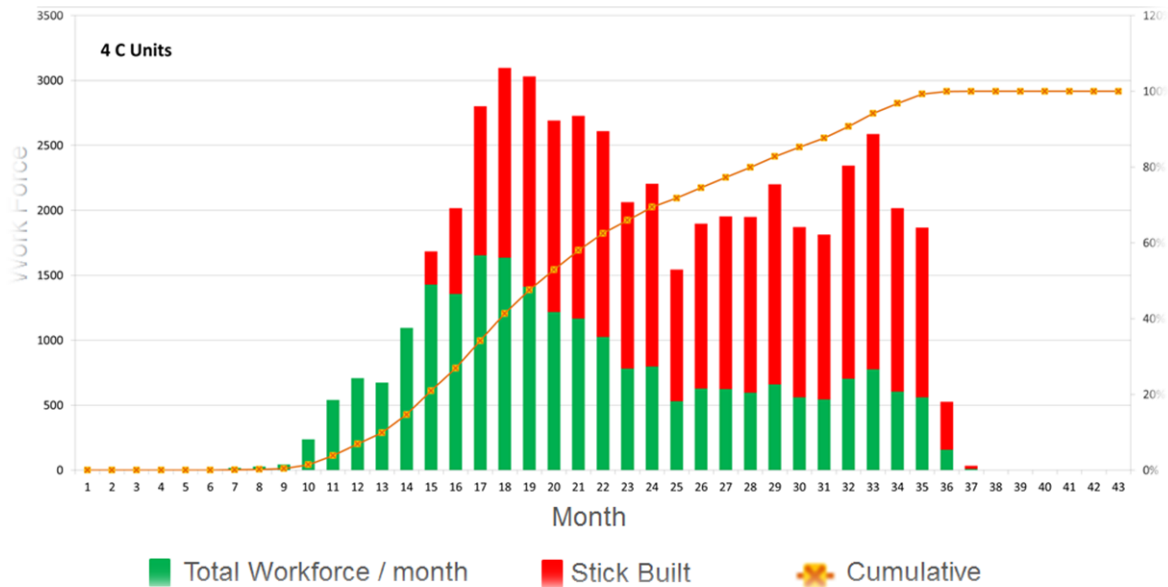


Figure 30 Modules vs Stick Built manpower diagram (The Company's A internal documentation)

## Appendix G Interview questions with supporting definitions

### *Construction Productivity Questions*

1. What is Construction Productivity? (some definitions are provided below)
2. How Construction Productivity is measured (what is considered as input/output)?
3. Does the Company A has database of productivities from previous projects?
4. Are costs included in progress measurements?
5. Which data/programs are used to track progress (quantities, man-hours, costs, etc.)?
6. Which departments are involved in progress/ productivity tracking?
7. How is the work of subcontractors evaluated (are the systems aligned)?
8. Are contracts with subcontractors clear about productivity measurements?
9. What is the impact of prolonged overtime (over few weeks) on productivity?
10. What is the impact of shift work on productivity?
11. Do high densities on site become an issue? What is your experience?
12. What do you think is the impact and importance of the following:
  - Lack of materials, tools, equipment, information,
  - Site attributes and Temporary Facilities set up,
  - Logistics on-site,
  - Changes, rework,
  - Labor market conditions?
13. Do you think there are sufficient construction resources? If not, which specialists, levels, qualities are missing?
14. Over the past decades safety standards have significantly increased. Do you think it affected productivity? If so, in what way.
15. What is your opinion on management skills of supervisors? With respect to communication, given direction, motivations, cooperation with clients, etc.
16. What is your experience with Advanced Work Packaging and Work Face Planning practice? What are the main challenges?
17. The project you were working on was partially modularized. Have any challenges occurred due to that strategy?
18. Would you like to add something that would help with addressing construction productivity?

### *Construction Productivity definitions*

Productivity is in general represented by output to input ratio. For construction related measurements output is usually described by installed quantities. Input is represented by actual work hours for Labor Productivity whereas for Construction Productivity it consists of labor, materials, equipment, etc. In the end, output and input factors are further transferred to costs in order to be quantified. For progress tracking reasons, productivity or profitability measurements are being followed. Productivity measurements are focused on quantities whereas profitability focuses on the costs aspect. Earned Value Management technique is an example of profitability measurements. Furthermore,

profitability can be broken down to productivity plus price recovery elements, preserving information on both: quantities and costs.

$$1. \text{ Labor Productivity} = \frac{\text{output}}{\text{input}} = \frac{\text{installed quantity}}{\text{actual work hours}}$$

$$2. \text{ Construction Productivity} = \frac{\text{output}}{\text{input}} =$$

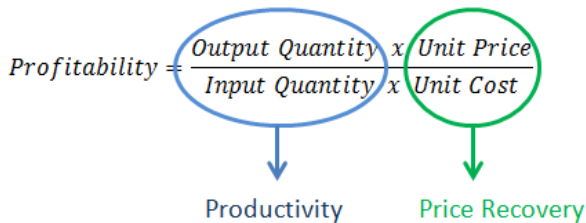
$$= \frac{\text{installed quantity}}{\text{labor, materials, equipment, energy, capitals}}$$

$$3. \text{ Productivity (E\&E)} = \text{Efficiency} \times \text{Effectiveness} = \frac{\text{Output}}{\text{Input}} \times \frac{\text{Output}}{\text{Goal}}$$

4. Earned Value Management:

- Earned Value measurement shows value of an actual work completed at a given time.
- Planned Value is calculated before starting a project and is considered as a baseline, showing estimated value of work done, at a given time.
- Actual Cost represents a total amount that has been spent for an actual work done, at a given time.

$$5. \text{ Profitability (EVM)} = \frac{\text{Revenue}}{\text{Cost}}$$



## Appendix H Case Study descriptions

In this appendix the interviewees' background and their relation to the construction productivity will be described. Furthermore, the main points derived from the interviews will be presented.

### Case Study A

#### *Introduction*

The project A was executed in North America, from 2012 till 2018. The Company A scope was around 2 billion dollars comprising of the process units. The project was done on reimbursable basis. The construction work was a mix of subcontracting and direct hire. The applied construction strategies were: Advanced Work Packaging and the construction work was around 60 to 70 percent modularized and around 30 percent stick built. Project A was done under third generation modularization in order to condense the plant foot print and minimize the usage of materials.

#### *Interviewees*

Construction expert A1 was involved in the project from the beginning and had two complementary roles on the project; as a Senior Construction Director and a Deputy Safety Director. The expert A1 was involved in the execution and turnover and was responsible for managing construction works on the process units. Construction expert A2 had 3 different roles on the project; Deputy Construction Engineering Manager, Process Field Engineer and an overall Hydro-test Coordinator.

#### *Main points of discussion*

#### *Construction Productivity definitions and measurements*

Expert A1 defined productivity as the measurement of man-hours allocated to install certain amount of quantity. It could be a number of man-hours needed to install a one meter of pipe. Allocated man-hours are considered in terms of costs. The installed quantity will comprise of certain activities and percentage allocated to them, for example, 30 percent for installing the pipe, 10 percent for locating the pipe, 30 percent for welding, etc. Expert A1, did not fully agree on the presented split and would recommend different percentages' allocations. Equipment and materials were considered separately from the productivity measurements. Expert A2 added that equipment is progressed per each piece of delivered equipment. Expert A2 said that productivity should be reported against the initial estimated man-hours and the estimated construction quantities per construction discipline. Based on the latter productivity outcome should be as good as the initial estimate.

Despite the comprehensive guidelines provided by experts, there have been certain issues occurring during the productivity measurements and during the progress reporting. It should be added that the construction discipline chooses construction metrics for each project based on their preferred standards. Following that, the confusion was found to be around those construction metrics. There were found inconsistencies in progress reporting styles varied per constructed process units within the project A. As an example, in two units, welding was progressed based on number of welds with no differentiation over the weld type. However, the remaining construction scope was progressed with differentiating weld types which further vary with amount of time needed to complete them. It was further suggested to use weld inches to report the progress not the number of welds.

Another example was found to be during a pre-commissioning phase where test packs were reported without an initial estimate.

Another measurement for progress reporting was based on quality records. When the quality record is delivered it means that the work is complete.

Overall progress reported by construction through daily reports from field supervisor is further delivered to project controls department where construction progress becomes a part of the overall progress report of the project.

### *Construction Strategies*

#### *Advanced Work Packaging*

AWP strategy is used as the Company's A baseline construction strategy. It had a profound positive impact on the labor productivity and is the preferred way to execute projects. On the project A the time on tools measurement was found to be 15 percent higher than the Company's A benchmark due to the applied AWP strategy. Estimate was also considered as a really good one. The only challenge with the AWP lies in starting very early during the engineering phase in order to set up the proper breakdown structure. The other issue is with the amount of papers created during the work preparation. Expert A2 suggested that standardization of documents could be made to reduce the bulks of papers.

#### *Modularization*

Expert A1 claimed there were no issues with the modularization and it was just a matter of a proper logistics of modules. Furthermore, modularization helped with achieving higher efficiency, certainty of the outcome and increased safety on site. The only issue occurred due to the changing weather and affected further logistics of modules. Modules needed to be prematurely shipped being incomplete before the scheduled time due to the unseasonable weather causing weight restrictions on the local roads.

The main driver for modules was cost. Expert A1 claimed that the quality of welders is no different in Asia than in Europe or North America. Also, even if 50 percent of rework would be needed on modules delivered from Asia it would still end up cheaper than doing a stick built construction in Europe or North America. Those cost reductions were possible due to significant differences in labor and material costs between Europe and Asia.

#### *Labor Related Factors:*

The standard working schedule on the project A was 12 days, 10 hours a day on the jobsite and 2 days off. It included one lunch break for 30 minutes and two shorter breaks for 15 minutes each. However, due to the extensive walking time from the job site to temporary facilities, the latter scheme was changed to two longer breaks for 30 minutes each, in order to reduce the total walking time.

Both experts agreed that any more than 10 hours is creating additional time without the actual quantities delivered.

However, in the end of the project in order to accelerate a part of the scope, the night shift was introduced. The latter was a conscious decision made at the expense of productivity in order to reach desired objectives on the schedule.

Temporary facilities set up had a considerable bearing on the productivity. As one facility near completion started operating, the temporary facilities needed to be relocated away from the initial location due to blast zone created by this operating facility. This ended up in additional time wasted for workers on moving from the site to the resting facilities.

There was no man camp provided on the project A. For the large scope of construction work there was expected significant road traffic to the jobsite. In order to mitigate that, the client has provided busses to the jobsite and additional ones internally on the jobsite.

### *Industry Related Factors:*

#### *Contracting schemes*

As the project was a mix of a direct hire and subcontracting, there have been certain differences with respect to productivity reporting. Both experts have allocated much higher efficiency and control over the productivity with respect to a direct hire approach. When it comes to subcontractors, they report their own progress which the Company A needs to supervise and rely on. Furthermore, subcontractors tend to subcontract further their own work which creates additional layers of people to report their work. This way, productivity reporting may become skewed with respect to the actual percentages and the chosen metrics. When multiple subcontractors are working simultaneously, it creates congestion on the job site, one contractor is much better to handle. It is also essential to mention that some of the subcontractors were dictated by the client and the Company A had little freedom with choosing their preferred ones.

#### *Complexity*

Expert A2 said that one facility had much lower productivity in comparison with others due to higher complexity of that facility. The latter was exemplified in a difficulty of construction activities: complex heavy lifts, usage of non-standard materials, etc. Therefore, the construction activities took much longer than expected. It should also be mentioned that the facility with lower productivity was not initially a part of the Company's A scope. Due to the highly satisfactory performance of the Company A on the remaining scope, this facility was transferred by the client to the Company A in a delayed manner.

### *Management related factors*

#### *Management Team*

Expert A1 expressed that the productivity and thus success or failure of the project is influenced by the management team. They are responsible for a budget and tend to follow mostly engineering and procurement needs. However, construction owns the project. Engineering scope represents around 10 percent if they go over by 5 percent wrong in their estimates it will not influence their deliverables. However, overrun of 5 percent in the engineering will result in around 30 percent impact in the construction later on. Expert A1 suggested that Construction Director should be equal to the Project Director with respect to decision making during the construction phase. Expert A2 has also strengthened the importance of proper management with regard to construction productivity. He also suggested the importance of red flags raised by construction craft in decision making.

During the project, a critical path unit was schedule driven rather than driven by cost of materials. The strategy of fabricating pipe spools in India was changed to fabrication at the module assembly yard, to save around 6 weeks in a shipping time. This was recommended to and accepted by the client in order to mitigate potential schedule overruns and maintain the overall project schedule. However, in the end it was not obvious if that change had a positive effect to the overall project's performance. The process facility needed to commence operations as early as possible to recoup capital and had high impact on productivity on site due to the aforementioned changes.

### *Client's involvement*

Furthermore, the client has dictated the system schedule which resulted in disrupted work fronts. Construction was not ready for this acceleration due to the pre-work needed to be finalized before commencing the job. The expert A2 said that construction cannot lose sight on the most critical activities. Any problems that occur in the previous phase will take a long time to recover. However, systems that are commissioned are simple and easy to fix if any problems occur. Thus, it is important to finalize activities that will cause bigger difficulties later on and delay the ones that are simpler to fix in the future.

## **Case Study B**

### *Introduction*

The project B was executed in Europe and the project scope was around 1 billion euros. Construction work was subcontracted and the project was done on the reimbursable basis. The applied construction strategies were: Advanced Work Packaging and the construction work was around 40% modularized. Project scope consisted of for instance substations, preassembled racks, coolers and considered major equipment.

### *Interviewees*

Construction expert B1 was involved in the project from the beginning and was responsible for grass root areas, with a function of a Construction Area Manager. The expert B1 was involved in the construction execution and turnover and was responsible for managing construction work on the project. Construction expert B2 was a Superintendent/ Piping Supervisor on the project B and was responsible for a certain area.

### *Main points of discussion*

### *Construction Productivity definitions and measurements*

Expert B1 and B2 both described the construction productivity as a ratio of output to input, where the input is represented by man-hours allocated to deliver certain output in a form of quantities. When it comes to chosen construction metrics, Expert B2 said there were no available standards on the most suitable metrics for reporting progress. For construction disciplines: piping and steel, weight measurement was chosen and presented in the installed tonnage. Expert B1 expressed that different people have different ideas for reporting progress and it may be progressed based on the tonnage or number of welds, depending on the manager's preferences. As long as the logic behind the used data is well understood, there are multiple ways of representing the construction progress. Furthermore, the construction data on a gathered construction progress is forwarded to Project Controls department on a weekly basis and construction has no input over how the overall progress is presented. Both experts said that construction progress of budgeted man-hours was tracked against the actual man-hours and earned man-hours, following the Earned Value Management concept.

What is more, during the Project B one subcontractor was found to have a significantly poor performance. This subcontractor in order to prove they were performing well, requested an external party to conduct a Time on Tools analysis. This analysis was found successful for the majority of the subcontractors, with the final results exceeding the Company's A benchmark. Only the subcontractor who initiated this analysis was confirmed to perform very poorly also during the Time on Tools analysis.

This subcontractor was a local subcontractor, with majority of local craftsmen who were used to 40 hours working scheme and have struggled to work on the agreed overtime.

### *Construction Strategies:*

#### *Advanced Work Packaging*

Advanced Work Packaging was applied on the project B to a certain degree. It was driven by the Company A as a client did not want it initially. However, the construction team was stubborn and has convinced the client over the criticality of the AWP strategy. The AWP had really good benefits to planning work on-site, increasing the labor productivity, maintaining control over schedule and costs. However, both experts agreed that it should have been applied in the FEED phase of the project in order to reach the strategy's highest potential. The challenge lies in convincing, selling this philosophy of packaging work to engineers and to the client. Packaging work under the AWP strategy requires very detail planning and engineers tend to work on the higher level of details. When the aforementioned issues are resolved, the AWP is highly effective during the construction phase.

#### *Modularization*

Based on the Expert's B feedback, modularization had a massive impact on increasing productivity on site. Substations, pre-dressing and precast concrete were done away from the job-site. It immensely helped with transferring large amount of man-hours to the fabrication yards, especially due to constrained areas and high densities on site initially. Expert B1 added that the modular component was divided into three different fabrication yards within Europe. Furthermore, minimal damage was done to the modules during shipping and no major changes were needed to incorporate those modules on site. Expert B1 added that the modules were fully tested at the fabrication yards to ensure no additional testing will be needed on site. Expert B1 explained that it was a conscious decision as sometimes even if modules are considered 100% complete, there is still a lot of additional work on the construction site, for which additional man-hours are not allocated in the estimates.

### *Labor Related Factors:*

When it comes to working hours it was initially set up on the 40 hours per week. However, work on site differs from the office work and it is more realistic to work longer on the site in order to maintain high productivity. Based on the European directive, that would be 48 working hours per week. During the project in order to stay on schedule, night shift was introduced. This additional shift helped in preparing the work front for the next day so the construction could smoothly proceed with the planned activities. As both shifts were well organized the impact on productivity resulted from that combination was positive. Further on, expert B1 suggested that overtime should be only introduced if deemed necessary in order to facilitate the productivity. Prolonged overtime will only result in low morale among the workforce. He further said the people are the Company's A most valuable asset and if they are happy with the company's conditions they will happy to work for this company again.

When it comes to site attributes, the construction site was very small and needed a lot of equipment, which further increased the density issues. The latter were resolved by introducing the two aforementioned work shifts. Furthermore, laydown area needed to be located away from the site due to the space constraints. However, the remote laydown area was satisfactory for the project's needs and it was ensured that the right materials were brought in the right place and at the right time.

Also, existing process facilities close to the construction site were in operations and thus the temporary facilities needed to be located away from the blast zone area. This constraint created a lot of time



wasted on walking back and forth from the temporary facilities to the job site. Overall there were provided busses and walkaways in order to ensure good logistics on site. It should be added that the initial logistics, temporary facilities and laydown areas were dictated by the client from the beginning. The Construction Team of the Company A made a high level assessment on the time wasted on workers walking. About 700 workers were wasting around 45 minutes for walking daily each in order to have a short break. This amounts to 525 working hours per day. To mitigate that wasted time, the Company A provided small containers for coffee breaks, closer to the site. This change was fully covered by the Company A and was deemed necessary to increase the on-site productivity. There were also no issues with inspection and quality checks.

### *Industry Related Factors:*

#### *Contracting schemes*

The whole construction work was subcontracted during the project B. The Company's A construction team was supervising and directing the subcontractors to ensure the work is executed efficiently. Subcontractors were maintaining their own progress in the log and then reported it to the construction managers of the Company A. Construction supervisors were performing random spot checks in order to evaluate the progress reported by the subcontractors. Expert B1 and B2 said that although they could rely on the data provided by the subcontractors, those experts were aware that the subcontractors tend to underreport their work progress. Furthermore, it was relatively easy to spot if something was wrong based on what was agreed upon in the contract. Both sides: the Company A and the subcontractors, are quite well aware on what the contract consists of.

Both experts have expressed that different cultural backgrounds of subcontractors' craft had crucial impact on the labor productivity. The subcontractors, who mobilized craft from abroad only for project duration, were found to be much more productive than a local craft. The former subcontractors did not mind working overtime and in general were more eager to work harder. This satisfactory performance could have been a result of a different working culture, training but also being away from a family home facilitates work focus.

#### *Design Processes*

Expert B2 expressed that design processes tend to drive the execution strategy. During the project B, late engineering deliverables have impacted the material delivery and caused further delays on-site. The new revision materials (control valves) with lead time were not available on site at the right time. Expert B1 added that the construction team is not incorporated enough to the engineering discipline and is not giving enough construction input that could facilitate the actual execution. Furthermore, the construction team tends to start on-site execution when engineering team is not finished. Construction should be a part of engineering group and should help out in creation of engineering packages. Also those packages should be prioritized and aligned with construction sequence and construction deliverables.

### *Management related factors*

#### *Client's involvement*

During the construction phase, the client decided to construct a different sewage system than it was initially designed. This decision had the biggest impact on the productivity as the underground work needed to be extended from the initial 2 meters depth to 5 meters depth. All the initial ground analysis and surveys were however performed just to 2 meters depth and thus the bigger depth was an unknown. Despite the fact, that project was reimbursable and the client covered those expenses, this

late change has caused a lot of disruptions to the construction workflow. Further, the impact of that change was not fully factored into the planned work.

Expert B1 said that on the project B the Company A has relied too much on the client's temporary facilities set up and that the client was driving most of the execution decisions. It was further suggested that construction should be involved much earlier during bidding phase and be able to use their expertise in setting up the main strategies. Construction is usually mobilized and involved in decision making when everything is already designed and needs to deal with the outcome of those decisions on site.

## **Case Study C**

### ***Introduction***

The project C was executed in the North America and its scope was around 1bln dollars. The Company A scope consisted of boiler units, tank farms, control building, two cooling towers. The largest component comprised of interconnecting pipe racks which were going through all the other units and thus were a backbone for the remaining project's scope. The project was done on the reimbursable basis. The construction work was fully subcontracted. The applied construction strategies were: Advanced Work Packaging and the construction work was around 60 percent modularized.

### ***Interviewees***

Construction expert C1 was involved in the project from the beginning and had two complementary roles on the project; early on in the project, expert C1 was a Project Engineering Manager and for the last 3 years of the project, expert C1 was a Construction Manager. Therefore, the expert C1 was involved in engineering and construction execution managerial activities. Construction expert C2 was a Construction Area Manager for the interconnecting pipe racks. Expert C2 was involved in the EPC phase for around 3 years.

### ***Main points of discussion***

### ***Construction Productivity definitions and measurements***

Expert C1 defined productivity as amount of man-hours needed to install a certain quantity. The Company A is analyzing earned and burned man-hours with respect to installed quantities. Expert C2 added that the most important productivity measurements from his perspective are burnt hours against earned hours. When it comes to metrics, expert C2 explained that certain industry standards are used for determining the latter. Following that, steel is measured in tonnage, which is further differentiated by light, medium and heavy steel. As an example, for the structural light weight steel a lot of additional connections are needed which needs to be factored in productivity measurements. Expert C2 said that with respect to welding he prefers keeping measurements as simple as possible and thus to keep track on number of welds per day, with no differentiation over the weld types. Furthermore, concrete is measured in cubic yards whereas piping in diameters, length and number. It should be also mentioned that putting pipes on elevations increases the productivity factor. When it comes to percentages per activity, it was also a standard procedure however client had a say in the activities split. Further on, client is setting their own unit rates for each quantity however without sharing the actual rates and their budget. The Company only receives verbal feedback on whether the Company A is doing well or not.

Expert C2 revealed another important aspect of loading data correctly to the used tools. He advised that project controls should more frequently check the reality against the model, at least on a monthly basis. The latter has to do with change management in order to capture any leakages in man-hours and eliminate any productivity hindrance. During the project C, change management has become an issue as quantities were not loaded correctly to the software, which further hampered the correct reporting out of construction progress. Expert C2 added that the Company A has wonderful tracking tools for steel, piping disciplines, also for tracking isometrics, however those can only be utilized with a correct data input, following the garbage in, and garbage out saying.

### *Construction Strategies:*

#### *Advanced Work Packaging*

Expert C1 described AWP strategy as a great practice to increase productivity. Inside the unit, there were multiple levels of work where timing and sequencing of work was very important. Creation of individual work packages under the AWP strategy helped in planning the work around the construction sequence and resulted in opening many work fronts. Creation of those packages was done with close cooperation of subcontractors and any change in sequence was consulted with them accordingly. Expert C1 further suggested including superintendents, people who will actually execute the work, in creation of those packages. Expert C2 agreed on a high value that the AWP is bringing to the projects; however he said it will bring the highest benefits if all disciplines are aligned, especially with the project controls. The most important aspect with the AWP on the project C, was that it was not implemented from the beginning and it will be described further in the *Management Related factors* paragraph.

#### *Modularization*

60% of construction work was modularized with 40% of work done on the site. Expert C1 said that project C was a very unique one, where 100% of pipe racks were planned to be modular. There were multiple fabrication yards chosen for the modularization, mostly overseas and then they were integrated on the site. The choice of the level of modularization was however not a firm decision: during the front end planning the third generation modules were planned, however later on senior level has changed that decision. Expert C2 added that in the end for the interconnecting pipe racks the hybrid approach was chosen with around 75% modularized and around 25% stick built pipe racks. The latter change in the strategy will be elaborated in the *Management Related factors* paragraph.

### *Labor Related Factors:*

During the project C the highest productivity was found on the 60 hours work week and 10 hours a day. The schedule was 13 working days and 1 day off. When it was necessary the 70 hours work week, for 12 hours a day 6 days a week, was acceptable however not for longer than two weeks. Only after first week on the 12 hours a day scheme, there have been found about 20 percent reduction in the labor productivity.

At some point during the project C, the second work shift was introduced and it was a night shift. The latter was due to congestion in one unit. This additional shift helped in ensuring construction activities flow. As an example a hydro testing fill was done during the day time and the testing was done during the night time. Also, X-ray construction activities were planned for the night shift in order to avoid possible exposure to radiation to any human body.

The Company A has density standards which drive decision making on the amount of workers per square feet. Those benchmarks further depend on the construction activity and layout of the site. Further on

inside the unit there are multiple levels with regard to construction disciplines and working heights. Thus timing and sequencing of the work is very important.

Expert C2 added that weather played a big role during the project C. Hurricanes affected the craft and historical rains have impacted civil works. Thus, overtime was needed to overcome time loss due to the adverse weather conditions.

Site attributes during the project C have been addressed in detail. Temporary facilities were considered very early, taking into account surrounding areas, roads, heavy lifts, etc. It was further considered how to most efficiently bring craft in and out of the site. Transition from suppliers to site was sequenced in the Company's A materials tool.

Even though, laydown areas were close to each unit, there have occurred issues with sequencing and prioritizing the transportation of materials. The company A was not responsible for laydown areas management as it was subcontracted to another party. The latter party did lose a control over the incoming materials and their sequence. At that point the Company A needed to get involved, advise the client and take over some of the third party's responsibilities. Expert C1 added that some of those issues could also be a result of wide variation in the material types and sizes. Expert C1 further suggested that standardization in types of materials could solve to some extent those issues. As an example, there were 2 identical units however varied materials and sizes were used in their design. Expert C1 said the main challenge lied in convincing the client that the standardization of materials has several benefits to the overall procurement and logistics.

### *Industry Related Factors:*

#### *Contracting schemes*

The construction work was fully subcontracted. The client wanted to use local subcontractors in order to facilitate local economy. The subcontractors were tracking quantities and man-hours based on the work complete and were reporting those numbers further to the Company A. Those measurements were tracked in the Company's A tool. However, expert C1 said that this tool is as smart as the information that is put there. This is why the criticality lies in using the right data and the understanding over the used information.

#### *Design Processes*

Expert C2 said that the Company A is more of an engineering company than a construction one. During the front end planning phase, engineering discipline did not complete a lot of design. The latter was a client's decisions based on the running out of the engineering hours and thus it was decided to push those hours to the field. However, starting the construction work without a complete design is much more expensive as any issues occurring on site are much harder to be solved than still during the engineering phase. Expert C2 also expressed the importance of design standardization. As an example, during the project C, foundations and form works were designed from the scratch. However, this is usually a repetitive work and could have been standardized in order to reduce the engineering hours. Also, tanks were designed from the beginning, despite the availability of previous similar designs on different projects.

## *Management related factors*

### *Management Team*

Expert C1 expressed his concern over the communication styles between younger and older generation, with him representing the latter. He said that the former group is mainly communicating by phone and that they are very much attached to electronics. Expert C1 said that better coaching and mentoring in the front line is needed from the Company's A supervisors, following a more direct contact, face to face contact. Expert C2 added that construction managers should be involved in the home office during the front end development in order to oversee all specifications and design that will support construction phase later on.

### *Client's involvement*

AWP strategy was applied very early on the project C, still during the front end development. However, due to additional investments needed for the strategy, the client seized the investments on the aforementioned strategy, still in the beginning. As the project C went forward, a lot of difficulties with planning and sequencing the construction work have occurred. The need for the AWP strategy has been realized by the client and thus the strategy was brought back in the middle of the project, when construction was already in the field. Expert C1 said that despite the AWP strategy is highly beneficial; the transition of bringing it back was quite difficult. Further on there was high cost associated with that change. Expert C2 added that at that point in time it was difficult to create packages and to convince subcontractors over the AWP strategy. Also, a lot of AWP experts needed to be urgently mobilized to the project.

Expert C2 further elaborated the already aforementioned change in the modular strategy. From the beginning, full third generation modules were considered, however the client after contacting a third party for advice has decided to reduce the modular component due to the initial cost associated with it. As a result the modular program was reduced to only 30 modules in total. Based on the client's decision, the Company A prepared very detail substantiation and recommendations for reconsidering the increase of the modular component. This report included the criticality of modularizing the interconnecting pipe racks, and that it would not be possible to finish them under the stick built execution, based on the initial schedule. Also, engineering planned their design based on the modular approach. The whole process, site logistics, temporary facilities, laydown areas heavy lifts were planned under that business strategy. Any change at that point would result in a reorganization of the whole project. Furthermore, construction activities were planned in parallel, while the modules were prepared in the fabrication yards the civil works at site could be completed at the same time. In the end, it would be considerably harder to do activities planned for modules on a stick built portion. The client, after considering all the aforementioned arguments, decided to increase the number of modules from 30 to 75 modules, with majority of the interconnecting pipe racks being modularized.

Overall, the expert C1 strengthened the importance of selling construction strategies to the client based on the historical data base, explaining and walking the client through the process in order to convince them over the benefits of those strategies. Furthermore, those strategies should be executed till the end, as initially planned. The Company A has great solutions facilitating the productivity on-site, however any change in their application procedures may result in not full utilization of the potential benefits.

## Case Study D

### *Introduction*

The project D was executed in the Middle East. The Company A scope was around 2 billion dollars and consisted of multiple process units, utilities and infrastructure for the new refinery. The Company A has executed the project in a joint venture and had about half of the project D scope. The project was done on the lump sum basis. The construction work was subcontracted. The applied construction strategies were: Advanced Work Packaging and the construction work was around 60 percent modularized. It should be mentioned that the project D was initially sold and awarded as a fully stick built project. Later on, due to the schedule constraints the construction strategy was changed to a partially modular and a partially stick built construction.

### *Interviewees*

Construction expert D1 was a Modular Manager on the project D and has been involved from the beginning till the end of the project. He was responsible over the modular component of the project hence his perspective is highly related to that construction strategy. Furthermore, expert D1 has multidisciplinary background with considerable experience in engineering, project controls and project management. Construction expert D2 is a Construction Director in the Company A. However, during the project D he was a Project Manager for temporary facilities and was overseeing the engineering work. The temporary facilities design and set up took one year on the construction site and the expert D2 was further supporting the project from a home office on a regular basis.

### *Main points of discussion*

#### *Construction Productivity definitions and measurements*

Expert D1 explained that there are multiple ways of measuring productivity which depend on the construction activity type, whether the welders work at grade or on heights, etc. In general construction productivity is measured in quantities delivered per man, and further set against the estimated values. Expert D2 added an example of activities needed for delivering 1 cubic meter of concrete. The latter would consist of the following activities: excavation work, compaction, lean concrete, rebar, form work, concrete, painting and backfill. In the end, the aforementioned activities would comprise of around 50 hours of work. Those baseline hours will however differ per region, depending on the conditions like for instance weather. Furthermore, expert D2 added that work should be differentiated depending on whether the work is done with gravity or against gravity, with a lower factor for the former and a higher factor for the latter.

Expert D1 added that construction metrics are very complex and there is inconsistency in their usage. Based on the latter any comparisons in productivity rates are difficult. There are also available tools in the Company A, however they are not suitable for all construction activities. Overall there is a lot of data available on productivity however it is not centralized nor standardized in a user friendly way. On each project data should be processed in the same way and data recording should be standardized. Furthermore, the data gathered by construction is not linked to other departments, for example from the cost perspective. Information on productivity is simply forwarded to a project controls department, without close cooperation between both; construction and project controls departments. Despite that the project controls department plays very important role it is not involved enough in the construction. Expert D1 suggested that construction progress should be set against the expenditure at least on a monthly basis. Expert D2 also agreed that the productivity is exemplified in the allocated and utilized

budget, thus the overview on both, the productivity and the budget is relevant. Furthermore, expert D2 highlighted the general split of scope of work between different construction disciplines during the process facilities projects. He further suggested to focus on the activities that consume the greatest scope, starting with 40 percent for piping work, 30 percent for civil, structural, architectural, 10 percent for mechanical work, 10 percent for electrical and insulation, and around 10 percent for pre-commissioning and commissioning activities.

### *Construction Strategies:*

#### *Advanced Work Packaging*

Expert D1 expressed that the AWP strategy was implemented however not to its full extent. There has been set up a control room, in which all documentation on construction progress was gathered on the construction site. This set up helped in planning construction workflows between the Company A and subcontractors. However, expert D2 added that work packages had limited coverage on materials. The latter means that the work packages include all needed engineering data, like isometrics, however not all elements shown on those isometrics were available for workers. The unavailability of the right materials indicates a misalignment with a procurement discipline. Expert D2 further highlighted that the availability of the right drawings and materials at the right time is a predominant factor for the productivity improvement.

#### *Modularization*

Expert D1 said that modularization is a great strategy; however it needs to be executed under different considerations than a stick built construction. As the project D was initially designed as the stick built and changed to the partially modular component, strategic and technical directions did not fully match. Modularization did not create more work but different variables needed to be considered. Modular decision needs to be made early on in order to enable engineering and procurement to finish their deliverables earlier. This shift for engineering and procurement is needed due to introduction of a fabrication yard. Engineering also needed to work in a different manner, which will be further described in the *Industry Related factors*. The crucial part of deciding for the modularization is to establish material, labor, fabrication and logistics costs. Furthermore, early engagement of vendors facilitates this construction strategy. Expert D2 also added that the modularization should be weighed against its costs and the most cost effective strategy should be chosen. As an example, hydro testing activities should be planned so they are not performed twice, at the module yard and at the construction site.

### *Labor Related Factors:*

Expert D2 said that initial work schedule was based on 10 hours per day, 6 days a week scheme, which amounts to a 60 hours work week. The working schedule was however adjusted based on the targeted schedule. Overtime was introduced in order to recover schedule. The latter was done at the expense of the productivity. Also, an additional night shift was introduced for the same reason. The night shift further helped in preparation and supporting construction activities for the next morning. Despite that, the overtime and the night shift both result in the lower productivity, premiums for the latter are still relative in comparison with the penalties, in case of exceeding the initial schedule.

During the project D, due to remote location of the construction site, the man-camp with full temporary facilities was set up at the site location. As the allocated construction area was considerable there were no space constraints for setting up all the facilities, multiple camps and fabrication shops. Expert D2 further suggested that the laydown areas should be approximately twice the size of the construction site. The temporary facilities construction was further influenced by work packaging which helped in

sequencing all construction activities. The freedom given by site attributes further helped with bringing materials, equipment and people in and out of the construction site.

### *Industry Related Factors:*

#### *Contracting schemes*

The construction work was fully subcontracted. Expert D1 said that subcontractors did not plan their work to the level needed by the AWP: project should get to the level 4 schedule but subcontractors were only on the level 3 schedule, which impacted planning processes.

Some very specialized contracts were also not specified to enough detail and thus created difficulties in evaluating the subcontractor's work. Expert D1 suggested to manage and control subcontractors more frequently and to not fully rely on the information provided by them. The earlier construction realizes any issue the more effective it will be in solving it. Expert D1 stressed the urgency in decision making.

Expert D2 suggested that embedding subcontractors into the Company's A planning team would facilitate planning the construction workflow. Furthermore, deliveries of materials should be prioritized in order to support the construction sequence. However, suppliers have no drive to bring materials in a certain sequence as that would result in additional costs for them.

#### *Design processes*

Expert D1 expressed that modular component requires engineering discipline to work in a different manner. Reduction of variability in engineering components during the design phase helps later on with procurement and fabrication of modules in the fabrication yards. He further explained that engineers sometimes mistake standardization with repetition of previously designed facilities. Standardization is supporting modular solutions and its main goal is to reduce variability of components. It is much easier to order same materials in bulks and thus establish continuous cooperation with suppliers. Furthermore, during the fabrication it is easier to manage pre assembly of the same components. Expert D1 added that engineers should be more commercially aware of a cost effective design that supports further construction. Savings of 5 percent in steel during the design will not necessary help in effective construction and the latter costs may override the 5 percent steel savings.

#### *Complexity*

Due to the large project scope, the work was divided between 3 joint venture partners and was further subcontracted to multiple subcontractors. The latter split resulted in many interfaces and issues between the joint venture partners, between the joint venture partners and subcontractors, and between the subcontractors themselves. Those issues were mainly related to the responsibilities over the construction activities and work transfers.

### *Management related factors*

#### *Management Team*

Expert D1 expressed that during the project, construction acts more as a client than an equal decision maker in comparison with a project management team. He further explained that project directors usually have an engineering background and it drives their perspective in decision making. Both; project managers and construction managers should act as an integrated team.



Expert D1 explained that the nature of EPC projects is that the scope is very big and everything becomes a number. He suggested that more social engagement and individual approach from the management team is needed on the day to day basis.

#### *Client's management*

The previously explained limited construction role is affecting further cooperation with clients. Expert D1 said that business oriented managers with limited construction experience are not fully able to convince the clients over the right construction strategies. As much as multidisciplinary approach is very helpful in managing projects, understanding of construction is a crucial factor.

## **Case Study E**

### ***Introduction***

The project E was executed in the North America and the project's scope was around 1bln dollars. The Company A scope consisted of two process units. The applied construction strategies were: Advanced Work Packaging and the construction work was around 70 percent modularized. The project E was also an EPC, reimbursable project.

It should be mentioned that the project E differs from the remaining project sample. The rest of the projects were schedule driven due to the urgency of operating the process facilities. The schedule on the project E has been extended due the client's planning and thus the Company A have gained additional two months for construction.

### ***Interviewees***

Construction expert E1 was a Construction Manager on the project E and was involved in all activities at site and in the modular yard. He was involved in the project from pre-FEED through FEED, detail design till mechanical completion. Construction Expert E2 was also a Construction Manager on the project E and from pre-FEED until a handover to a client. In total he was involved 3,5 years on the project.

### ***Main points of discussion***

### ***Construction Productivity definitions and measurements***

Expert E1 defined productivity as an input in a form of hours spent in order to deliver certain quantity. He further explained that there is a wide variety within construction activities. As an example, scaffold should be checked against its rental cost, which is different than costs for other activities. Expert E1 added that existing tools for progress recording are not set up properly. The input of made estimates is not done to enough detail that would support construction.

Expert E2 further added that man-hours per activity are calculated through existing template in order to determine the level of modularization. Furthermore, those man-hours are calculated based on the different factors associated with different geographical regions. In the end, man-hours and quantities are transferred to costs and based on those costs decision over the level of modularization and stick built construction was made.

## *Construction Strategies:*

### *Advanced Work Packaging*

Advanced Work Packaging immensely helped with maintaining proper logistics on site. Under this strategy, all construction activities, materials and equipment need to be planned in two weeks look ahead. Expert E1 said that the main challenge with the AWP lies in setting it up properly from the beginning. The whole AWP team should be brought to the project early in the FEED, and both project management and construction disciplines should drive the strategy. Expert E2 added that construction work packages backed with daily meeting with all subcontractors further helped in organizing the workflow. During those meetings, the work for next day was organized to ensure all the needed drawings are available and that subcontracted parties will not interfere with one another. Also, work packages before being released, needed to be accepted by other subcontractors. They needed to confirm that all the information was correct.

### *Modularization*

Expert E1 said that the modularization strategy helped in executing construction activities under controlled conditions in the fabrication yards. This strategy is however new to Europe and requires other disciplines to understand the modular concept and how this strategy will affect them. Modular component requires for instance electrical discipline to be involved earlier than during the stick built execution.

Expert E2 added that the modular design was very carefully planned in advance and considered integration of modules. Discussions with subcontractors were held to plan the most effective way of bringing in modules and incorporating them to the overall schedule. Those planning sessions really helped in ensuring a constraint free on site execution. Furthermore, modular component brought in a lot of benefits. While the modules have been done off site, the civil and stick built portion was done in parallel on site. The integration of modules to the stick built portion on site went very well. Also, there were no issues with bringing materials to the Chinese fabrication yard. Weekly and daily meetings with procurement helped in aligning the materials' intake.

## *Labor Related Factors:*

The working scheme on the project E was based on the North American standard for 48 hours a week (4 days for 10 hours and 1 day for 8 hours work). Expert E1 added that different regions will have different working schemes. The night shift will depend on the construction activities and can highly support the workflow, if set up properly with interfaces between day and night shift. Expert E2 said that during the project E, night shift was introduced only for two subcontractors. The additional shift was found to be very productive reaching the progress standards set by the Company A.

Temporary facilities and man camp were set up 5 minutes away from the construction site. The man camp was a necessity as the closest city was around 2 hours' car drive away from the job site. Expert E2 also confirmed that the temporary facilities' set up was really good, very close to the work site, with a convenient parking. Furthermore, there were questionnaires provided to craft in order to evaluate their satisfaction with the temporary facilities set up. Any feedback was carefully considered and taken into account to increase welfare and wellbeing of craftsmen.

### *Industry Related Factors:*

#### *Contracting schemes*

While working with subcontractors, hours for construction are included in the initial budget. Based on the latter construction work is subcontracted. There always seems to be confusion with reporting the progress, and it keeps coming back from the subcontractors and then Construction Team revises it on a regular basis.

#### *Design processes*

Expert E1 expressed that the most devastating thing to productivity is when engineers are not allowed to finish their work completely and construction starts with not complete engineering deliverables. Usually the construction work cannot be planned to enough detail and it ends up with more work than initially estimated. Expert E2 also agreed that challenges were mostly in engineering. This discipline needed to deliver information earlier than on a normal stick built construction.

#### *Management related factors*

On the project E there were no issues with respect to management team and client's cooperation. There was introduced Integrated Management Team (henceforth IMT) environment in which the client, the contractor and other subcontractors, were making decisions jointly under alliance format. The main driver was to have high quality of information as an input, to create high quality outputs. In case of any disagreements the team tried to solve the problems in a way that will be the most beneficial in achieving the project's goals.