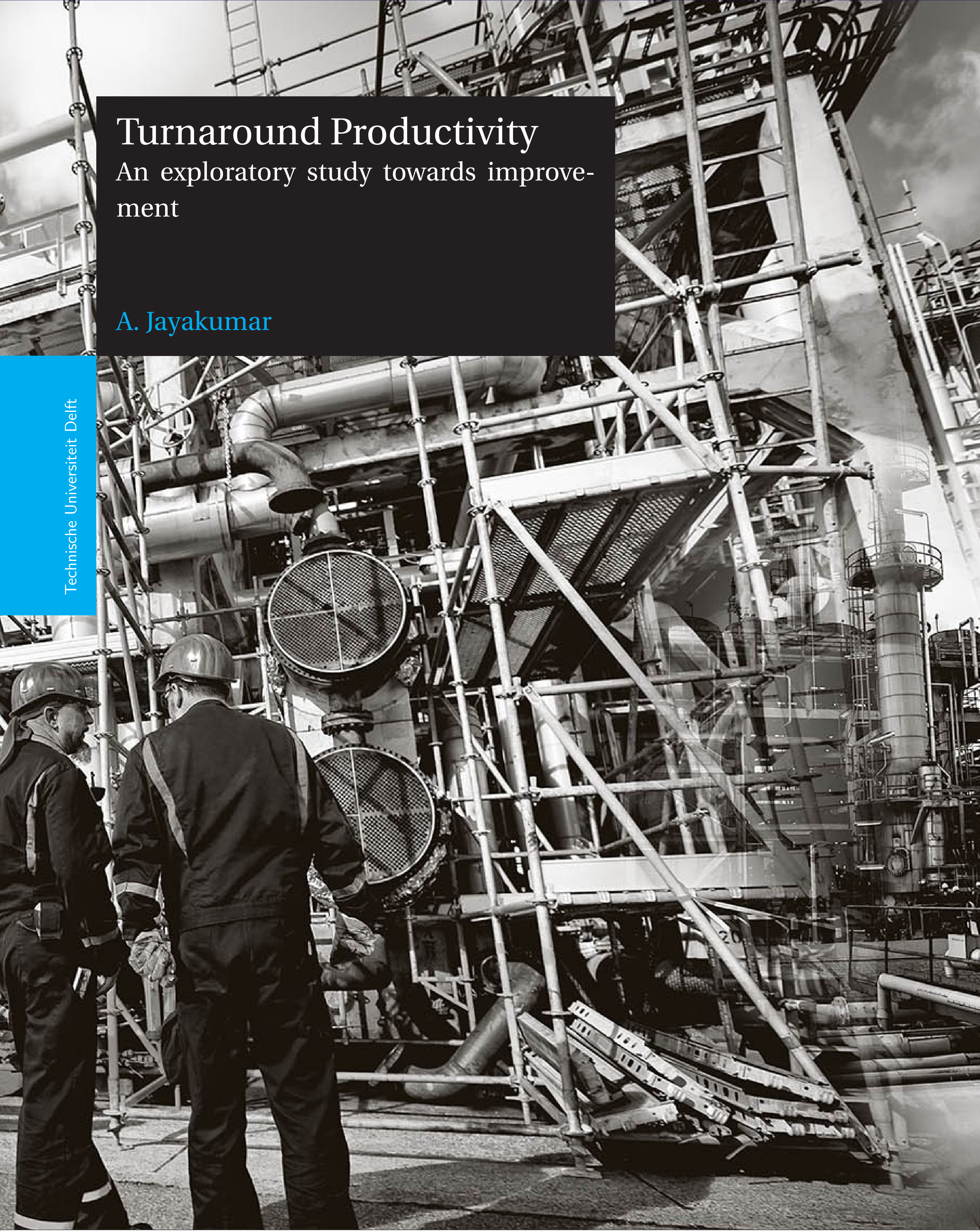

Turnaround Productivity

An exploratory study towards improvement

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TU Delft Delft University of Technology

Challenge the future

Turnaround Productivity

An exploratory study towards improvement

by

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This thesis is confidential and cannot be made public until July 25, 2018.

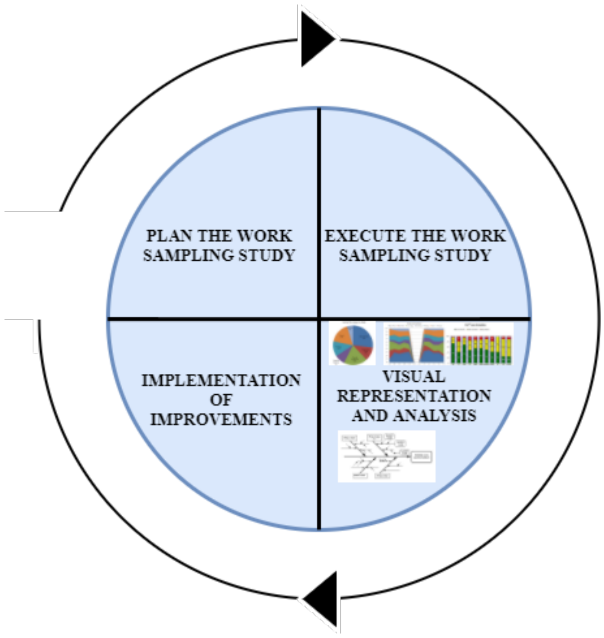
Executive Summary

Turnaround maintenance is crucial to the performance of plants but its actual impact is famously hard to measure and manage. This master thesis was initiated by ENGIE Services West Industrie B.V., a technical service provider whose services include turnaround maintenance works, which constitutes a significant portion. In today's competitive environment, it is not just the quality product but also the aspiration towards continuous improvement that ensures success. This thesis explores whether it may help to conceptualize the productivity of turnarounds for further improvement, in three research phases. In general, the term productivity is defined as the ratio of output over input. However, the concept of productivity is much beyond this simple definition, even if there is no disagreement on this general notion.

First, literature was reviewed to conceptualize productivity for turnarounds in the form of an equation. This was done from a contractor perspective since it was aimed that ESWI would benifit the most from this research. Considering the fact that unit rates, around which turnaround contracts are created, are based on standard hours required to execute work scopes, it was proposed that the productivity of turnaround execution should be explored. The proposed euqation comprised of a resource utilization factor, an efficiency factor and an effectiveness factor. It was then compared to the actual state of productivity within the organization which led to the conclusion that there existed a misconception that productivity is synonymous to efficiency. This value was found to already have an established system for measurement and tracking.

In the second phase, the focus was how turnaround productivity could be improved in practice. Since the organization was found not giving importance to work force utilization and effectiveness, the focus of the research further narrowed down to these components of the proposed equation. The workforce (resource) utilization measure was proposed as a starting point for improvement, since ESWI would have more control over this measure than efficiency measures, while effectiveness measures were proposed to be maintained above a certain level at all times. Literature was once again investigated to find an appropriate starting point to arrive at the improvement recommendations. Work sampling was found to be a popular method of work measurement study and its underlying principles seemed to match with the proposed workforce utilization measure. Further investigation into work sampling led to the definition of productive and unproductive activity categories of the workforce that form the foundation of such a study. These catgories were tailored for turnarounds. It was hypothesized that time spent in the activity categories (especially the unproductive activity categories) could be improved. In order to confirm this, a qualitative survey was designed and conducted within ESWI and ABC company, an organization that provide similar technical services as ESWI. The data collected was then analyzed using appropriate statistical tests and led to the conclusion that there exists perceived opportunities for improvement in the defined categories.

Eventhough the opinions varied for each category, the raters statistically agreed on the central tendency measures, which implied that there were percieved significant opportunities for improvement within many categories. It was also concluded that the working culture of ESWI had minimum effect on the responses, considering there was no statistical disagreement between respondents from ESWI and ABC. Meaning, both technical service providers had similar opinion regarding improvement opportunities from a contractor perspective.Having confirmed the presence of opportunities to improve workforce utilization, the next objective was to translate the findings into a solution for practical implementation. A conceptual model for continuous productivity improvement (represented in the diagram in the next page) was developed for this purpose. The underlying theory behind the model was Total Quality Management (TQM) which thrives for continuous improvement. In order to make it practical, the *Plan*, *Do*, *Check* and *Act* (PDCA) cycle was selected as the structure of the model.



In the third and final phase, the validity and the predicted impact of the proposed conceptual model were described and discussed. Various elements of the model were split among expert interviews and a focus group meeting for the purpose of validation. The validation procedure gave rise to the final turnaround productivity equation, which is as follows:

$$T/AProductivity = \left(\text{\% of Productive Time}\right) \times \left(\frac{\text{Earned Hours}}{\text{Burned Hours}}\right) \times \left(1 - \text{\% of Rework}\right)$$

The validation also led to the conclusion that the model couldn't be implemented immedietly within the organization since ESWI were not accustomed to the components of the model. Moreover, the need for such a model was only confirmed through a qualitative study and the committee demanded more numerical backing regarding this. Hence, a learning process was suggested to help make the implementation of the model practical within the organization. The learning process was split into three stages and the first stage included pilot studies in order to confirm the opportunities for improvement that has been found through this research. Conclusions drawn from the validation procedure also gave more insight into certain limitations of this model, helping in identifying barriers to the practicality of such a model. These are reflected in the recommendations given in the concluding sections of this report. This research started with the main research question "*How can ESWI improve in terms of productivity in Turnarounds?*". This was answered by sequentially answering a set of sub-research questions, which guided the research methodology. The seperate answers to these can be found in the final chapter of this report. Answering these questions led to the answer to the main research question which is as follows:

"*Improvement can only begin by truly understanding what is to be improved. Hence, the first step in improving turnaround productivity is to have a well established definition for it. It was seen the productivity is currently restricted to efficiency measures within ESWI, which contradicts findings from literature which conclude that productivity should be seen as a combination of both efficiency and effectiveness. A turnaround productivity equation has been formulated and validated within the organization. Based on this equation, a continuous productivity improvement model has also been designed, the feasibility of which, has also been tested within ESWI. Although the implementation of proposed model is feasible based on the validation procedure conducted for the purpose of this research, it requires further ESWI specific investigation and management commitment.*"

A. Jayakumar
Delft, July 2018

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Finally, I must express my very profound gratitude to my family and to my friends for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you…

A. Jayakumar
Delft, July 2018

CONTENTS

1
Introduction

1.1. Context of research

We currently live in a world where resources, may it be raw materials or well-trained technical staff, are getting scarcer. Although this is the case, consumer demands are higher than ever and the unwillingness of consumers to pay more for their products, forces companies to strive towards better utilization of their current resources and improvement of the processes involved in delivering their product. In today's competitive environment, it is not just the quality product but also the aspiration towards continuous improvement that ensures success.

1.1.1. Introduction to Turnarounds

Industrial processing plants consist of a plethora of complex equipment and machinery that work under demanding operating conditions and are subjected to deterioration over time. This can be due to aging, wear, corrosion, fatigue and more. These machines work under extreme work conditions and any failure in demand, even the slightest, may result in severe financial consequences for the operating company [1]. Since many of the processes involved are continuous, these plants often have to stop production entirely for a certain period of time in order to allow for maintenance tasks to be conducted. In various processing plants, large-scale maintenance activities must be conducted on a regular basis. Entire production units are shut down for dismantle, comprehensive inspection and renewal. These production stops, also known as *Turnarounds*, are costly affairs both in terms of lack of production and the direct maintenance costs involved in them. Hence, these maintenance activities are executed after months of planning even though their execution may last only a few weeks. These predetermined events involve a cluster of periodic and condition-based maintenance activities that are conducted periodically in order to ensure that the plant always operates at required levels of performance. Turnarounds do not necessarily involve shutting down the entire plant. They may also be periodic shut downs (total or partial) of a process unit in order to perform maintenance.

1.1.2. ENGIE Services West Industrie B.V.

This master thesis was initiated by ENGIE Services West Industrie B.V. (hencefort refered to as ESWI), a department within a world wide company. ENGIE Netherlands falls under the ENGIE group, with 154,950 employees worldwide and operates in 70 countries.ESWI (part of ENGIE Services) works with a variety of industrial customers in the petrochemical, marine & offshore, storage & transfer, food and pharmacy. Technical solutions delivered include smart design, minor revisions, major construction projects, maintenance, etc. Out of the services provided by ESWI, turnaround maintenance works constitute a significant portion. ESWI has been directly involved in a total of around 200 turnaround related activities spread across several major turnarounds between 2011 and 2016 [Internal Data]. Moreover, there are also numerous turnarounds that are currently being carried out by ESWI (planning/execution). ESWI has also signed long term agreements with various companies, some extending up to the year 2021 and the works that would be encountered through these contracts includes turnarounds as well. Majority of the turnaround activities directly carried out by them are mechanical, electrical and instrumentation works.

Over the past years, turnarounds were mostly carried out based on reimbursable contracts, where the contractor is entitled to be paid for all the work that is carried out, may it be planned or unplanned. However, there has been a recent shift in the contracting trend towards a unit-rate type of contract. Such contracts are based on estimated quantities of items included in the project and unit prices (hourly rates, rate per unit work volume, etc.). The contractor's overhead and profits are included in these unit rates. Generally speaking, deviations from estimated rates will be more critical for the contractor, when compared to the previous contract type. Although provisions for additional work do exist, especially in an event like a turnaround where the scope is only partially defined, there is minimal room for errors from a contractor view point. Hence, resource utilization and process quality are not just to be maintained but continuously looked into for improvements, since ESWI now faces more risks as a contractor compared to reimbursable contracts where every manhour is paid for. This transfer of risks towards ESWI rooting from the new contract type provided the initial spark for this research.

1.1.3. THE PRODUCTIVITY RIDDLE

Since turnaround contracts previously were mostly on a reimbursable basis, there was no real focus on the concept of productivity at ESWI due to the lower risks when resource utilization and cost/schedule performances were considered. However, the new type of contract transfers substantial amount of risks to the contractor (ESWI) and productivity becomes an area of importance and worth exploring. In general, the term productivity is defined as the ratio of output over input. A glance through the available literature on productivity and its various applications is enough for a reader to understand that the concept of productivity is much beyond this simple definition, even if there is no disagreement on this general notion. Various literature talks about business productivity, project productivity, construction productivity, labor productivity and more. The fact that there is more than one way of measuring each simply adds to the discrepancies that surround this term. The issues surrounding the definition as well as the measurement of productivity have been the topic of research for various disciplines including economics, engineering and operations research [2]. Since the main theme of this research is turnaround maintenance and given its importance in terms of time as well as quality of execution while also keeping in mind the new contract type, productivity becomes a crucial component for success.

1.2. RESEARCH DESIGN

The primary objective of this research was to provide recommendations to the technical service provider (ESWI) on turnaround productivity. In order to achieve this objective, the main research question for this thesis was proposed as follows:

"How can ESWI improve in terms of productivity in Turnarounds?"

The attempt to answer the main research question was made by splitting it into the following sub-research questions. The answers to these would combine to answer the main research question stated above.

1. How are turnaround maintenance services currently handled by ESWI?
2. How can turnaround productivity be defined with reference to ESWI?
3. What is the actual productivity in the turnaround context at ESWI?
4. How can improvements be made in the proposed turnaround productivity?
5. How can the theoretical improvements be translated into practice at ESWI?

The first sub-research question focuses on the current way of organization and execution of turnarounds by ESWI, to get an overall view on the relevant managerial components. At the same time, it was vital to define the term turnaorund productivity for the purpose of this research. The second sub-research question was framed accordingly. After defining the term in the most appropriate way for ESWI, it had to be compared with the current state of productivity in the turnaround context at the organization. Conclusions drawn from this comparison would lead to answering the next sub-research question which was focussed on finding appropriate methodologies existing in literature that could improve productivity with respect to the proposed definition. Suggestions or recommendations in order to translate the proposed improvement methodology into practice was also to be looked for. The final sub-research question was aimed to achieve this objective.

These sub-research questions are related to each other and answering one was required in order to answer the next. Hence, the sub-research questions would be answered in the same order in which they are presented above. These questions guided the research methodology which will be described in the next chapter. Providing an answer to each sub-research question would ultimately provide an answer to the main research question.

2

Research Methodology

This chapter explains in detail the research methodology followed in this thesis. The sub-research questions defined in the previous chapter guided the research approach which is put forward in the first section. The research framework, scope of research and the report structure are also detailed in the following sections.

2.1. Research Approach

The research approach, as mentioned earlier, was to answer the sub-research questions in the same order as presented in section 1.2. The research was split in three phases which were formed by clustering the sub-research questions. The fist three sub-research questions were grouped together into the first research phase. This phase focused on exploring the current state of affairs regarding turnarounds and productivity at ESWI. The second and third research phases were aimed at answering the next two sub-research questions respectively. The answer to the main research question was provided based on the conclusions of the three research phases. Given below is a schematic representation of the research methodology that was followed in this research, followed by detailed explanation of each of the research phases.

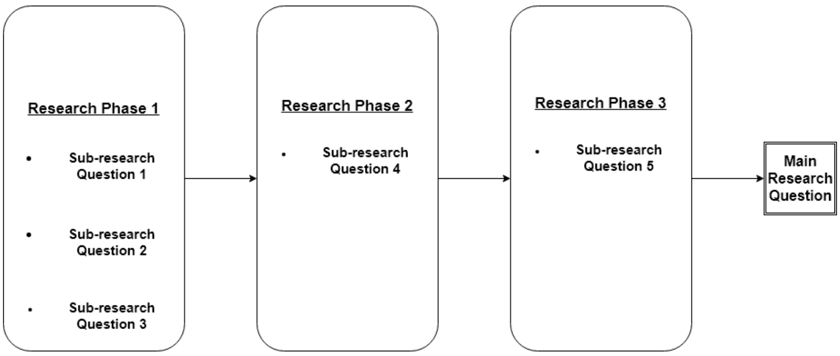


Figure 2.1: Research Methodology

2.1.1. Research Phase 1

This research phase was aimed at answering the first three sub-research questions.The expected outcome of this phase was to get insight into the current measures being implemented at ESWI in order to track/improve productivity in turnarounds. In order to reach this outcome, turnaround organization and management at ESWI had to be investigated initially. Side by side, the term turnaround productivity had to be defined with the support of existing theories, keeping in mind that this definition should be appropriate for ESWI while having substantial scientific relevance. After that, the proposed definition had to be compared with the actual state of productivity within the organization, in order to truly understand the position of productivity in the turnaround context.

EXPLORATORY INTERVIEWS

Qualitative interviews were conducted in order to achieve the underlying objectives of the first and the third sub-research questions. These kind of interviews are usually exploratory and are used to generate insights using an inductive approach i.e. starting with observations and developing hypothesis [3]. The interviews were aimed at achieving as much as information regarding turnaround management at ESWI. The interviews were also semi-structured, meaning gaining the information was ensured but the interviewees were not restricted in sharing opinions and additional insight.

LITERATURE REVIEW

A review of literature was done in order to achieve the primary objective of defining the term turnaround productivity. The sources selected for this purpose included all available literature sources that were relevant to both productivity as well as turnarounds. Literary sources linking both these topics were also searched for but were found to be less in number. Moreover, it was seen that the concept of productivity was less explored in the field of turnaround management compared to other sectors such as construction, maintenance, etc. Considering the scientific nature of this research, relevant information was gathered from scientific sources such as journals, reports, books, etc. available on the internet. **Google Scholar** and **Science Direct** were the primary sources of literature that were used for this research. The search for literature was done using a set of search terms or keywords. The keywords in the context of turnarounds were "*Turnaround*" (*Management*) (*Maintenance*), "*Shutdown*" (*Management*) (*Maintenance*) and "*Outages*". Keywords in the context of productivity were "*Productivity*" and "*Productivity in projects*". After the literature search, the scientific sources had to be filtered to gather sources that would be relevant to this research. The abstracts/ executive summaries at the beginning of these sources helped in identifying these. Turnaround related information was also gathered from websites that proved to contain much useful and relevant information.

2.1.2. RESEARCH PHASE 2

Once the definition was proposed and compared with the actual state of productivity in the turnaround context at ESWI, ways on how turnaround productivity can be improved were identified, since it was not just establishing a definition, rather, paving a path towards productivity improvement that was aimed through this research. After that, relevant methodologies that can contribute to the improvement of the proposed productivity were searched for in existing literature sources, which eventually led to a conceptual productivity improvement model.

SURVEY QUESTIONNAIRE

The opportunities for improvement were investigated using a qualitative survey. The need for this was to know the extend up to which the proposed problem in turnaround productivity exists at ESWI, since literature will only give a backing based on turnarounds in general. It was important to design the survey questionnaire in such a way that the respondents were not restricted in expressing their opinions regarding the research findings. A qualitative survey is best used in order to describe something. A Likert scale survey was proposed for the purpose of investigating opportunities for improvement. More explanation regarding the survey will be presented in the coming sections.

CONCEPTUAL MODEL

This research phase was also focused on creating a solution as to improve turnaround productivity. The outcomes of the preceding phase and the qualitative survey formed the basis for this. The underlying objective was to translate the existing theories into practice. A conceptual model was developed for this purpose. The model was developed with continuous improvement in mind. Hence, it contains a series of steps that have to be repeated periodically in order to continuously assess and improve productivity. More explaination regarding the model can be found in the coming sections.

2.1.3. RESEARCH PHASE 3

Evidence from literature may well be used to defend the definition in turnarounds in general but may not be sufficient to truly understand the adequacy of this definition proposed for ESWI. Also, the model developed as a solution for productivity improvement had to be tested for implementation within the organization. Hence, this research included a final research phase in order to validate the research findings. Conclusions and recommendations were drawn from the validated model in order to provide an appropriate answer for the main research question. It was also kept in mind that the proposed model would only be complete by providing the reader with the limitations and recommendations for future research, since the model was only validated through qualitative interviews/ a focus group meeting and not by testing it in a real-time case(s).

2.2. RESEARCH FRAMEWORK

A research framework based on the proposed research approach is schematically represented in the following diagram.

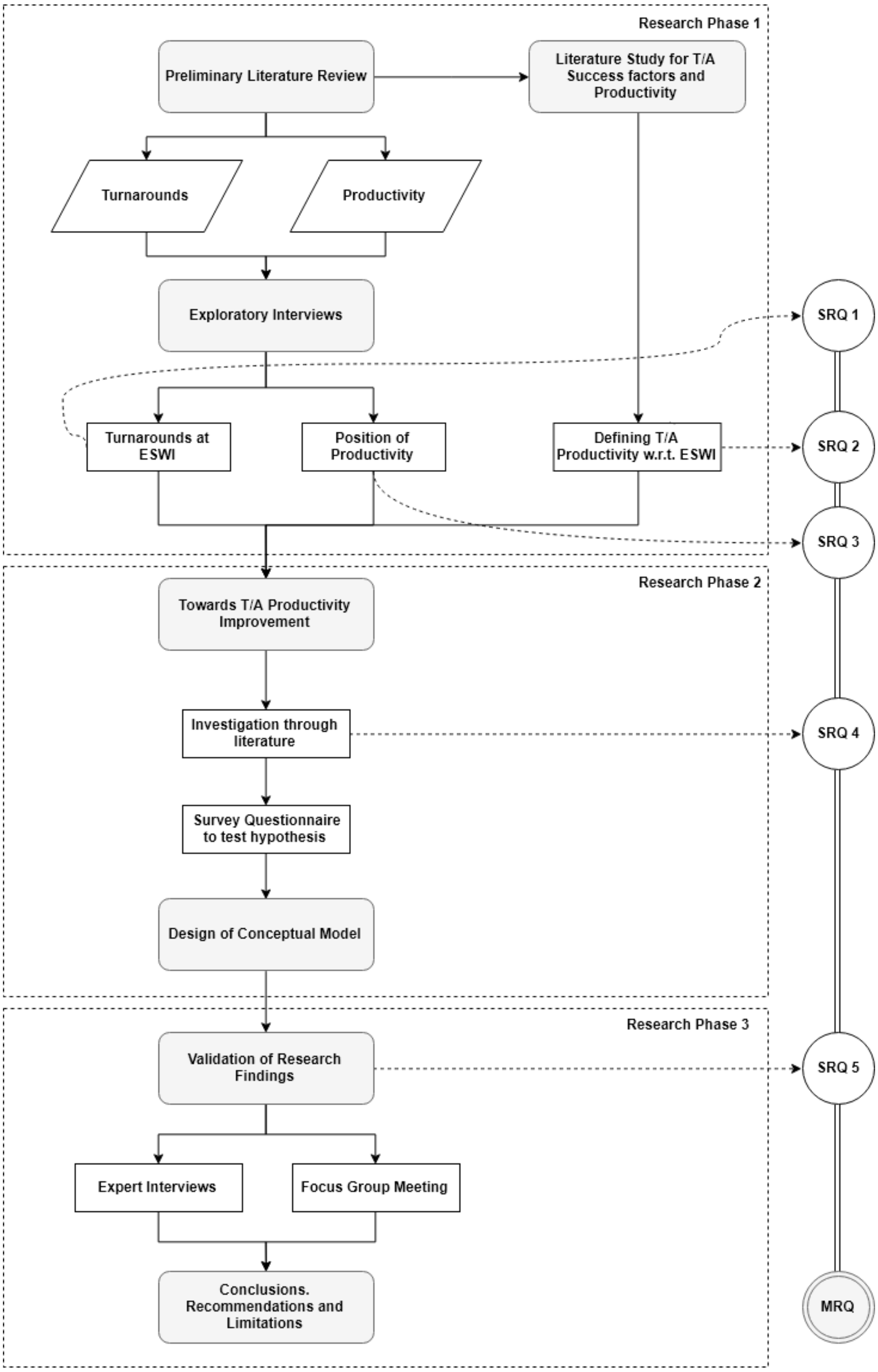


Figure 2.2: Research Framework

2.3. SCOPE OF WORK

This research was carried out in ESWI and hence was confined to the boundaries of turnaround management at ESWI. Holistically, it was conducted from the viewpoint of a contractor in order to ensure that ESWI would benefit more than anyone from this research. However, care was taken in order to maintain not just the practical, but also the scientific relevance for this research.

2.4. REPORT STRUCTURE

The report structure is presented in this section. The first two chapters provided a brief introduction into the research context and the research methodology respectively. The next three chapters will be research phases 1, 2 and 3 respectively. The concluding chapter proposes recommendations to ESWI with respect to the research findings. The limitations of this research and recommendations for future research were also put forward in this chapter. Given below is a schematic representation of the report structure.

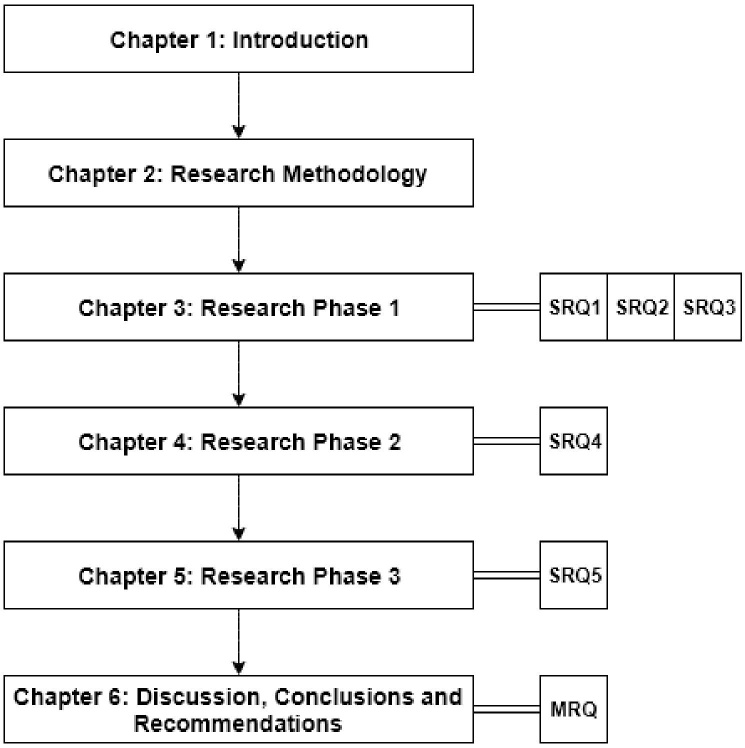


Figure 2.3: Report Structure

3

Research Phase 1

This phase was aimed to understand the general characteristics of turnaround management at ESWI as well as to identify the position (or relevance) of the concept of productivity in the turnaround context at ESWI. The research approach described in Chapter 2 puts forward exploratory interviews as well as a literautre review as the basis for this research phase. These exploratory interviews were conducted at ESWI in order to achieve the underlying primary objectives. This aided the author in answering the first and the third sub-research questions. However, before conducting these interviews, an initial literature study into the topics of turnaround maintenance and the concept of productivity was conducted. The reason for this being the unfamiliarity of the author in these particular knowledge areas. Moreover, the preliminary literature review would help structure the exploratory interviews better. This will be presented in the first section of this chapter. Once the literature review was over, the exploratory interviews were conducted among few relevant personnel at ESWI and conclusions were drawn from them. The second section of this chapter explains in detail the proposed definition of turnaround productivity. Cocnlusions drawn from the comparison of this definition with the actual state of productivity will form the basis of the second research phase.

3.1. Preliminary Literature Review

The literature study was done in two domains in particular. One is turnaround maintenance and the other being the concept of productivity. The first sub-section explores Turnaround Maintenance, its features and norms of practice in the process industry whereas the second one delves into the concept of productivity and the discrepancies involved in it.

3.1.1. Literature Review of Turnaround Maintenance

Turnarounds are *"planned periodic shutdowns of a refinery's processing unit (or possibly the entire refinery) to perform maintenance, inspection and repair of equipment that have worn out or broken in order to ensure safe and efficient operations and replace catalysts that have deteriorated"* [4]. There are quite a few number of literature sources that discuss turnarounds and their management ([4], [5], [6]). Literature suggests that turnarounds have been an area of interest for researchers for quite some time now due to their importance in the operability and the reliability of a processing plant. Turnarounds are expensive both in terms of loss of production of the plant and the direct maintenance costs involved in them[5]. Hence, numerous researchers have explored ways to improve turnaround management.

The preliminary study was conducted to get an overall idea of the relevant characteristics of turnarounds. Turnarounds are events which are planned well in advance of execution. Most activities that take place in turnarounds are maintenance activities along with inspection and repair works. However, it is also possible for improvement activities such as installation of new equipment to take place during these events [4]. The most notable distinction of turnarounds when compared with projects of other nature, is the usually loosely defined scope that can stem from past turnaround experience, inspection reports, operations requests and historical estimates [7]. A few other characteristics of turnaround projects identified from literature includes variable manpower staffing requirements during execution, frequent schedule updates and lack of room for schedule acceleration [7]. The partially defined scope of turnarounds adds to the already existing difficulties related to managing these highly labor intense activities in very short and restricted time periods.

Once the key features of turnaround projects were identified, the next focus of study was turnaround management in practice. Turnaround manuals written by Lenahan, Levitt, Sahoo were given priority as reference in order to gain better understanding of how turnarounds are managed in reality. All these books and other related sources of literature divides turnarounds into various phases. Levitt argues that this division is necessary to apply project management techniques in turnarounds. The identified turnaround phases include the initiation phase, the preparation phase, the execution phase and the termination phase. This phase-wise division is similar to that of a project like an Engineering Procurement and Construction (EPC) project but the time and resource allocation profile for each phase in a turnaround is very different. Turnarounds are associated with extensive front-end loading and short duration of execution, even if emergent works are inevitable [8]. The next study was conducted aiming to understand the organization or the “team" behind a turnaround. According to various researchers, the turnaround organization is one of the key success factors of a turnaround. Literature suggests that the turnaround manager plays the most vital role in the turnaround organization. He or she has total control over the turnaround project [5].

Vichich suggests that the days of turnarounds being considered as a natural extension of plant maintenance are behind us. He highlights the importance of turnarounds by arguing that they must be considered as business events. The partially defined scope and concurrent operations are obvious challenges that exist in the context of turnarounds. Few other challenges include drain on resources,potential hazard regarding plant reliability, safety challenges and the obvious challenge of not overspending money or time [6] and additional challenges such as environmental,operability, quality and even community affairs targets [9]. Although these events are associated with the aforementioned challenges (and more), while also rendering the plant non-operational for a certain duration, turnarounds, as mentioned earlier are an inseparable part of the plant operations. The reasons for this includes maintenance needs, changes in market demand, profit enhancement, changes in law and many more [5].

3.1.2. LITERATURE REVIEW OF PRODUCTIVITY

The issues surrounding the definition as well as the measurement of productivity have been the topic of research for various disciplines including economics, engineering and operations research [2]. The term productivity finds its origins back to as early as over two centuries ago [10]. The initial literature search regarding productivity was aimed not only at understanding the various contexts where this concept finds a place but also to define it better for the purpose of this research. Various definitions of productivity have been put forward by different researchers over the years. There obviously is high amount of similarity between the different definitions proposed. However, it is the slight variations over the years that is of interest for this research. For example, earlier literature such as [11] suggest that productivity in its simplest form is the ratio of output over input. Various other literature sources support the same view [12], [2], [13]. With this view in mind, this concept was first widely studied in the manufacturing sphere [14]. In recent times, productivity has been explored in domains other than manufacturing such as information technology [15], agriculture [16] and the service sector [17]. The term productivity is defined differently in different contexts but these definitions are mostly derived from the simplest form of productivity i.e. the output over input ratio. Take the service sector for example. Grönroos and Ojasalo relate the productivity of an operation to how effectively input resources in a process are transformed into economic results and value for customers. Another varying definition worth mentioning is the one put forward in [18] which defines productivity as the efficient use of resources in the production of various goods and services. Although the definition of productivity takes various forms in different contexts as was seen in the literature study, the basic concept of productivity is always the relationship between output and input [18].

A common mistake related to productivity management is the inability to distinguish it from concepts that are similar or may even be part of productivity. Tangen tries to distinguish the concept of productivity from related terms such as profitability, performance, efficiency and effectiveness. According to Tangen, productivity is usually mixed up with the aforementioned terms and hence real productivity is unknown and the measured productivity may be dangerously misleading [19]. Interestingly, there is also literature suggesting that the concept of productivity should comprise of both efficiency and effectiveness ([18], [14]). It is only the combination of high values of efficiency and effectiveness of the transformation processes that lead to higher productivity [14].

The quest to find an appropriate method to measure productivity still exists. There is a lack of a standard/norm related to the measurement of productivity due to its multidimensional nature [19]. There exists both mathematical and verbal definitions and approaches of productivity.

3.1.3. OUTCOMES OF PRELIMINARY LITERATURE REVIEW

The first phase of the literature study provided more insight into what turnarounds really are and their characteristics that differentiate them from other kind of projects and maintenance activities. In today's competitive world, organizations look for various ways to improve. The concept of productivity has been established for decades now and various research have been conducted to understand productivity in different contexts. In pursuance of understanding this phenomena at deeper levels, the next phase of the literature study was conducted. It was seen that productivity is associated with discrepancies in terms of definition and measuring in various contexts. The literature study as a whole provided the basic knowledge regarding the topics of interest for the author. The knowledge gained from this literature review in fact opened the door to more questions and aided in designing the exploratory interviews.

3.2. EXPLORATORY INTERVIEWS

The underlying objectives for conducting the exploratory interviews have been already been mentioned a few times now. These interviews were means of getting more insight into the topics of interest. Since the interviews were of an exploratory nature, there was no clearly set interview protocol. The respondents were chosen based on the information that was required in order to achieve the underlying objectives. Since ESWI are responsible for both work preparation as well as execution of turnarounds, respondents were chosen such that insight regarding both could be gained. The first sub-section describes the interview and the respondents whereas the second sub-section is aimed at presenting the relevant outcomes from these interviews.

3.2.1. DESCRIPTION OF INTERVIEWS

Keeping the sub-research questions in mind, exploratory semi-structured interviews were conducted among few personnel at ESWI relevant to the topics of interest. Since both the underlying objectives were focused towards ESWI, the respondents were limited to only personnel working for the organization. Out of all the personnel available for conducting interviews, two respondents from the project management team and one from work preparation were selected. The two respondents from the project management team were selected keeping in mind the first sub-research question in particular i.e. to get an idea about the organization and the management of turnarounds at ESWI. The third respondent was chosen in order to get an idea of work preparation measures at the organization.

The author gained sufficient basic knowledge from the preliminary literature study in order to conduct these exploratory interviews. The framework of themes to be explored were set at the initial stages of the research. However, the specific topics that the author wanted to explore during the interviews were thought about well in advance of conducting the interviews.

3.2.2. OUTCOMES OF EXPLORATORY INTERVIEWS

The understanding or the insights relevant to the topic of research that were achieved from the exploratory interviews are presented in this section. These outcomes can be split and better detailed under certain aspects as follows.

TURNAROUNDS HANDLED BY ESWI

Turnarounds have constituted a significant portion of the total services carried out by ESWI in the past and their specialization and long term agreements with major players in the process industry suggest that turnarounds will continue to do so in the future as well. While considering only turnarounds, ESWI as a technical-service provider, focuses on the work preparation and execution of turnaround maintenance activities. Turnarounds involving ESWI are usually planned and scheduled for by the plant owner/operator with (or without) their consultation and a specific contract is given to them based on the overall turnaround plan and schedule. There are usually a number of contractors involved in a turnaround. ESWI as a contractor are specialized in E&I (Electrical and Instrumentation), piping and mechanical works. If at all ESWI is in charge of supporting works outside of their scope, these works are sub-contracted out to relevant contractors. These support works may include catalyst dumping, painting, non-destructive testing and so on. Hence, interface management has an obvious importance in this context.

ORGANIZATION OF TURNAROUNDS AT ESWI

As mentioned previously, in the turnaround context ESWI's services mainly focus on work preparation and execution of maintenance activities. From the first respondent, an overall idea of a typical turnaround organization under ESWI was obtained. Although the focus of this research in essence should focus on ESWI, it was still important to get an idea about the conventional client side organization as well. Getting a holistic view of the turnaround organization was essential in understanding the nature of organizational challenges that would be faced by ESWI as an organization in the turnaround context. In order to ascertain the typical client side organization, a long term agreement(LTA) between ESWI and XYZ company, a major owner/operator organization in the Netherlands was approached. This LTA would also prove to be useful later on in this research phase. The turnaround organization that is typically followed by ESWI along with the conventional client organization with regards to turnarounds, adapted from the interviews and the aforementioned LTA are illustrated in Figure 3.1.

An important point to be remembered while referring to Figure 3.1 is that the organization structure for the entire turnaround will almost always be more complex due to the fact that there will usually be more than a few contractors (like ESWI) involved in the same turnaround. The multiple number of contractors can be attributed to the contrast between various turnaround activities that are to be carried out in terms of technicality. Hence, the turnaround is usually divided into activities of different technical levels before assigning them to various contractors. The contractors can in turn sub-contract portions (whole) of the work assigned that fall beyond their technical capabilities. However, at this point in research, it was only important to know the presence of multiple contractors rather than investigation into the organization.

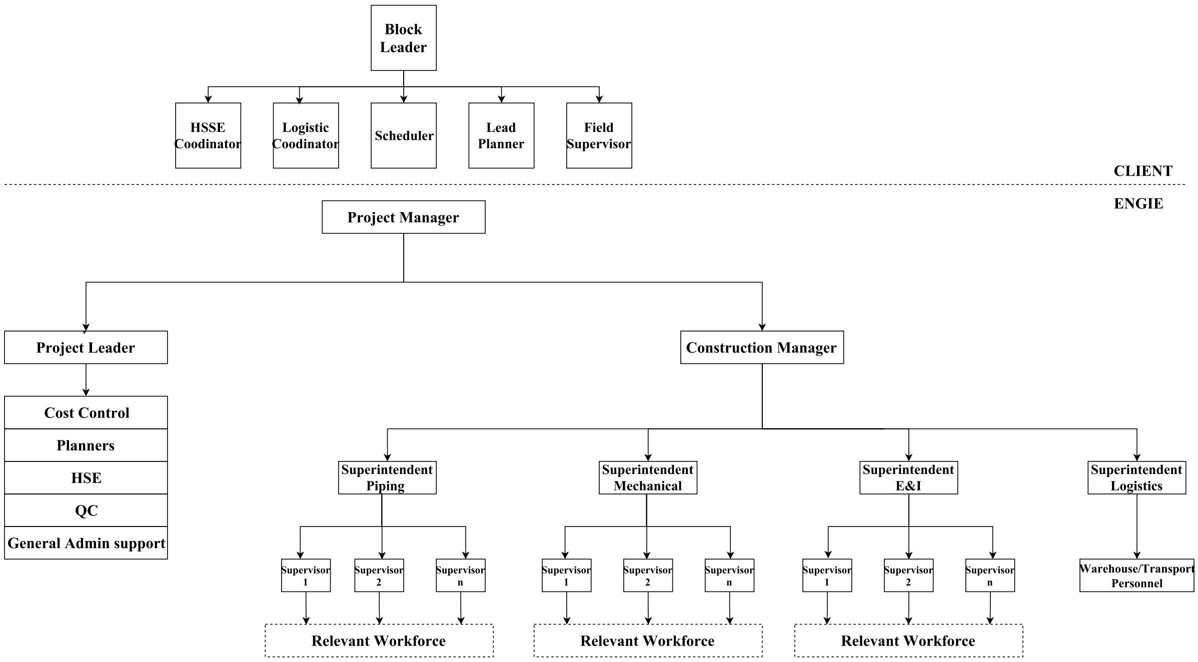


Figure 3.1: Typical Turnaround Organization of ESWI and Client(Source: Adapted from LTA with XYZ company and interview insights)

MANAGEMENT OF TURNAROUNDS AT ESWI

ESWI are specialists in preparation and execution of turnaround maintenance activities of certain nature and hence are almost never in charge of the entire turnaround. As mentioned earlier, turnarounds are associated with emergent works that may present themselves right up till the beginning of the turnaround but they are still to be dealt with within the initially planned time frame. This poses a real challenge in turnaround management. In order to take care of these emergent works, turnarounds are associated with scope freezes around 6 months (can vary) prior to the turnaround execution. This would give contractors like ESWI sufficient time to plan in detail, schedule and develop the budget. From that point on, any item being added to or removed from the work list should ideally go through the change management process.

When it comes to the actual management of the turnaround work, ESWI utilizes the Roser Systems® software which is a complete software package to prepare, manage and execute the scope of maintenance projects such as a turnaround. The software facilitates and centralizes communication between various contractors and also between personnel from different departments in the same organization. Authorization and user group rights enables personnel to work on the software simultaneously in a secure manner. The software is capable of work preparation , scheduling and management of turnarounds. Other softwares that are used together with Roser are ACTO, SAP and OpenIMS.

Work preparation is done by importing scope lists from existing data or creating new scopes based on standard diagrams such as the ISO diagram. It facilitates generating cost estimates and material selection for each activity. After the verification and approval of the data from work preparation, it is transferred into SAP (the Enterprise Resource Planning system utilized at ESWI) or any other ERP System/ the scheduling module which is part of the Roser Systems®, along with the resources, costs and operational deadlines in order to create a schedule. The schedule can be then transfered back into the system which would provide a controlled work flow for progressing activities and phases. The software system also enables obtaining progress status. The handover module of the software system enables the user to establish, link and monitor the quality requirements. There is also a materials module which provides instant overview of received and issued materials. While there are many important components core to the success of a turnaround, for ESWI as a contractor, a major share of success relies on the effectiveness in using the aforementioned softwares. The current established methodology for management of turnaorunds revolves around these softwares.

3.3. DEFINING TURNAROUND PRODUCTIVITY

The first step towards productivity tracking and improvement is to establish a clear definition for the term. Before trying to define turnaround productivity, it was important to have a clear idea about the concept of productivity as a whole. Hence, firstly, various definitions and other concepts related to productivity available through literature were scrutinized. Then, productivity in turnarounds was looked into, in order to establish what exactly is meant by productivity for the purpose of this research with reference to ESWI.

3.3.1. UNDERSTANDING PRODUCTIVITY

The issues surrounding the definition as well as the measurement of productivity have been the topic of research for various disciplines including economics, engineering and operations research [2]. The concept of productivity, generally defined as the relation between output and input, has been available for over two centuries and applied in many different circumstances [10]. A couple of general definitions of productivity found in literature are cited below:

"It is the ratio of output to input for a specific production situation." [2]

"A ratio of output over input that indicates the efficiency of a productive system." [20]

These definitions are as simple as it can get, but these definitions only form the base of a concept that is being exploited by researchers and industries across the globe. In fact, these definitions give rise to more than one question. For example, *How can productivity be measured?*, *What is the relation between the input and the output?*, *How can the input and the output be quantified?*, *What are the consequences of having different outputs and inputs?* and many more. This ambiguous nature of the general definition sparks further research into the concept.

According to Tangen, productivity is closely linked to the use and availability of resources on one hand and, to the creation of value on the other. Although, so far the term productivity seems to be easy to understand, its ambiguous nature has caused much confusion and there are several implications for this [10]. For example, the term productivity is often mistakenly used synonymous to measures of production. However, increased production doesn't necessarily mean increased productivity [10].

Another important point to be noted is that there exists different kinds of productivity. The main reason behind this being that almost any transformation process is fed with several types of input (e.g. labor, capital, material and energy) and emits more than one output [10]. Based on this reason, productivity can be classified into two, namely, partial productivity(output related to one kind of input) and total productivity(output related to multiple types of input) [10]. It must also be comprehended that productivity may take different meanings due to the existence of various hierarchical levels within a company or a transformation process [10].Also, the term productivity is often mistaken for/used instead of four related concepts according to [19]. These concepts are profitability, performance, efficiency and effectiveness and it is worthwhile to have a clear distinction between these terms before proceeding further.

Profitability is the overriding goal for the success and growth of any business, and is generally defined as a ratio between revenue and cost (i.e. profit/assets). Although we can see a component of productivity in it, profitability can change for reasons that have little to do with productivity, such as inflation and other external conditions that may bear no relationship to the efficient use of resources. A company can recover more than the cost of its input by raising prices for its output, which would increase its profitability even when its productivity is decreasing. Hence, cost recovery is what distinguishes productivity from profitability [19].

Performance on the other hand is a term which includes almost any objective of competition and manufacturing excellence. Various performance objectives can have a large effect on the productivity in an operation. Performance objectives should be seen as factors affecting productivity rather than as a part of the concept of productivity [19].

Effectiveness is simply defined as *'doing the right things'* whereas efficiency is defined as *'doing things right'*. Efficiency is strongly linked to resource utilization and hence mainly influences the input of the productivity ratio. It is also easier to quantify efficiency in various terms (money, time and so on). However, when it comes to effectiveness, quantification becomes difficult in most cases. It is often linked to the creation of value for the customer and affects the output of the productivity ratio. A single focus on efficiency proves to be unfruitful when it comes to positively affecting productivity. It is the combination of high values of both efficiency and effectiveness in the transformation process that leads to high productivity i.e. is it possible for an effective system to be inefficient or an efficient system to be ineffective [19].

The relationship between productivity and the concepts discussed above are schematically depicted in the Triple P model (Figure 3.2) developed by Stefan Tangen to give an idea of how the different terms are to be used. The major differences between the five terms i.e. Productivity, Profitability, Performance, Efficiency and Effectiveness can be easily grasped from the model. Productivity constitutes the central part of the model, following the straightforward definition of productivity i.e. the ratio of output quantity to the input quantity. Profitability is also the ratio of these quantities but includes/influenced by price related factors (i.e. price recovery). Performance not only encompasses productivity as well as profitability but also non-cost factors such as quality, speed, delivery, etc. Effectiveness is to be used when the focus is aligned towards the output whereas efficiency represents the how well the resources are utilized.

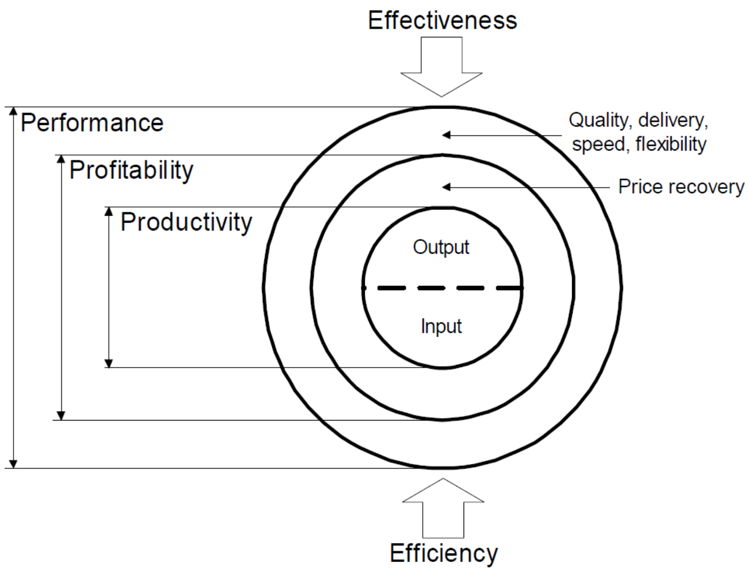


Figure 3.2: Triple-P Model
Retrieved from *A theoretical foundation for Productivity measurement and improvement of Automatic Assembly Systems* [21]

3.3.2. MEASURING PRODUCTIVITY

Literature suggests that the measurement of productivity is not straight forward considering the lack of a standard/norm related to this concept. The term 'Productivity' is a multidimensional term [19]. This view is supported by the following statements which are made about productivity by Stefan Tangen [19]:

- Those who use the term productivity rarely define it.
- There is a lack of awareness of the multiple interpretations of the term, as well as the consequences, to which such discrepancy leads.
- There are both verbal and mathematical definitions and approaches.

Hence, the meaning and the measuring technique can vary, depending on the context within which the term 'productivity' is used [19]. Though the term is widely used, it is often misunderstood, leading to productivity being disregarded or even contra productive decision making [19]. When it comes to partial productivity measures, the advantage is that it is easier to understand and measure in reality. The required data are easily obtained and partial productivity indices are calculated with not much difficulty [22]. Another advantage when it comes to partial productivity measures is that it is possible to recognize a specific partial productivity measure in an important smaller area, function or department, meaning partial measures can detect improvements and the reasons behind them more easily when compared to broader measures. [12].

A major objection or disadvantage of partial productivity measures is that it considers only one production factor and any improvement efforts might affect another partial productivity measure which considers another production factor, which, in turn, might hamper the total productivity although an increase in the former partial productivity measure is seen [12]. An example to this is a problem known as capital-labour substitution, which means that labour productivity can be improved at the cost of capital resulting in a decline in the total productivity. Hence, partial productivity measures tend to overemphasize the increase in productivity [23]. Furthermore, partial productivity measures do not have the ability to explain the overall cost increases, making them misleading if used alone [22].

Total productivity measures provide a good picture of the overall productivity of a process or a company. An advantage of these measures is that they take into account the relationship between various production factors [12]. Having said that, pitfalls of total productivity measures include the fact that they are more difficult to understand and to measure or even quantify [23]. Hence, in practice, they are not always accurate [12]. Total productivity measures are more or less based on a number of carefully made assumptions and can produce varying results based on the weightings given to various factors [12]. A few other difficulties faced when total productivity measures are considered are tracking the activities that improve productivity and also retrieving the data that was used in calculating the total productivity [12].

Productivity measurements are of various nature. Each serve different purposes [24]. A few of these measurement models [25] (retrieved from [24]) are mentioned below:

1. Economic Model

   Total Factor Productivity = Dollars of Output / Dollars of Input

   This model is typically an economic model, which converts output and input into terms of cost and applied in the simple productivity formula. A major challenge of this model is on deciding what costs are to be included (in both output and input). The equation can be modified, based on the type of project, to take into account the variations between project types. Even then, this equation may be subject to significant inaccuracies when applied to individual projects [24].

2. Project-specific Model

   Productivity = Output Units / Input Cost

   This model is derived from the economic model where output are in terms of a specific unit while input remains in terms of cost. Since inputs can be either materials, labor or equipment, input units are converted to respective costs before adding them together. The unit of the output can be specific to the kind of project. Typical units are square feet, cubic meter, etc. This model is more appropriate in cases where productivity is to be determined separately for each kind of output that are present in a project. However, this model may be misleading, when inputs are not sufficiently differentiated based on their respective contribution to the output under scrutiny i.e. it is possible that same inputs are wrongly added in separate productivity measures, which tend to give misleading results with regards to overall productivity.

3. Activity-oriented Model

   Productivity = Estimated unit-rate / Actual unit-rate

   Activity oriented models have their focus on not just the output, but also the activities related to producing these outputs. Labor productivity is an example of this kind of productivity measurement since, labor productivity typically measures man-hours that are required to complete a certain unit of work. Various related activities can be combined using the concept of earned-value [25] (Cited in [24]). These measures are sometimes synonymously used with terms like 'efficiency' [24]. This measurement model is useful when it comes to assessing how the work is progressing as a whole. A major pitfall regarding this model is that its robustness largely depends on the estimation regarding completed work.

3.3.3. CONCLUSIONS

The concept of productivity has been well explored in various project management contexts. A few examples are construction [26], software maintenance [27] and many more. However, there is no clear cut formula in order to measure productivity due to the multi-dimensional nature of the concept. In essence, it is simply the ratio of output over input in a transformation process. However, literature suggests that productivity cannot be restricted to this simple formula. It should rather be seen as a combination of efficiency and effectiveness since productivity is linked to both resource utilization as well as creating value for the customer. Efficiency is easier to quantify while effectiveness measures are difficult in most cases. However, measuring either of these alone might be misleading with respect to productivity. Productivity is also found to be a component of both profitability and performance. However, these concepts shouldn't be taken into consideration while trying to measure/improve productivity due to the various other factors which may have no influence on productivity, but can influence these terms.

When it comes to measurement, there exist both partial as well as total productivity measures. Partial productivity measures are easier to understand and measure while also facilitating the possible detection of improvements and the reasons behind them. However, these measures may lead to misleading conclusions regarding total productivity improvements. On the other side of the coin, total productivity measures may not be as easy to measure and may be based on numerous assumptions, while tracking improvement activities becomes more difficult. Partial productivity measures seem more appropriate than total productivity measures in this research.

3.4. DERIVING THE EQUATION FOR TURNAROUND PRODUCTIVITY

Now that the author has obtained more insight into the concept of productivity through literature, it was time to derive a definition of the term with regards to ESWI, in the turnaround context. The definition was proposed so that it is applicable to the turnaround scope of ESWI as a contractor.

3.4.1. STEP 1: ANALYSIS OF ORGANIZATION AND MANAGEMENT FRAMEWORK

The first step in defining the term productivity would be to identify the relevant area in which the term is to be used, since it was concluded in section 3.3 that partial productivity measures will be more suitable for this research. The term may be interpreted in several ways in the turnaround context, since the simple definition of the term productivity defines it as input over output ratio. Inputs can be in terms of money, materials, labor, time and so on. Moreover, variables like cost and time may not necessarily related to overall measures. They may also be specific to certain management areas, organization actor/ actor groups and more. Output also will be harder to define in a turnaround context, since it is not just money and time, but also quality which is an essential factor. Since ESWI's main focus is turnaround execution, the productivity definition should also be with regards to turnaround execution only. From a customer perspective, it would be imprudent to just focus on the productivity of the execution phase alone, given the interrelations that exist not only between the various phases of a turnaround , but also from turnaround to turnaround [8]. However, since it was concluded earlier that the proposed definition should be from a contractor perspective, attention should be given to the execution phase.

Looking into the execution of turnarounds, as mentioned earlier, ESWI is restricted to activities or jobs of certain nature that fall within their technical capabilities/ specializations. Hence, a typical turnaround execution that involves ESWI most likely involves other contractors as well. Certain supporting activities are subcontracted as well, which makes the execution place a playground for various contractors, sub-contractors and related relevant personnel. Hence, the focus should be refined towards the activities that are managed by ESWI alone. It was earlier seen that these maintenance activities are clustered and managed using typical project management principles of planning, scheduling, etc. by ESWI. Execution of these conventionally involves large amount of workforce executing their respective works as per the work preparation. Productivity in management is a possibility but considering the difficulties in identifying inputs and outputs, along with the correlation that exists between different management areas, it might be easier to identify the productivity of the workforce. Starting productivity measurement and tracking at the lowest level in the organization may prove useful later in setting the foundation for identifying barriers to productivity that exist at higher levels of the organization.

Moreover, it is safe to conclude that out of all the relevant actors in the turnaround, ESWI would have the most control over their own workforce. Turnarounds are characterized by large amount of highly intense workforce during execution [5]. Meaning, workforce productivity is a crucial measure in the turnaround context. Workforce productivity can be viewed as an important factor in terms of contribution to the overall maintenance effectiveness. Maintenance effectiveness can be viewed as a balance between the maintenance costs and plant availability [28]. Figure 3.3 highlights the contribution of the maintenance workforce productivity to the overall maintenance effectiveness.

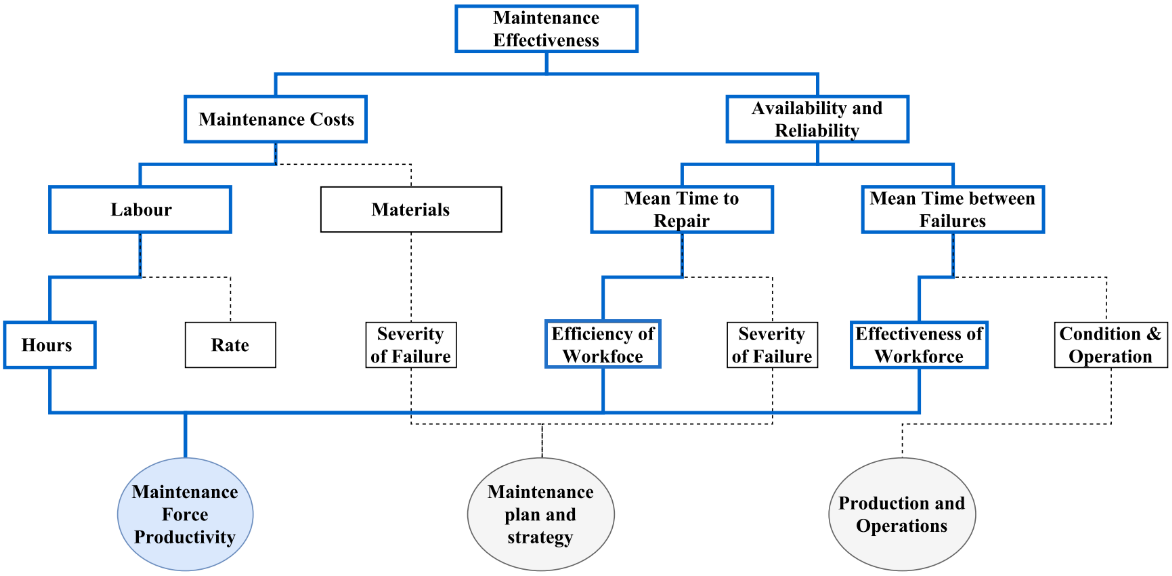


Figure 3.3: Contribution of Maintenance Force Productivity to the overall Maintenance Effectiveness adapted from *WorkforceAlpha.com* [28]

Although the above diagram revolves around maintenance effectiveness, it may well be applied in the turnaround context as well. Literature suggests that turnaround effectiveness is not just a balance between maintenance costs and availability. Four main drivers of turnaround effectiveness namely, turnaround cost performance and deviation, turnaround schedule performance and deviation, the plant's availability/reliability after turnaround completion and safety performance, are essential in evaluating turnaround effectiveness [29]. Plenty of evidence regarding this can be found in literature.

Given in the Table 3.1 are the various turnaround success criteria that were found across related literature. From this table, it is seen that **SC01** (*Meeting Budget*), **SC02** (*Meeting Schedule*) and **SC10** (*Resultant Benefits*) are the most important success criteria (based on the number of citations found) when it comes to turnarounds. These are in accordance with the first three components of turnaround effectiveness discussed above. All of the selected articles/books highlight their importance. Meeting the turnaround budget and schedule are considered as management successes [30]. Resultant Benefits can be a group of criteria on its own and may include not just improved plant availability/reliability, but also plant health restoration, reduction in routine maintenance, reduction in breakdowns and machine safety [30]. The importance of each of these sub-criteria by no means should be downplayed but for the purpose of this research further investigation into these are not required at the moment and hence can be grouped under one criterion.

The next most important turnaround success criteria in terms of occurrence in literature is **SC03** (Quality). Measuring quality of the project is not straight forward but various literature such as [31] and [32] highlights the importance of quality in turnarounds. Quality requirements are usually laid out by the client and evaluation may include assessing level of reworks and level of adherence to technical specifications [30].The next three success criteria are **SC06** (*Personnel Injuries*), **SC05** (*Facility Incidents*) and **SC04** (*Environmental Incidents*) respectively. These can be clustered together under "Safety", which as discussed above, is an important determining factor with regards to turnaround effectiveness. The remaining criteria SC07, SC08 and SC09 are less mentioned in literature. Even then, their significance cannot be ignored and hence were included in the criteria list.

Having confirmed the drivers of turnaround effectiveness by relating them to the identified success factors from literature, the contribution of workforce productivity to these components is to be analyzed. From Figure 3.3, the role of workforce productivity in turnaround cost performance as well as turnaround resultant benefits can be deduced. As mentioned earlier, turnarounds involve both direct costs as well as costs due to

		Lenahan, 1999	Duffuaa and Ben Daya, 2004	Obiajunwa, 2007	Pokharel and Jiao, 2008	Ben-Daya et al., 2009	Ghazali and Halib, 2011	Sahoo, 2013	Obiajunwa, 2013	Number of Citations	Relative Occurrence	Factor of Importance
SC01	Meeting Budget	■	■	■	■	■	■	■	■	8	100%	1.00
SC02	Meeting Schedule	■	■	■	■	■	■	■	■	8	100%	1.00
SC03	Quality	■	■	■	□	■	□	■	■	6	75%	0.75
SC04	Environmental incidents	□	□	■	□	□	□	■	■	3	38%	0.38
SC05	Facility incidents	□	■	■	□	■	□	■	■	5	63%	0.63
SC06	Personnel injuries	■	■	■	□	■	□	■	■	6	100%	0.75
SC07	Successful commissioning	■	□	■	□	□	□	□	□	2	25%	0.25
SC08	Contract claims	□	□	■	□	□	□	■	□	2	25%	0.25
SC09	Stakeholder satisfaction	□	□	■	□	□	■	□	□	2	25%	0.25
SC010	Resultant Benefits	■	■	■	■	■	■	■	■	8	100%	1.00

Table 3.1: T/A Success Criteria identified from literature

lost production which make them expensive [5]. *Direct costs* are calculated by adding up all the manpower, equipment, material and service costs throughout the entire life-cycle of the turnaround i.e. from preparation to termination [6]. *Indirect costs* in a turnaround project are those costs that are incurred in order to support the project and not directly associated to a work order. These may include supervision costs or certain equipment rental costs. Also, there are *Potential costs* that may include costs due to emergent work, overrun, throughput and more [6]. Having said that, since turnarounds are highly labor intensive activities, labor related costs might be more determinant than the various other costs (mentioned above) when it comes to the overall turnaround cost performance and deviation.

As mentioned earlier, effectiveness has its focus more on the output than the input. The same can be said about workforce effectiveness in determining the resultant benefits of a turnaround. Although meeting certain technical specifications and standards are part of the turnaround, the effectiveness of the maintenance workforce goes beyond just meeting these and may prove to be a deciding factor in the overall turnaround effectiveness [28]. Turnaround schedule performance and deviation, although may be affected by many factors (such as management delays, occurrence of additional work and so on), are essentially influenced by the efficiency of the workforce. The role of workforce effectiveness in achieving the required safety performance levels is obvious but the same cannot be said about efficiency.

Concluding this step, a few points are worth mentioning before moving on to the next step in formulating the required definition. Firstly, ESWI should focus on the workforce productivity in the turnaround context. The reason for this can be related to the fact that ESWI is a technical-service provider whose specialties include turnaround maintenance execution. Also, considering the fact that turnarounds involve large amount of workforces and the performance of the turnaround, at least from a contractor perspective, will mostly depend on the productivity of the workforce, ESWI should have its focus on improving workforce efficiencies/effectiveness. Hence, it is vital to define what is turnaround workforce productivity with regards to ESWI. Secondly, the drivers for turnaround effectiveness (found from literature) should also be kept in mind.

3.4.2. STEP 2: FORMULATING THE EQUATION FOR WORKFORCE PRODUCTIVITY

Now that the focus is set on workforce productivity, it is time to provide an equation in order to determine the same. To get a starting point, the preliminary literature study on productivity that was conducted in section 3.3 will be most helpful. Productivity is the measurement of the efficiency with which resources are managed to complete a specific task within a deadline and a given quality standard [33]. Loera *et al.* argues that the final result involves efficiency and effectiveness because it is not feasible to produce an amount of work if it is done without quality standards. As concluded in the section 3.3, productivity should be seen as a combination of both efficiency and effectiveness. Hence, a base formula of sorts can be proposed as follows, keeping in mind that the focus should remain on workforce productivity:

$$\text{Workforce Productivity} = (\text{Efficiency}) \times (\text{Effectiveness}) \tag{3.1}$$

In the above equation, workforce productivity is defined as a product of efficiency and effectiveness. This equation is just a baseline equation given the vagueness surrounding its definition. For instance, at this point, the unit of the final productivity is unknown. Also, the units of efficiency and effectiveness measures are undefined. Moreover, it is assumed that effectiveness and efficiency are the only two core components of productivity. Efficiency takes care of resource utilization whereas effectiveness, in essence, focuses on the output.

Efficiency is commonly defined as the minimum resource level that is theoretically required to run the desired operations in a given system compared to how much resources that are actually used. It mainly affects the denominator of the productivity ratio [19]. In the initial productivity formula defined above, efficiency is one of the two components. Efficiency can be looked at from different perspectives. Work efficiency can be calculated as the estimated work completed compared to the actual work that has been done. The concept of earned-value are applicable in this case. The " earned / actual " ratio, may it be in terms of time, cost, etc. will give an idea as to how efficiently the work is being carried out. Monitoring this ratio enables identifying the work related progress as a whole. If this ratio is seen falling behind desired levels, conclusions can be made about the deviation from the work plan.

Workforce utilization may be defined as the efficiency with which the workforce is being utilized to produce useful work. Although workforce utilization is not a direct efficiency measure, it will be useful in identifying problems with regards to the overall work efficiency. Workforce utilization shouldn't be seen as a substitute measure of efficiency, but rather as a component of productivity. These measures, if used alone may lead to misleading results in terms of the actual work that is being carried out. It is possible that the workforce is found being efficient in terms of work-rate, but this doesn't necessarily ensure that the work that is being carried out is going in the right direction (with regards to the work preparation and planning/compliance to estimates). Hence, the initial equation can be further modified as:

$$\text{Workforce Productivity} = (\text{Work Utilization}) \times (\text{Work Efficiency} \times (\text{Effectiveness}) \tag{3.2}$$

Since the term productivity, in its simplest form, is defined as output over input, the above equation can be further rewritten as follows:

$$\text{Workforce Productivity} = \left(\frac{\text{Output}_{\text{Workforce Utilization}}}{\text{Input}_{\text{Workforce Utilization}}}\right) \times \left(\frac{\text{Output}_{\text{Work Efficiency}}}{\text{Input}_{\text{Work Efficiency}}}\right) \times \left(\frac{\text{Output}_{\text{Effectiveness}}}{\text{Input}_{\text{Effectiveness}}}\right) \tag{3.3}$$

Given this equation, it is time to define the appropriate input and output measures for each factor. In order to do so, it is important to define the unit in which the measurements are to be made. Work efficiency measures are currently readily available through Roser Systems® software. The software facilitates work efficiency measurement by making use of the concept of *Earned hours* and *Burned hours*. Although the software doesn't directly provide efficiency values, the output data based on the predefined KPIs in Roser ® are transfered to excel documents and calculated accordingly. Work efficiency calculations have been calculated in turnarounds by ESWI using this methodology for a few years now. Since the management seems to be satisfied with the use of the software and since work efficiency already has an established methodology for calculation at ESWI, the work efficiency in the equation is assumed to be this measure. Going back to the findings from section 3.3.2, it can be seen that current work efficiency measurements are based on the activity-oriented model because of which, the progress of the work can be tracked.

Now that it has been decided that the work efficiency is to be calculated as per the already existing methodology, it is wise to calculate the remaining metrics in the same units i.e. time. Although the final work efficiency measure will be a dimensionless fraction (or percentage), this research assumes that all the measures in the equation are to be measured based on time.

TIME-BASED PRODUCTIVITY MEASURES

Usually, output in a transformation process is not a single product. It may be a combination of various products/services varying in size, type and more. One way of combining these outputs into one single output is by converting them into monetary values and adding them up to give a total value [12]. However, such solutions might cause the measures to be influenced by price-recover factors [12]. Arnold *et al.* (1991) proposed that the unit of time can be used as a common measure for productivity [12]. He argued that time study techniques can be used to determine the standard time for an activity. Jackson (1999) proposed productivity measurements solely based on the ratio between value-adding time and the total time for an activity [12]. According to him, time-based measures are easy to measure and also easily understood by everyone [35] (cited in [12]). However, a major limitation to an exclusive time-based measure is that total time measurement doesn't provide information about the consumed resources [12].

Concluding this step, it can be said that turnaround workforce productivity should include both efficiency and effectiveness measures. When it comes to efficiency, workforce utilization should be calculated along with work efficiency, since using either of these measures alone may be misleading in terms of productivity assessment. The unit time has been chosen as a common unit of measurement since work efficiency measures have already been established at ESWI in terms of time units.

3.4.3. STEP 3: MEASURING THE THREE COMPONENTS OF WORKFORCE PRODUCTIVITY

The last equation has three parts namely, workforce utilization, work efficiency and effectiveness. Now that it has been decided that time is be used as a common measurement unit, it is time to propose measurement techniques for each of these components.

WORK EFFICIENCY

It was concluded in the previous step that work efficiency measurement will remain the same as the one that has been practiced by ESWI over the past years with the help of Roser ®. Work efficiency can be measured and tracked on a daily/weekly basis using this approach. One main reason for not attempting to vary this measurement technique is the fact that Roser Systems® software is a turnaround specific software that can accommodate additional works/reworks while calculating the work efficiency. Since, turnarounds are characterized by additional work scopes that may present themselves while pre-shutdown/turnaround execution phase, utilizing a turnaround specific software such as Roser ® is assumed to provide more accurate results than manual calculations using time study/ activity study techniques.

$$\frac{\text{Output}_{\text{Work Efficiency}}}{\text{Input}_{\text{Work Efficiency}}} = \frac{\text{Earned Hours}}{\text{Burned Hours}} \tag{3.4}$$

In this formula, the earned and burned hours can be calculated in various ways. These calculations can be daily/ weekly or even an overall measure based on all completed work to keep track of the progress. These measures may also be separated based on various activities of different nature (E&I, Mechanical and so on).

EFFECTIVENESS

As mentioned in section 3.3.1, effectiveness is often linked to the creation of value for the customer [19]. Another way of stating this is that effectiveness has its focus aligned towards the output. Effectiveness is something that may be difficult to quantify, since it can have various interpretations as well as drivers. Hence, in order to arrive at a formula to calculate the effectiveness of workforce, the four drivers of turnaround effectiveness that were analyzed in Step 2 will be looked into. Schedule and cost performances are more or less related to efficiency measures and resource utilization. Speaking in terms of output alone, an effective turnaround is a safe turnaround, which meets the required quality specifications of the client. For the purpose of this research, it is assumed that workforce effectiveness has no relation to the safety performance of the turnaround. Moreover, from the exploratory interviews conducted in research phase 1, it was seen that ESWI considers a turnaround as a failure in case of occurrence of any safety incidents, even if cost, schedule or quality performances are off the charts. Hence, "zero safety incidents" should be a target and not a measure of productivity. When it comes to quality, technical specifications are more of a target than a success criterion. Meeting these are considered as requirements.

When the workforce is considered, the quality of work shouldn't be sacrificed for improved efficiencies. Hence, quality becomes an integral part of the productivity equation in order to avoid "fake efficiencies" [28]. Quality assurance/quality control audits are carried out by both ESWI as well as the customer. However, quantifying the audit results can be difficult. There might be predefined scores based on various criteria or adherence to technical specifications. However, it wouldn't make sense to simply incorporate these scores into the equation for workforce productivity, since it was established earlier that time will be the common unit of the proposed workforce productivity measurements. Hence, effectiveness should also be calculated in the same units.

One approach for this can be measuring the percentage of time spent on resultant reworks from failed quality inspections. For example, if an activity required 8 man hours in which 90 minutes were spent on reworks, then the effectiveness should be around 80% i.e. (6.5 hours/8 hours). The proposed formula for workforce effectiveness alone is as follows:

$$\frac{\text{Output}_{\text{Effectiveness}}}{\text{Input}_{\text{Effectiveness}}} = \frac{\text{Burned Hours-Rework Hours}}{\text{Burned Hours}} \tag{3.5}$$

This formula has its drawbacks. Firstly, reworks cannot be associated to deficiencies in workforce effectiveness alone. Poor definition of work elements which would lead to further misunderstandings regarding work expectations, can also be a reason for rework [4]. Secondly, the sincerity of the organization (contractor) in measuring and recording the reworks comes into questioning. Personnel may be aligned towards adjustments of sorts to cover up reworks. They may be recorded as additional work, which would further lead to false productivity results. Only once they are accurately recorded, reworks can be managed [36].

WORKFORCE UTILIZATION

Work efficiency can be considered as an extension of workforce utilization. However, unlike work efficiency which may be interpreted in monetary terms, unit time terms or other, workforce utilization essentially measures the degree to which a workforce is utilized in a given time period [36]. Reduction in workforce utilization can occur due to various reasons such as waiting for equipment access, lack of planning resources and so on [36]. Accepting Jackson's view on productivity measurement based on ratio between value added time and the total time for an activity, *"Wrench Time"* or *"Hands-on-Tool time"* is proposed as a measure of workforce utilization. Wrench time in its simplest form can be defined as "*the average hours/shift that a crafts-person spends directly working to execute construction, maintenance or shutdown activities*" [37].

Wrench time essentially is a measure of utilization of a craft workers time which can be viewed as a resource. Wrench time includes all the time spent on activities that directly contribute to the finalization of a maintenance task. Time that is spent on supporting activities and the time wasted due to delays or other reasons do not fall under this category.

$$\frac{\text{Output}_{\text{Workforce Utilization}}}{\text{Input}_{\text{Workforce Utilization}}} = \frac{\text{Wrench Time}}{\text{Total Time}} \tag{3.6}$$

Wrench time measurements may not be as simple as it may seem. All the various workforce related activities have to be first differentiated based on contribution in terms of value to the process, system and/or the asset. The reminder of the workforce time other than wrench time may or may not support wrench time activities [38].

3.4.4. STEP 4: TURNAROUND WORKFORCE PRODUCTIVITY

Having defined the measurements required for each of the three components, the final equation proposed for turnaround workforce productivity tracking is as follows:

$$TurnaroundProductivity = \left(\frac{\text{Wrench Time}}{\text{Total Time}}\right) \times \left(\frac{\text{Earned Hours}}{\text{Burned Hours}}\right) \times \left(\frac{\text{Burned Hours-Rework Hours}}{\text{Burned Hours}}\right) \tag{3.7}$$

The above equation was designed from a contractor perspective in order to track productivity. In the first step, it was concluded that the focus of ESWI should be on the productivity of the workforce. From there, the various components of this workforce productivity were defined and each of these components were separately analyzed in order to reach the aforementioned final equation. As far as the information obtained from exploratory interviews is concerned, it can be said that there has been no well sort out method for productivity improvement/tracking in turnarounds even though components of productivity such as efficiency exists within the organization. In fact, at present, ESWI only measures earned by burned ratio out of the three componenets of the proposed turnaround productivity equation.

The equation doesn't provide a clear implication of how the 'Total Time' and 'Burned Hours' is to be recorded. These are to be measured on a daily/weekly basis and recorded over time, while also calculating separate productivity values for works of various nature. This is advantageous in two ways. Firstly, recording on a daily/weekly basis would allow to keep track of the progress of the work as well as the productivity of the workforce. Secondly, barriers to productivity can be identified in different activities. The recorded data can also be integrated into one final value for the entire turnaround. Another point to be noted is that wrench time is not a value that is calculated only once, for a single activity or a single craftsman. It should be recorded in a manner such that the average wrench time of the entire workforce can be found. However, recorded wrench times may be based on random calculations and not measured for the whole crew, meaning these calculations may have limited scalability across the entire workforce [28].Having derived this equation, the second sub-research question has been answered.

3.5. PRODUCTIVITY IN THE TURNAROUND CONTEXT AT ESWI

The second primary objective of conducting the exploratory interviews was to identify the current state of productivity with reference to turnarounds at ESWI. Current state would include the importance given to productivity, current tracking/improvement methods as well as the perceived meaning of productivity at the organization. From the respondents a few important insights regarding the current state of productivity were obtained. Firstly, the term "productivity" is almost absent in the organization. Neither of the respondents were able to provide an established definition of productivity in general, let alone in the turnaround context. Given the current methods of turnaround management at ESWI, the organization is enabled to track efficiency rates through the ratio of earned rate and burned rate. Earned hours data can be readily obtained at any point during the turnaround, through Roser Systems®and efficiency measurements are made by transferring this data into spreadsheets.

Another interesting point to be noted is with regards to the LTA with XYZ company mentioned earlier. The LTA includes a KPI (Key Performance Indicators) scorecard that the contractor is supposed to fill out in order to keep track of the project performance. The scorecard contains several modules such *Cost, Quality,* *Scheduling, HSSE,* etc. which in turn are sub-divided into various sub-modules. Each sub-module has certain established criteria for evaluation. Even though the KPI scorecard includes productivity (*Earned by Burnt* rate) as one of the sub-modules (under the *Cost* module) to be tracked weekly during a turnaround, in reality, the relevant scores are given based on intuition and experience of the turnaround team rather than through actual validation using the formula mentioned in the scorecard. Interestingly, components of productivity (Quality, Efficiency, etc.) ca1n be seen within the KPIs.

The LTA also provided more insight into unit rates. According to this agreement, unit rates for work scopes were calculated using the following equation:

$$UR = \sum Norm \times F_c \times F_u \times F_i \times SoNRate \tag{3.8}$$

In the above equation, 'Norm' denotes a defined time to perform an activity or a list of activities. The schedule of norms (SoN) rate basically denotes a standard price based on the euros per hour. The various SoN rates were part of the appendices of the LTA. The contractor factor (F_c) represents the time savings or additional time required by the contractor in comparison to the SoN. The unit factor (F_u) takes into account the ease or the complexity in performing the scope in a specific plant or production unit. Finally, the improvement factor (F_i) represents the efficiency that the contractor is deemed to gain in performance of multiple turnarounds and therefore includes for contractor's increasing experience on the worksite, local procedures and circumstances during the contract period.

From the exploratory interviews, it was also seen that work preparation had a well established methodology in place for progress tracking. The efficiency of the work preparation is calculated based on earned and burned hours. The earned hours are caclulated based on 9 defined KPIs: (1) *Field check executed* [15%], (2) *Plan card perpared* [40%], (3) *Material list prepared* [15%], (4) *Estimations/calculations ready* [20%], (5) *Multi-disciplinary work breakdown ready [intermediate]*, (6) *Plan card ready [intermediate]*, (7) *QA/QC filled in* [5%], (8) *Review by client* [5%] and *Preparation permit recieved (final)*. The progress is presented with the help of an S-curve to track the deviation from the plan. A sample work preparation dashboard can be found in Appendix D.

Work efficiency measures are also currently made available for the execution phase. Most records (regarding efficiency) of previous turnarounds are more or less for the entire turnaround. Even though they are recorded on a weekly/daily basis, these recorded data would eventually be used in order to arrive at the overall performance sheet(s) and this overall performance data is what is preferred to be held by the organization. Hence, out of the three defined components of the proposed turnaround productivity euqation, only the work efficiency measure is being currently recorded and analysed in the exectution phase.

3.6. CHAPTER CONCLUSIONS

ESWI are involved in the work preparation and execution of works of specific nature in turnarounds. Most of the turnarounds will involve other contractors and sub-contractors as well, meaning, ESWI is more focused towards certain kinds of activities in a turnaround such as piping works, mechanical works, E&I works and so on. Although turnarounds are associated with high uncertainties regarding scope until the actual execution of the works, a scope freeze few months prior to the turnaround execution enables contractors like ESWI to plan, schedule and prepare for the turnaround just like any other project in which project management principles can be applied. Any emergent work after that will go through a scope change process and it is safe to say that ESWI are not new to these kind of emergent works and there exists an established methodology to take care of these emergent works. The established methodology for turnaround management deploys turnaround specific softwares such as the Roser Systems®and it was seen that current methodologies have been accepted, given there hasn't been any perceived need for significant efforts to improve current management methodology.

When it comes to productivity, there is a lack of a clear established definition of the term as such. Current productivity measures are more or less restricted to efficiency measures at ESWI. Of course during the turnaround, these values would be thoroughly studied in order to keep track of the progress of work. However, in many cases, these values are just used for analysis/problem solving and not for improvement reasons. It can be concluded that productivity in general has not been given much importance in terms of definition, tracking and improvement in the turnaround context at ESWI. It was stated earlier that there has been a recent shift in contract type in the turnaround context. Further exploration into unit rates revealed that they contain factors that account for additional or less time required for the work, ease or complexity of the work and efficiency which the contractor is deemed to gain over time. Since unit rates already account for these factors, the contractor is obliged to make sure that actual work does not go beyond these rates. The improvement factor forces the contractor to push for continuous improvement. Hence, the boundaries for mistakes are substantially restricted in a unit rate setting compared to a reimbursable setting. Productivity, which was not given much importance now seems like an area worth exploring.

Hence, ESWI could make use of a research that focuses on the concept of productivity in turnarounds. Given the organizational complexity that exists in a turnaround, it is wise for ESWI to focus on their portion of the work. This would benefit ESWI more, compared to a hollistic focus because a turnaround involves more than a handful of stakeholders, in which case, cooperation between the stakeholders, communication and interface management would be the initial concerns and would need more insight into each key player and their perceived productivity definitions and requirements. In such a study, it is possible that the improvements in terms of the overall turnaround productivity wouldn't benefit ESWI as an organization as much as for an ESWI specific study. When it comes to turnarounds, ESWI are mainly responsible for work preparation and execution. Work preparation was found to have an already well established system for efficiency tracking. There are clear established KPI definitions within the organization for work preparation. Current measures for execution are also restricted to simple earned by burned calculations and as literature suggests, it is only a component of productivity. Although the same can be said for work preparation, considering the fact that unit rates are based on standard hours required to execute work scopes, diving deeper into productivity in work preparation may not be of imminent need. The focus should rather be on turnaround execution alone.

An equation for turnaround productivity was proposed for the purpose of self-assessment and tracking in the execution phase of a turnaround. The proposed equation for turnaround productivity focuses on the workforce. Three components (workforce utilization, work efficiency and effectiveness) of turnaround productivity were defined, of which, only work efficiency measures are currently being recorded and analysed within the organization. Summarizing the conclusions, it can be said that the stride towards better turnaround productivity is found to be stagnant. The current definition of productivity in the turnaround context is restricted to work efficiency measures. An improvement process can only begin with a well established definition of the term with reference to ESWI. Such a definition seems to be more vital than ever considering the recent shift in turnaround contract type, upon which, future commitments have already been made with a major client for the coming years.An equation for turnaround productivity was proposed in the first research phase. The proposed equation has three components of which only work efficiency is currently being measured and tracked.

4
Research Phase 2

From the previous research phase, it was concluded that productivity is defined vaguely in the turnaround context at ESWI. A definition of turnaround execution productivity for the technical service provider was also proposed in the previous research phase by scrutinizing the concept of productivity through a literature study. It was seen that currently productivity measures were restricted to just one component of the proposed equation (work efficiency). It was also seen that the lack of an established definition for turnaround productivity was the reason for the stagnant efforts to improve it at ESWI. Now that a definition had been proposed, it was time to provide recommendations on how to improve the newly defined turnaround productivity based on existing theories from literature. It must be noted that the definition proposed was from a contractor perspective, meaning the term turnaround productivity shouldn't be mistaken for the productivity of the overall turnaround process.

4.1. Towards Productivity Improvement

Deriving an equation for productivity tracking is only half the job. Obtaining the metrics accurately and efficiently is the key towards improvement. Having said so, the initial focus for ESWI should be to maximize the percentage of wrench time i.e improve the workforce utilization. Although the proposed equation tracks workforce utilization, work efficiency and effectiveness, improving wrench time percentages should come before work efficiency, while maintaining the quality of work by trying to keep the effectiveness measure at a favorable constant. The reason for initially identifying improvement opportunities in wrench time percentages, compared to the other components of the proposed definition is because wrench time values are directly related to the workforce alone and ESWI has the most control over them. Meaning, improvements can be easily identified and implemented at the workforce level. Once wrench-time improvements are made, maximizing the value of wrench time should be the focus [28]. This means, getting more work done in the same amount of time i.e. improving the work efficiency. Another reason for suggesting initial focus on wrench time is due to the fact that ESWI currently does not implement wrench time calculations for turnarounds. There may be possible improvement opportunities that have not been identified at the workforce level.

4.1.1. Wrench Time and Work Sampling Technique

Wrench time can be simply defined as the amount of time spent by a craft worker on direct work/activity i.e. performance of those elements of a task that directly advance its completion. Wrench time/ direct work rate studies have been have been attracting interests of practitioners from various fields for a long period of time [39]. In order to improve wrench time percentages, the real focus should be on the non-wrench time related activities. Identifying these activities is the first step towards wrench time improvements [28]. One popular technique for direct work rate measures is work sampling, which is a technique that was originally developed by Leonard Tippett in 1927, to measure standard work times in industrial processes [40]. Its key objective is to determine how the workforce uses its work time by establishing direct, support and ineffective work-time proportions [40]. It can be used to facilitate quantitative analysis in terms of the activities of workers, machines or processes [41].

The American Institute of Industrial Engineers define work sampling as:

"*The application of statistical sampling theory and technique to the study of work systems in order to estimate universal parameters from sample data. It is commonly used in the work measurement and methods engineering area to produce statistically sound estimates of the percentages of time that a work system is in any of a variety of states of work activity. With appropriate procedures, work sampling can produce information from which time standards might be determined*" [41].

However, work sampling can only be regarded as an indirect measurement of actual productivity since it just measures time utilization [42]. It is widely accepted as a tool to measure worker time for direct, support and idle conditions with ease, at less cost and minimum amount of time [43]. Having said so, it is clear that work sampling alone shouldn't be used as a technique for productivity measurement. The derived equation for turnaround productivity in section 3.4 is in accordance with this i.e. it includes not just wrench time percentage but also two other components (work efficiency and effectiveness).

REVIEW OF PREVIOUS STUDIES

Thomas *et al.* defined 'work study' as "*the systematic study of work systems for the purposes of finding and standardizing the least-cost method, determining standard times and assisting in training in the preferred method*" [25]. It may sometimes be referred to as 'time-and-motion study' since it mainly consists of two parts i.e. work-methods study (motion study) and work measurement study (time study) [25]. A work method study involves finding the preferred method of doing the work whereas a work measurement study is used to determine standard times to perform various tasks. Work sampling technique falls under work measurement study part of work study [25].

Thomas *et al.*, argued that work sampling technique can be used as a surrogate for productivity measurement as long as its practical limitations are recognized [39]. In the study, the authors conclude that work sampling can be used as a reliable estimator of construction productivity as long as the definition of direct work is narrowly defined. Yet, in a later research, Thomas *et al.* also argues that for labor-intensive activities (like turnaround execution), waiting or delay time is not related to productive time and productive time is unrelated to productivity [25]. Given these conclusions by Thomas *et al.*, it may seem as if wrench time studies may prove to be unfruitful when it comes to assessing productivity. However, Al-Ghamdi pointed out that even though Thomas's conclusions had strength and warranted further investigation, they contained the following weaknesses: the use of previous studies with different observers, objectives and work sampling categories; use of varying performance factors based on different studies; and reliance on the accuracy of unit-rate estimates (retrieved from [40]). Nevertheless, extensive research has been conducted over the years by various researchers to underline the benefits of work sampling in assessing/forecasting productivity. Out of these, a research conducted by Liou and Borcherding concludes that work sampling information has a close relationship to workforce productivity and confirms the usefulness of work sampling data as a predictor for the productivity projection model proposed in the article [41]. Liou and Borcherding statistically demonstrated that work sampling results strongly correlate with unit rate productivity (concrete man hours/cubic yard) for power plant construction projects with the help of 41 data points for concrete work elements [40]. Both Thomas *et al.* and Liou and Borcherding, assumed work sampling components to be the dependent variable and crew output/ unit rate productivity as the independent variable as part of the statistical regression analysis in their respective studies. This is contrary to an earlier research conducted by Drewin, where the assumption was that labor productivity is the dependent variable and work sampling data (direct,support, and delay) is the independent variable [40]. Another study, which focused on the Canadian housing sector, also showed that work sampling data could be used to indicate actual site productivity and crew learning rates [42]. Tsehayae and Fayek proposed a research framework for work sampling and its applications for comparative studies of work time proportions of crew members.

Much research has been reported on the direct, support, and delay activity proportions of various trades. Yet, none of these are based on a standard activity list for each category, and their results may lead to different activity proportions [40]. Having said that, work sampling has received increased emphasis from managers struggling to control costs, since its simplicity and low cost makes it a powerful technique for determining workforce utilization and productivity improvement [46].

4.1.2. ADVANTAGES AND DISADVANTAGES OF WORK SAMPLING

Every theory comes with its own set of benefits and limitations. A few of the advantages of work sampling technique, followed by the disadvantages, found in various literature are listed below (adapted from [44]) :

ADVANTAGES OF WORK SAMPLING

- It can be utilized as an indicator of workforce productivity [41].
- It is a relatively simple and easily understood technique [47].
- It is relatively inexpensive and can be done in an economical way [45].
- No special equipment is required to conduct the study [45].
- Interruptions of study can be tolerated to some extent [45].
- One observer can perform work sampling studies of different workers and/or different tasks as opposed to a one-on one (observer/worker) ratio in time/motion analyses [48].
- Observations can be made over an extended time period which decreases the effects of cyclic variations [48].
- Desired level of accuracy possible through statistical techniques [49].

DISADVANTAGES OF WORK SAMPLING

- Work sampling data are not as detailed as data collected by other methods [50].
- It is not a direct measure of workforce productivity [51].
- It does not include the basic information required for individual method improvement [47].
- It does not provide the researcher with any measure of the quality of the work performed [48].
- Although it is not likely due to the large number of observations made, workers may be able to change their work patterns upon sight of the observer. This type of reactivity in which individuals modify an aspect(s) of their behavior in response to their awareness of being observed is known as the "*Hawthorne Effect*" [48].
- The statistical basis of the study may be difficult for workers and/or management to comprehend [48].
- A work sampling study requires trained observers to make inferences concerning cognitive processes. Observers are expensive to train [48].
- If work conditions are continuously changing, then work sampling may prove to be inadequate [52].
- There is a lack of standard guidelines on how to perform it and statistical validation of its effectiveness [53].

4.1.3. ACTIVITY CATEGORY DEFINITION

The central problem of work sampling is to determine the percentage of either direct work or delays in a given environment and operation [41]. Different literature have put forward different category definitions, may it be for workforce, equipment or processes. In order to check the relevance of work sampling in the turnaround context, the activity categories have to be established first before investigating whether there are opportunities for improvement.

DIRECT WORK

This category contains all activities that involve exerting physical effort directed towards the finalization of a certain task. Direct work often involves workers installing materials and/or equipment but also includes the physical effort of support groups [54]. Wrench time is associated with the time spent on the direct work category. An important point to be noted here is that this research assumes that support activities such as preparatory works and instructions are not part of this category, unlike few researches such as [53]. Wrench time percentages can be improved by identifying opportunities to reduce non-wrench time. Non-wrench time activities can be of various nature. Broadly, non-wrench time activities can be classified into two main groups, namely *Indirectly Productive* activities and *Unproductive* activities.

INDIRECTLY PRODUCTIVE ACTIVITIES

These activities do not contribute directly to the maintenance jobs themselves, but they are meant to help accomplish the wrench time tasks in an indirect way by providing the right circumstances for the workers to be directly productive. Given in the table below are a list of various activity indirectly productive activities found from relevant literature sources.

Table 4.1: Indirectly Productive Activities listed in various literature

Source	Activities
(Thomas, Guevara and Gustenhoven, 1984)	Material handling, travel, line out, receiving instructions
(Handa and Abdalla, 1989)	Tools and materials, travel
(Thomas et al., 1990)	Instructions, tools and materials, transporting
(Chan and Kumaraswamy, 1995)	Carrying tools and materials within working area, work-related communications, measuring and other minor contributory work, Obtaining tools and materials outside working area
Yogender Kumar et al (2013)	Mixing mortars, scaffolding, transport, material handling
(Sheikh et al., 2017)	Tools and equipment, materials handling

Taking a look at Table 4.1, it is seen that there is some variation or the other in the activities that are defined as indirectly productive/support activities. Moreover, the selected sources of literature are not exclusive to one particular trade or field. Nevertheless, it can be seen that activities such as material handling, tools and equipment handling are common between all. Since there is no standard defined set of activity categories, for the purpose of this research, indirectly productive activities are grouped into three:

1. **Preparatory Works** (receiving preparatory instructions, setting-up works, discussing material/tool needs, etc.)
2. **Material Handling** (transporting materials to work areas, unloading materials, etc.)
3. **Tools and Equipment** (locating tools, putting on safety equipment, connecting electrical supply to tools/equipment, etc.)

These activities cannot be avoided. However, understanding the percentage of time spent on these activities may prove to be fruitful with regards to improving wrench time percentage.

UNPRODUCTIVE ACTIVITIES

These are activities that do not contribute to the maintenance job at all. While indirectly productive activities are essential, the same may not be true for all the activities that fall under this category. Hence, this set of activities can be further classified into unavoidably unproductive and avoidably unproductive activities [55]. Unavoidably unproductive activities are mainly due to the human factor in the workforce and are mostly related to personal time. It is impossible to expect the workforce to work all day without short sanitary breaks at the minimum [55]. Even if these activities are unavoidable, there might exist scopes for improvement considering possible unwarranted extension/misuse of allowed break times.

Avoidable unproductive activities do not contribute to the maintenance work in any way and also cannot be classified under personal time. Examples of this kind of activities include waiting for all kinds of reasons such as work permits, instructions, materials, tools and so on [55]. Unproductive work can also present itself in the form of reworks that occur due to correcting mistakes made earlier in a particular task. However, it should be kept in mind that these activities shouldn't be considered multiple number of times in the derived equation for turnaround workforce productivity, since the effectiveness measure also relates to the percentage of time spent on reworks.Given in the table below are a list of various unproductive activities found from relevant literature sources.

Table 4.2: Unproductive Activities listed in various literature

Source	Activities
(Thomas, Guevara and Gustenhoven, 1984)	Waiting (for instructions, field engineering, QC,etc.), travel, personal
(Handa and Abdalla, 1989)	Breaks, personal, late starts/early quits
(Thomas et al., 1990)	Waiting and idle, traveling, personal and breaks
(Chan and Kumaraswamy, 1995)	Walking empty handed, searching for tools and materials, waiting (for tools, materials, etc.), correcting finished work, idle (unexplained), non-work related communications
Yogendra Kumar et al (2013)	Idle, chatting
(Sheikh et al., 2017)	Personal, waiting

The activities listed in Table 4.2 fall within both unavoidable and avoidable unproductive activities. Avoidable unproductive activities are mainly associated with waiting and reworks. For the purpose of this research, avoidable unproductive activities are grouped into two categories as follows:

1. **Waiting**
   Waiting time can occur due to many reasons. These reasons may be due to the contractor, client or unforeseen circumstances. It is important to further categorize waiting time, since the contractor (ESWI) is not always entitled to reimbursement of waiting time. For instance, the LTA with XYZ company specifies that ESWI is only eligible for reimbursement in cases where the waiting time is caused by either delayed contamination, unplanned safety standstills, plot clear alarms or instructions from the company (XYZ). According to this LTA, ESWI is expected to, at all times, prevent waiting time by looking for alternative work (source: Internal Data). Waiting time due to obtaining work permits, inefficiencies, movements of personnel and equipment, planned safety standstills etc. are not considered to be unforeseen circumstances and shall not entitle ESWI to adjustment of prices or key schedule dates. Hence, it may prove to be worthwhile to track the proportions of waiting time for the following categories:

   - Waiting for permits
   - Waiting for instructions
   - Waiting for materials
   - Waiting for tools and equipment
   - Waiting for quality assurance/quality control
   - Waiting for sub-contractors

2. **Reworks due to mistakes made earlier in a particular task**
   Activitites that fall under this category can be also regarded as unproductive work. The reason for proposing this activity category is so that the management will be able to determine the percentage of time an average craftsman spends on reworks of this nature.

3. **Unavoidable unproductive activities**
   Unavoidable unproductive activities are mostly associated with personal time and traveling in and around the site. Even though these activities are unavoidable, in reality, it is possible that allowances for these are exploited by crew workers (for example unwarranted extensions of break time). Although

it may seem as if improvements in this category may be limited, research which has shown that significant improvements in productivity start at the simplest of improvements such as improvements in break times and traveling times. The activities that fall under this category can be grouped into either of the following:

(a) **Personal Time** (Toilet breaks, smoke breaks, lunch breaks, etc.)

(b) **Travel Time** (Traveling in and out of work area, lunch, traveling empty-handed etc.)

It is assumed that there exists only work related communications and hence non-work related communication was not included under the unavoidable unproductive activities. This is because it will be difficult to distinguish between work related and non-work related communication for an observer.

4.2. QUALITATIVE SURVEY

Now that the activity categories for a crew member had been established (for the purpose of this research) with the help of literature, it was time to investigate the opportunities for improvement in these categories. A qualitative survey questionnaire was designed for this purpose. The main focus of this survey was on the 'non-wrench' time activity categories i.e. those categories in which time can be reduced to improve wrench time percentages. Another reason for conducting this survey was to identify activity categories that are seen in practice (other than the ones found from literature).

4.2.1. QUESTIONNAIRE DESIGN

The survey questionnaire began with a short self introduction followed by a summary of the research context. The respondents were made aware that the entire questionnaire was with regards to turnaround maintenance only and not any other kind of projects. The questionnaire consisted of four sections, with each section starting with a brief introduction of the section. The four sections were as follows:

1. General Questions

   These questions were developed in order to give some context to the survey analysis results. They would also help to understand if the respondents' characteristics have any influence on the responses. The general questions contained 5 questions requiring the respondent's e-mail address, name, organization, the role or position and working experience in number of years. It was also mentioned that the personal details of every respondent will be kept anonymous.

2. Wrench Time

   This section contained one question, which required the respondents to give their perceived wrench time percentage of a crew worker in a standard shift. This data was acquired with the help of a 4-point Likert scale with 1 representing (0-25%), 2 representing (25-50%), 3 representing (50-75%) and 4 representing (75-100%). The purpose of this question was not to find an average wrench time percentage value for a standard shift but rather to get an idea from a contractor perspective of the believed current wrench time percentage.

3. Indirectly Productive Activities

   This section contained two questions. The first question required the respondents to rate the three defined activity categories (Preparatory Works, Material Handling and Tools & Equipment Handling) on a 4-point Likert scale based on the room for improvement in time spent on these activities. The Likert scale ranged from 1 to 4 with 1 representing 'No room for improvement' and 4 representing 'Lots of room for improvement'. The second question was an open question asking the respondents to list down any activity categories that fall under indirectly productive which were not listed.

4. Unproductive Activities

   The final section consisted of 4 questions. The first question required to rate the frequency of occurrence of the waiting time categories defined in section 4.1.3 on a 4 point Likert scale with 1 representing 'Rare' and 4 representing 'Frequent'. The follow-up question was constructed to facilitate the respondent to list any other waiting categories which were not listed. The third question asked respondents to rank the frequency of occurrence of reworks for correcting initial mistakes, based on the same 4-point Likert scale. The final question required respondents to rate the opportunities for improvement in the defined unavoidable unproductive activity categories (Personal Time and Travel time), based on a 4 point Likert scale similar to the one used in the third section.

The survey questionnaire can be found in Appendix B.

4.2.2. DATA COLLECTION

Keeping in mind, the purpose of this survey, it was decided that the survey respondents will be restricted to Project Managers(PMs), Construction Managers (CMs) and Project Leaders (PLs) with experience in turnarounds. This decision was made considering the fact that personnel fulling these roles would have a much clearer idea regarding the actual situation in the work site. Moreover, personnel falling in these categories would have a better understanding of the overall organizational hierarchy (from craftsmen to client) and its challenges. Hence they would be more able to assess improvement opportunities better compared to personnel fulfilling other specific roles (work preparation, planning, etc.).

A total of 45 PMs, PLs and CMs from ESWI and ABC company (another contractor organization whose specializations include turnaround maintenance), were approached to fill out the qualitative survey. Out of this, a total of 26 responses (approximately 56% response rate) were received, from which 16 responses were from ESWI and 10 from ABC company. One set of response (from ABC) had to be discarded due to erroneous markings of the answers. Additional respondents were invited from XYZ company to fill out the survey questionnaire, but due to low response rate, the decision was made to analyze the data from a contractor perspective alone and hence the related responses were discarded.

DEMOGRAPHICS OF RESPONDENTS

Out of the 25 respondents, 15 were PMs, 8 were PLs and the remaining 3 were CMs. Also, more than half the respondents (approximately 54%) had an experience of 20 years or more. An overview of the roles and experience of the survey respondents can be found in the graphs below.

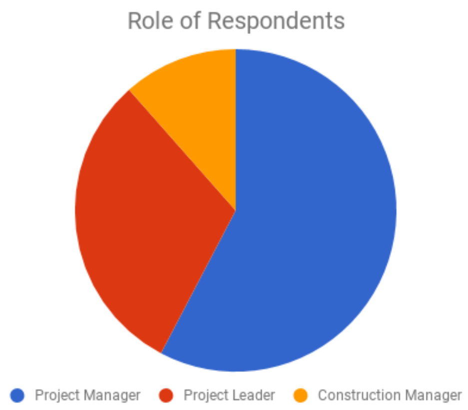


Figure 4.1: Role of Respondents. Source: Retrieved from Google Forms, Google Spreadsheets (Own Graph)

Figure 4.2: Experience of Respondents. Source: Retrieved from Google Forms, Google Spreadsheets (Own Graph)

4.2.3. DATA ANALYSIS

The data that was acquired through this survey questionnaire was mostly ordinal data. Agresti and Kateri defined ordinal data as "*a categorical, statistical data type where the variables have natural, ordered categories and the distances between the categories is not known*" ([56]). The Likert scale is one of the most common types of ordinal data. Various methodological and statistical texts suggest that non-parametric tests are the appropriate inferential statistics to be used while dealing with ordinal type data, since parametric tests require the data regarding interval levels [57]. Described in the following sub-sections, are the descriptions of the central tendency measure, the measure of spread and the non-parametric tests used for the purpose of this research.

MEASURE OF CENTRAL TENDENCY

Central tendency is the tendency of a certain set of random variables to cluster around the center of its distribution. It denotes a typical value that represents the center point of a distribution of a data set. A central tendency is calculated to get a value that is the most representative of a set of data collected [58]. An accurate description of the data can be arrived at with the measure of central tendency [58].

The measure of central tendency is often referred to as averages and is typically the measure of the Mean, Median or Mode. As mentioned earlier the central tendency can be derived from the measure of *'Mean'*, *'Median'* or *'Mode'* but based on the kind of data and study being conducted, some of these measures are more appropriate than the other [58]. Mean is the most popular measure of central tendency, but when data is skewed, mean tends to provide an inaccurate description of central tendency. Hence, in cases of skewed data median is preferred over mean. Median is the middle score of a data set arranged in either ascending or descending order. It is less susceptible to outliers (a data point that is far away from other data points) and hence more accurate to evaluate skewed data. Mode represents the most frequent value in a data set. It has two major disadvantages. First, in cases where two values have the same frequency in the data set, it is hard to choose one central tendency value. Second, in cases where the highest frequency value happens to be far away from the other observations, the mode value becomes misleading in terms of central tendency. Hence it can be concluded that to get the measure of central tendency, Mean is used in the case of normally distributed data, Median is used for skewed or ordinal data and finally Mode is used for nominal data [58]. The study carried out in this research deals with ordinal data that is skewed to a certain degree. Therefore, for the purpose of this research 'Median' will be used to measure the central tendency of the data collected.

MEASURE OF SPREAD

Central Tendency measure alone is insufficient to provide an overall description of a data set. A measure of spread (dispersion) should be used in conjunction with the central tendency measure to represent the variability [59]. A measure of spread is important due to its relationship with the central tendency measure. For example, if the spread of values in the data set is large, the mean will not be as representative of the data as it will be for a small measure of spread [59]. Examples of measures of these kind include Range, Interquartile Range, Variance, Absolute deviation and Standard deviation. Since the data collected through the survey questionnaire was based on a Likert scale, arithmetic measures such as variance or standard deviation would not make sense. Moreover, since median was chosen as the measure of central tendency, the interquartile range would be the most appropriate measure of spread [59].

The interquartile range is a measure of spread based on dividing the data set into four equal parts [60]. The data set has to be first arranged based on rank just like in the case of median. In fact, out of the three values that divide the data set into 4 equal parts, the second one is the median of the data set. These values are called the first (Q1, middle value in the first half of the rank-ordered data set), second (Q2, Median) and third (Q3, middle value in the second half of the rank-ordered data set) quartiles[60]. Both Q1 and Q3 are calculated just like the median in cases of two middle values i.e. taking the average of the two. The interquartile range is calculated by the formula[59]:

$$IQR = Q3 - Q1 \tag{4.1}$$

The interquartile range is a better measure of spread compared to range (difference between the highest and lowest value in a data set) because it is not affected by outliers [60].

Mann-Whitney U test

The Mann-Whitney U test is a non-parametric test used to compare two random independent samples for significant differences by choosing a dependent variable that is ordinal or continuous but not normally distributed [61]. The test is carried out by making some base assumptions regarding the data collected, and based on these assumptions conclusions can be drawn as to whether the samples differ based on their respective medians and the shape of the distribution. There are four basic assumptions that data needs to meet in order to carry out a Mann-Whitney U test[61]:

- Assumption 1: The data of the dependent variable should either be ordinal or continuous.
- Assumption 2: The data for the independent variable should two independent groups.
- Assumption 3: The independent groups need to be observed separately, meaning there should be no relationship between the two sets.
- Assumption 4: The data should not be normally distributed

The respondents can be divided into two categories based on the organization. The participants from each company were different and the data was not normally distributed. Hence, given the nature of the study and the data collected, the Mann-Whitney U test was the most appropriate test to compare both sets of samples.

In this particular research, employees from two companies i.e. Engie and ABC company, were asked a few questions regarding the defined activity categories, most to which the answers were recorded on an ordinal scale. For the purpose of the study it was important to understand the similarity and dissimilarity between the answers recorded from both companies. Since this study was conducted from a contractor perspective alone, understanding the agreement between ESWI and another contractor (ABC) would give more insight into whether there are any significant differences in perceptions due to the company culture/environment. Another reason for conducting this test would be to assess the agreement between the two groups regarding various opportunities for improvement in the defined activity categories.

Running a Man-Whitney U test will generate a set of values. The relevant values for the study are the 'p-value' also known as the significance value, Mann-Whitney U value known as the 'U value' and a standardized test statistic value or known as the 'z value'. The p-value is used to determine if the null hypothesis should be rejected or accepted and the other two values support the decision. In case of the p-value greater than 0.05 the null hypothesis (H0) should be accepted as there is no statistically significant difference in opinions of both the groups studied. If the p-value is less than 0.05 then the null hypothesis should be rejected as there is a statistically significant difference in opinions of both the groups studied.

H0: *The distribution of the two groups are similar; hence there is no significant difference in opinion.*

HA: *The distribution of the two groups are not similar; hence there is significant difference in opinion.*

Kendall's coefficient of concordance

Kendall's coefficient of concordance is a non-parametric test used to study the degree of agreement between the several raters who are analyzing a common set of variables. It measures the strength and level of association between the values that are measured on an ordinal scale. The coefficient of concordance can range from 0-1 and higher the value greater is the level of agreement [62]. In order to carry out a test for Kendall's coefficient of concordance, the data needs to meet two base assumptions [61]:

- Assumption 1: The variables need to be measured on an ordinal or continuous scale.
- Assumption 2: The data follows a monotonic relationship, though this is not a strong assumption that needs to be abided by.

Given the nature of the data gathered and the requirements of the study, a Kendall's Coefficient of Concordance test was the most appropriate test to study the level of agreement between all the raters (inter-rater reliability)[61]. Running a Kendall's coefficient of concordance test will generate a test summary with a significance value (p-value) and decision. Further information can be extracted from the Kendall's W value, which will tell the level of agreement. The p-value will tell if the null hypothesis needs to be rejected or accepted. If the p-value is greater than 0.05 then the null hypothesis should be accepted as there is no statistical agreement between the raters. The Null hypothesis indicates that Kendall's W is Zero thereby indicating no agreement. If the p-value is lesser than 0.05 then the null hypothesis should not be accepted as there is statistical agreement between raters and the alternate hypothesis should be accepted. In this case the Kendall's W is not equal to zero thereby indicating agreement.

H0: *W = 0; There is no statistical agreement.*

HA: *W != 0 ; There is statistical agreement.*

IBM SPSS SOFTWARE

All the aforementioned measures and statistical tests were conducted with the help of the IBM SPSS (Statistical Package for the Social Sciences) software which is a popular software that is used exclusively for statistical analysis. The software makes it possible to input data easily and conduct a plethora of statistical tests and results are presented in either graphical forms or numerical values of significance. The results regarding the Likert scale questions presented in section 4.2.4 is adapted from the output received from the software.

4.2.4. SURVEY RESULTS

This section elaborates on the outcomes of the survey questionnaire and the subsequent analysis conducted. Out of the 7 questions that were asked (apart from the general questions), 2 were open questions and the remaining required the respondents to provide a rating based on a 4-point Likert scale. First, the open questions will be looked into, followed by the ordinal data that was collected and analyzed through the remaining questions.

OPEN QUESTIONS

There were two open questions in the survey questionnaire, one regarding the indirectly productive activities and one regarding waiting time.

- *Indirectly productive activities*
  The respondents were asked to list various indirectly productive activity categories that were missing in the provided list. Given below in figure 4.3 is the collective response of the respondents regarding this. In the list below,the response "*improving workmanship, using multi skilled people, use more efficient*

Are there other categories of indirectly productive activities than the ones mentioned above? If yes, please mention

8 responses

Logistics

Scaffolding in time
Coordination with other contractors

Latest available tools and out of the box thinking on how to work and direct our activities

Improving workmanship. Use multi skilled people. Use more efficient tools

Workpreparation, setting up access (cranes & scaffold), securing and connecting utilities (power, water, etc)

Preparation of the job it self by the supervision. All materials Bag and Tag Ready.

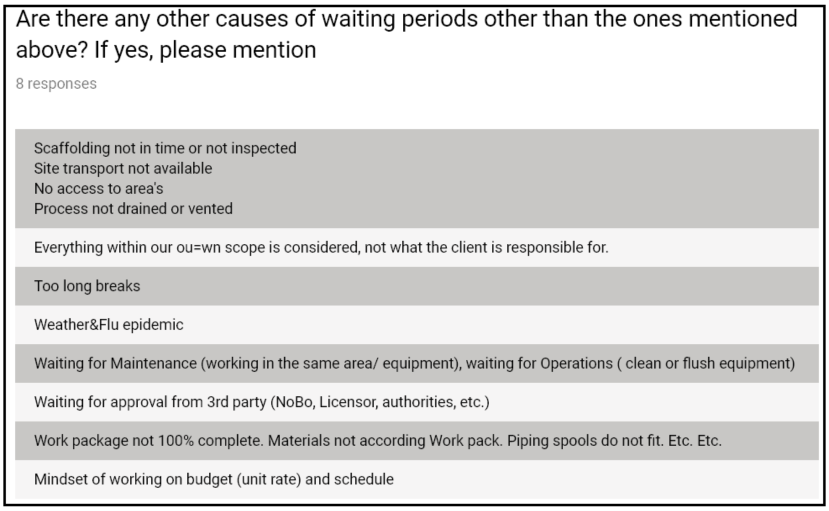
Improvement of the workplace

Planning of the works

Figure 4.3: Responses to Open Question 1. Source: Retrieved from Google Forms

  tools" cannot be considered as activity categories for workforce utilization. All the responses seem to fall entirely or partly under either of the three indirectly productive activity categories that are already defined. Logistics usually have a team which (usually made up of material marshals, store men and drivers) assists the logistics coordinator in executing the logistics plan [6]. Hence, logistics shouldn't be considered as an indirectly productive activity (at least for the purpose of workforce utilization assessment). Rather, the reasons for waiting/delays in work flow must be tried to be associated with logistics.

- *Waiting*
  In the second open question, the respondents were asked to list various reasons for waiting that were missing from the provided list. Given below in figure 4.4 is the collective response of the respondents regarding this. Out of the responses received, "*Weather and Flu epidemic*" should be of interest. In cases



Are there any other causes of waiting periods other than the ones mentioned above? If yes, please mention

8 responses

Scaffolding not in time or not inspected
Site transport not available
No access to area's
Process not drained or vented

Everything within our ou=wn scope is considered, not what the client is responsible for.

Too long breaks

Weather&Flu epidemic

Waiting for Maintenance (working in the same area/ equipment), waiting for Operations (clean or flush equipment)

Waiting for approval from 3rd party (NoBo, Licensor, authorities, etc.)

Work package not 100% complete. Materials not according Work pack. Piping spools do not fit. Etc. Etc.

Mindset of working on budget (unit rate) and schedule

Figure 4.4: Responses to Open Question 2. Source: Retrieved from Google Forms

of extreme weather conditions or flu epidemics, the entire work will be halted and hence, it doesn't seem practical to record proportions regarding this, at least, for a work sampling study. However, there are possibilities that waiting can also occur due to other unforeseen reasons and hence "**Waiting due to Unforeseen events**" should be added to the proposed activity categories. Another additional category that were found missing was "**Waiting for Operations**". All other responses fall within the already defined causes for waiting.

LIKERT SCALE QUESTIONS

The remaining five questions in the questionnaire were Likert scale questions. The respondents were asked to choose an appropriate answer based on a 4-point Likert scale. The scale represented different interpretations for different questions and these can be found in the table below.

Table 4.3: Various Interpretations of the 4-point Likert scale

	A	B	C
1	0-25%	No room for improvement	Rare
2	25-50%	Little room for improvement	Occasional
3	50-75%	Considerable room for improvement	Common
4	75-100%	Lots of room for improvement	Frequent

The first question followed interpretation A, the second and seventh question followed interpretation B and the remaining followed interpretation C. An overall view of the data distribution is represented in Figure 4.5. In the figure, each category has the respective representation of the 4-point Likert scale indicated next to it. The following sub-sections will elaborate on the statistical test results and their interpretations that were conducted as part of the analysis for this research.

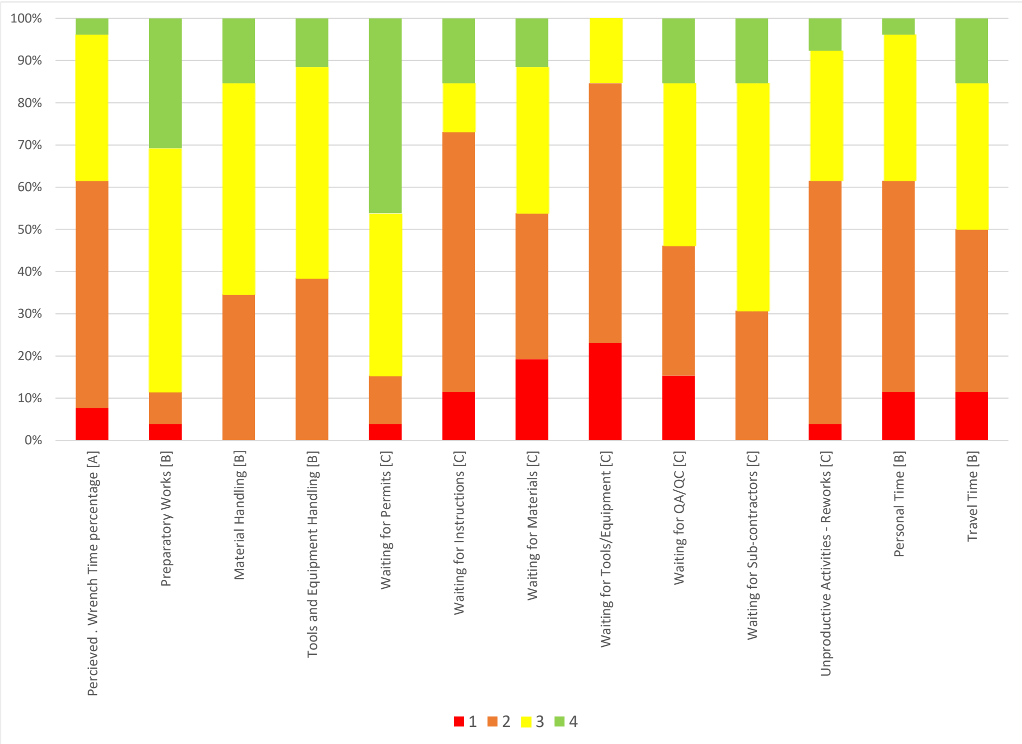


Figure 4.5: Overall view of data acquired from survey questionnaire data. Source: Retrieved from MS Excel (Own Graph)

- *Perceived Percentage of Wrench Time*
  According to [63], average wrench time percentage in the oil and gas industry is somewhere between 25-35%. The research conducted by Van den Heuvel contained data regarding wrench time collected by Buro Walravens, a Dutch company that specializes in work efficiency measures. The figures that was provided by Buro Walravens were representative of maintenance work in general and the data was collected from plants ranging from refineries to chemical plants [55]. The empirically found average wrench time value from Buro Walravens was 33% [55].

  The first Likert scale question was asked in order to get an understanding of the current perception of wrench time percentage. While more than half the respondents believe that on 25-50% of the time is used for directly productive work, a fair share seem to believe that current wrench time percentages fall within the best practice range of 50-75% wrench time. Very few also believe it to be at the extreme ends. Based on the data collected, it can be said that there is a divided opinion regarding wrench time percentage. There is a near equal belief regarding these values when it comes to being above or below the average range mentioned above. The same can be said about responses from ESWI alone also.

  Obviously, the data is based on just intuition and hence any real assessment cannot be made from these numbers. However, considering only responses from ESWI, it is possible that the misconception of wrench time percentages may be the reason why workforce utilization was never focused on at the organization. It may also be that personnel are unaware of the advantages of the gains in wrench time percentages, especially in a unit rate setting.

- *Indirectly Productive Activities*
  Given in the following three tables are the results related to indirectly productive activities obtained from the SPSS software. The Mann-Whitney test was run to check group differences and the Kendall's Coefficient of Concordance value was calculated to assess the level of agreement.

Table 4.4: Central Tendency and Interquartile Range for Indirectly Productive Activities

Activity Category	Median	IQR	Comments
Preparatory Works	3	1	The CT value tends towards the opinion that there is considerable room for improvement.
Material Handling	3	1	The CT value tends towards the opinion that there is considerable room for improvement.
Tools and Equipment Handling	3	1	The CT value tends towards the opinion that there is considerable room for improvement.

Table 4.5: Mann-Whitney U test results for Indirectly Productive Activities

Activity Category	p-value	Result	Comments
Preparatory Works	0.073	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Material Handling	0.597	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Tools and Equipment Handling	0.39	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.

Table 4.6: Kendall's Coefficient of Concordance results for Indirectly Productive Activities

Kendall's W	Significance Value	Result	Comments
0.188	0.011	Reject Null Hypothesis	The raters statistically agreed but the rate of overall agreement was very low (18.8%).

Test results suggest that overall alignment of the respondents was towards the opinion that considerable room for improvement opportunities exist for the time spent in all the three activity categories defined (Central Tendency). However, the IQR values suggest that this opinion is not very strong and is spread around the nearby options. Through visual inspection of figure 4.5, it is seen that respondents believe improvements are the most possible in preparatory works, followed by material handling and then closely followed by tools/equipment handling.

The Mann-Whitney test run on the three indirectly productive activity categories suggest that the nature of response between ESWI and ABC company are not statistically different in either case. The Kendall's coefficient of concordance value suggest that there was significant statistical agreement between all the 25 respondents but the rate of overall agreement was very low.

- *Unproductive Activities - Waiting*
  Given in the next three tables are the results related to waiting time obtained from the SPSS software. The Mann-Whitney test was run to check group differences and the Kendall's Coefficient of Concordance value was calculated to assess the level of agreement.

Table 4.7: Central Tendency and Interquartile Range for Causes of Waiting

Activity Category	Median	IQR	Comments
Waiting for Permits	3.5	1	The CT has a value that points towards mid-way between common and frequent.
Waiting for Instructions	2	1	The CT value tends towards the opinion that waiting for instructions is occasional.
Waiting for Materials	2.5	1	The CT has a value that points towards mid-way between occasional and common.
Waiting for Tools/Equipment	2	0	The CT value tends towards a strong opinion that waiting for tools/equipment is occasional.
Waiting for QA/QC	3	1	The CT value tends towards the opinion that waiting for QA/QC is common.
Waiting for Sub-contractors	3	1	The CT value tends towards the opinion that waiting for sub-contractors is common.

Table 4.8: Mann-Whitney U test results for Causes of Waiting

Activity Category	p-value	Result	Comments
Waiting for Permits	0.345	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Waiting for Instructions	0.318	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Waiting for Materials	0.433	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.

Waiting for Tools/Equipment	1	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Waiting for QA/QC	0.85	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Waiting for Sub-contractors	0.59	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.

Table 4.9: Kendall's Coefficient of Concordance results for Causes of Waiting

Kendall's W	Significance Value	Result	Comments
0.335	0.0001	Reject Null Hypothesis	The raters statistically agreed but the rate of overall agreement was fairly low (33.5%).

Test results suggest that overall alignment of the respondents is towards the opinion that waiting for permits, QA/QC and sub-contractors are common (with waiting for permits more than the others) and waiting for instructions, materials and tools/equipment are occasional (waiting for materials more than the others). However, the IQR values suggest that these opinions are not very strong and are spread around the other options, except for waiting for tools/equipment, which the respondents strongly agree are only occasional.

The Mann-Whitney test run on the six causes of waiting time suggest that the nature of response between ESWI and ABC company are not statistically different in either case. The Kendall's coefficient of concordance value suggest that there was significant statistical agreement between all the 25 respondents but the rate of overall agreement was on the lower side.

- *Unproductive Activities - Reworks due to early mistakes*
  Given in the next two tables are the results related to unproductive work that present itself in the form of reworks due to mistakes made earlier. The Mann-Whitney test was run to check group differences.

Table 4.10: Central Tendency and Interquartile Range for Reworks due to early mistakes

Activity Category	Median	IQR	Comments
Rework due to mistakes made earlier	2	1	The CT value tends towards the opinion that reworks of this nature are occasional.

Table 4.11: Mann-Whitney U test results for Reworks due to early mistakes

Activity Category	p-value	Result	Comments
Rework due to mistakes made earlier	0.144	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.

Test results suggest that overall alignment of the respondents is towards the opinion that reworks due to a mistake committed earlier are occasional. However, the IQR values suggest that this opinion is not a very strong one and is spread around the other options. A point to be noted in this question is that the respondents may have been tempted to choose an option that may not look so bad for his/her respective organization. However, visual inspection of figure 4.5 suggests that a fair share of respondents do believe the occurrence of such reworks to be on the higher side.

The Mann-Whitney test result suggests that the nature of response between ESWI and ABC company are not statistically different for this category of unproductive work.

- *Unavoidable Unproductive Activities*
  Given in the next three tables are the results related to unavoidable unproductive activities obtained from the SPSS software. The Mann-Whitney test was run to check group differences and the Kendall's Coefficient of Concordance value was calculated to assess the level of agreement.

Table 4.12: Central Tendency and Interquartile Range for Unavoidable Unproductive Activities

Activity Category	Median	IQR	Comments
Personal Time	2	1	The CT value tends towards the opinion that there is little room for improvement.
Travel Time	3	1	The CT value tends towards the opinion that there is considerable room for improvement.

Table 4.13: Mann-Whitney U test results for Unavoidable Unproductive Activities

Activity Category	p-value	Result	Comments
Personal Time	0.515	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.
Travel Time	0.307	Retain Null Hypothesis	Median Scores for Engie and ABC Company were not statistically significantly different because p>0.05.

Table 4.14: Kendall's Coefficient of Concordance results for Unavoidable Unproductive Activities

Kendall's W	Significance Value	Result	Comments
0.125	0.083	Retain Null Hypothesis	The raters statistically disagreed and the level of overall agreement was very low(12.5%).

Test results suggest that overall alignment of the respondents is towards the opinion that there is considerable room for improvement in travel time and little room for improvement in personal time. However, the IQR values suggest that these opinions are not very strong and are spread around the other options.

Although the Mann-Whitney test results suggest that the nature of response between ESWI and ABC company are not statistically different in either case, the Kendall's coefficient of concordance value suggest that the respondents statistically disagreed. Meaning the data is unreliable.

4.2.5. CONCLUSIONS FROM THE ANALYSIS OF SURVEY DATA

Overall results show that the respondents did in fact agree that there is considerable room for improvement in terms of time spent on most of the defined activity categories. The cental tendency values confirm this. However, it must be noted that there do exist differences in opinion between individual respondents. The opinion seems to be spread towards both sides of the cental tendency measure in many cases, which is depicted by the IQR values. Two statistical tests were run for further analysis of the data. The Mann-Whitney test was run seperately on each category to analyze the differences between the two groups of respondents (ESWI and ABC). It was seen that in all cases, there were no statistically significant differences between the opinions of the two groups. The Kendall's coefficient for concordance was calculated in order to assess the inter-rater reliablity of the results. This test was run on the three main categories i.e. indirecty productive, avoidable and unavoidable unproductive activities. When looked at each respondent individually , the concordance values suggest that the respondents statistically agreed with regards to all the activity categories, with the exception of unavoidable unproductive activities. From the tests run on the data acquired a couple of things can be inferred. Firstly, respondents do confirm there exist opportunities for improvement in the defined categories. Eventhough the opinions varied in each category, the raters seem to have statistically agreed on the central tendency measures. It can also be concluded that the working culture of ESWI had minimum effect on the responses, considering there was no statistical disagreement between respondents from ESWI and ABC. Meaning, both technical service providers have similar opinion regarding improvement opportunities from a contractor perspective.

4.3. CONCEPTUAL MODEL FOR PRODUCTIVITY TRACKING AND IMPROVEMENT

In the first phase of this research, it was concluded that productivity improvement measures were stagnant at ESWI. The obscurity regarding a definition for productivity was found out to be the main reason behind this. This phase also had the objective of providing a best fit definition of productivity for ESWI in the turnaround context. Later, it was proposed that productivity improvements should start with workforce utilization and opportunities for improvement were investigated through the qualitative survey. The workforce utilization definition and improvement investigation, all revolved around the work sampling technique. This research phase also aimed to provide ESWI with a work sampling framework with the help of existing studies and recommendations on how it would fit in a conceptual model for workforce utilization improvement. The model was validated with the help of expert interviews and a focus group in the next research phase.

4.4. INVESTIGATION OF RELEVANT THEORIES AND TOOLS

In the broadest of terms, the conceptual model was developed with the aim of productivity improvement. The proposed definition of productivity indicates three factors, out of which workforce utilization was concluded to be the initial focus due to reasons stated in the beginning of section 4.1. Having narrowed down to improvement of workforce utilization, it was seen that improvements can only be implemented with the knowledge of current state and the variations over time. Hence, the purpose of the conceptual model proposed was mainly self-assessment and improvement. The following sections will briefly summarize the relevant theories and tools that were exploited to design the model.

4.4.1. TOTAL QUALITY MANAGEMENT (TQM) PHILOSOPHY

Total Quality Management (TQM) is a management method through which management and employees thrive for continuous improvement of the production of goods or services [64]. Its fundamental objective is to achieve customer satisfaction through continuous process improvement. Although originated in the 1950s in Japan, the roots of the concept are the teachings of Dr. W. Edwards Deming and Dr. Joseph. M. Juran, who emphasized that the systems and process through which work is done contributes to 85% of the problems encountered (remaining associated with workers) in any organization and that statistics can be used to control these systems [65]. The fundamental principles of TQM are as follows [65]: (1) Management commitment (2) Training and Education (3) Teamwork (4) Process measurement & Analysis (5) Continuous Improvement and (6) Interaction with Customer.

Although TQM focuses on the total quality of processes, its principles stand true when applied in a specific aspect as well. For example, Cortinas illustrates the possibility of improvement of on-site construction productivity through TQM philosophies. The aforementioned principles will form the base for the design of the conceptual model. Once the model has been presented, these principles will be looked into again in detail. However at this point, the most important thing to be kept in mind is the core assumptions of TQM i.e. "... *process quality is the outcome of all activities that take place within an organization; that all functions and all employees have to participate in the improvement process; that organizations need both quality systems and quality culture*"(cited in [64]).

4.4.2. CONTINUOUS IMPROVEMENT AND PDCA-CYCLE

Out of the principles of TQM stated in the previous section, continuous improvement is the most relevant for the purpose of this research since the purpose of this research itself is to improve turnaround productivity. Moreover, since the focus has been narrowed down to workforce utilization measures, continuous improvement seems to fit in perfectly because improvements in wrench time percentages should not be and cannot be done through a single step of improvement [28]. According to Cortinas, in order for continuous improvement to happen, the management must take steps to [65]:

- Maintain and incrementally improve current procedures and methods through process control oriented thinking.
- Support major innovations with sufficient resources.

Deming proposed that continuous improvement could only be realized with relevant tools for improvement run through a cycle of four groups of activities. This cycle is known as *Deming's Quality Cycle* or the *PDCA* (Plan-Do-Check-Act) *cycle*. It is implemented in order to achieve process improvements and to ensure that the benefits of the improvements are maintained [65]. Today there are numerous tools that can be used for process improvement. However, it is important to know how, when and which tools should be used in the improvement process [64]. The PDCA cycle facilitates just that. Certain improvement tools will fit under different quadrants of the PDCA cycle (refer Figure 4.6).

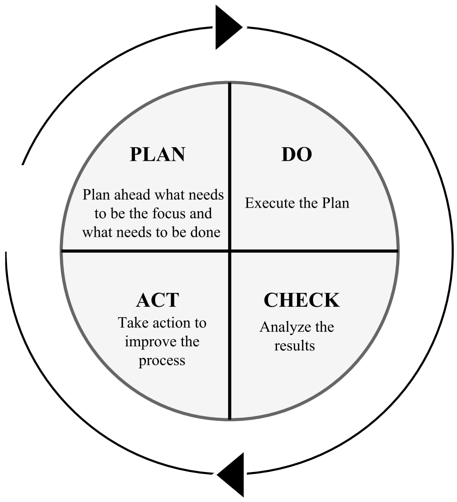


Figure 4.6: PDCA Cycle (Own Figure; adapted from [64]

Brief elaborations of each component of the PDCA cycle are discussed below:

- *Plan*
  The *Plan* aspect refers to defining the desired outcome of the process, establishing objectives in measurable terms and exploring methods to achieve these objectives [66]. An improvement process should not be started without the plan. It is in this stage that the stakeholders come together to establish objectives and investigate the available resources to achieve these objectives. Potential problems and bottlenecks are also realized and methods to mitigate these are adopted [67].
- *Do*
  The *Do* aspect is the implementation stage of the methods delineated in the *Plan* stage [66]. During this phase the outputs need to be recorded and compiled on a regular basis. A measurement needs to be decided upon against which the effectiveness can be gauged [68]. Recording of output regularly brings to fore the unexpected observations and issues that will be studied in detail in the Check stage [69].
- *Check*
  In this stage the observations from the *Do* stage are analyzed and studied to check if the objectives established in the Plan stage have been achieved or not. If not then the deviations from the initial plan need to be observed and the causes for these deviations need to be identified. In this stage, the objectives and methods delineated in *Plan* stage need to be revisited to check if they still hold good and if they are still valid. [66].
- *Act*
  Once the deviations from the initial plan are brought to attention, in the *Act* stage, the root cause needs to be identified and the changes to the implementation need to be decided upon [66]. Decisions regarding changes and adjustments to the *Plan* phase of the next cycle need to be determined [69].

4.4.3. QUALITY IMPROVEMENT TOOLS

While theoretically there exist quality tools that can be part of more than one quadrant of the PDCA cycle, for the purpose of the conceptual model, only tools that are part of the *Check* quadrant will be investigated. This is because work sampling which requires special planning and execution, will cover the *Plan* and *Do* phase of the cycle, while implementing improvements (*Act*) is based on the analysis of work sampling results which is ESWI specific and is out of the scope of this research. The third phase of the PDCA cycle consists of two steps in general. First is the visual representation of the results which will facilitate the next step, which is analyzing the results. The seven basic QC tools emphasized by Ishikawa (in the 1960s) are (1) *Stratification* (later became flow chart/run chart) (2) *Pareto Diagram* (3) *Check-sheet* (4) *Control Chart* (5) *Histogram* (6) *Scatter Plot* and (7) *Cause-Effect Diagram* (or fish bone diagram) [70]. The PDCA road map retrieved from [70] will give a better idea of where these tools fit into the PDCA cycle.

Table 4.15: Seven basic quality tools under various steps in the PDCA cycle. Retrieved from [70]

Seven Basic QC Tools	Steps of PDCA Cycle			
	Plan	Plan,Check	Plan, Act	Check
	Problem	Process Analysis	Solutions	Result Evaluation
Flow Chart	✓		✓	
Cause-Effect Diagram	✓	✓		
Check Sheet	✓	✓		✓
Pareto Diagram	✓	✓		✓
Histogram	✓			✓
Scatter Plot		✓	✓	✓
Control Charts	✓	✓		✓

In the above figure, the *Check* quadrant seems to be divided into two sub-sections i.e. 'Process analysis' and 'Result Evaluation'. For visual representation purpose of the work sampling study, the result evaluation column will be useful whereas for analysis of these results, the process analysis column should be of interest. The aforementioned quality tools form the basis of other quality tools that have been developed over the years for different purposes [64]. Although these 'graphical problem solving tools' are very simple and easy to understand, they are widely used as effective tools of improvement [70].

For the visual representation of the work sampling results, it may be possible that preferences vary from management to management. Out of the 7 basic tools, the Pareto diagram is the only tool that best fits for this purpose. Nevertheless, the nature of the work sampling study can vary. Some studies represent the results based on hourly intervals, whereas some represent the results based on discipline. In both cases, the Pareto chart may not be the best option. The Pareto diagram contains both bars and a line graph, where individual values are represented in descending order by bars and the cummulative total is represented by the line. Since, the purpose of visual representation is to only the various proportions of each activity category, a simple pie chart or similar will be easier to visualize. From previous studies related to work sampling, it is seen that few tools are more popular than other for representing the results. Hence, for visual representation, the 3 tools that were found to be commonly used in various work sampling related studies (not part of the 7 basic QC tools) were proposed. Out of the seven aforementioned tools, Cause-Effect diagram was chosen for the purpose of analysis of work sampling results. A brief summary of these tools are presented below.

VISUAL REPRESENTATION: PIE CHART, STACKED BAR CHART AND STACKED AREA CHART

- *Pie Chart*
  Pie chart is a statistical graph wherein a circle is divided into numerical proportions of data. It represents the relative size of the different parts to each other and to the whole. The arc of each portion is proportional to the magnitude of quantity in comparison to the whole and is usually presented in terms of percentage [68]. It is the most commonly adopted method to represent relative contribution of a category to the whole [68]. The figure below depicts a general pie chart, representing how four different groups contribute a category.

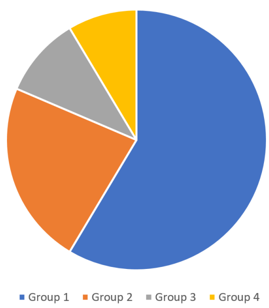


Figure 4.7: Typical Pie Chart (Own Figure). Source: Microsoft Excel

The use of pie chart has its own advantages and disadvantages. Advantages of using the *Pie chart* includes the fact that data is represented in an easy to understand manner and also presented pictorially as a fraction of the whole making it easy to comprehend for a layman. Regardless of the advantages, data visualization experts consider pie charts to be an inferior form of data representation [71], as human brain can comprehend length better than angle specially in situations where the difference in the size of pie is very small. The lack of the human brain to perceive angles correctly leads to inaccurate conclusions as decisions are made on visual impact as opposed to the actual data. Pie chart also falls short in cases where there are too many pieces of data that need be presented as it becomes cluttered making it hard to read. Another important disadvantage of pie charts is that central tendency, dispersion etc cannot be depicted [71].

- *Stacked Bar Chart*
  Similar to the pie chart, a stacked bar chart helps represent different parts in comparison to the whole either vertically or horizontally. They can be represented along one categorical axis and a maximum of two numerical axis. The whole is represented as an entire bar and the parts are represented as the segments in the bar. It is used to depict the relationship of each part to the whole. As opposed to the pie chart, in a stacked bar chart different whole bars can be compared to one another and segments in each of these bars can be compared to one another. The figure below represents a stacked bar chart where the categories form the whole bar and the series are the segments of each bar.

  The use of stacked charts has its own advantages and disadvantages. The advantages of using a stacked bar chart is that segmented data are presented in one graph along with are categories and numerical values. In addition, the contribution of each segment to the overall is also represented in the same graph making it easy to understand. The second major advantage of a stacked bar chart in comparison to a pie chart is that different whole bars with similar categorical segments can be compared with one another and be depicted in one graph. It is the best way to represent trends as information is better presented compared to tables or arrays [68].

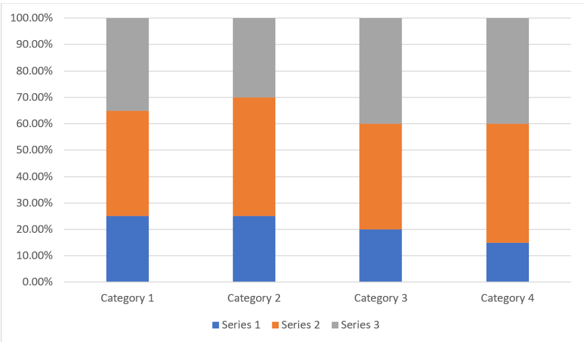


Figure 4.8: Typical Stacked Bar Chart (Own Figure). Source: Microsoft Excel

  Although stack bar charts have some important advantages there are some disadvantages that cannot be over looked. The graph can become very intimidating visually as the number of segments increase. The comparison between the whole bars also becomes complicated if there are more than two. The chart will require additional written explanation to explain the segments and categories, in addition, important information such as central tendency, dispersion etc. cannot be depicted [71].

- *Stacked Area Graph*
  Area graph represents data plotted on two axes and connected by a line with the area between the line and axis shaded. When multiple groups are represented in the same fashion, it becomes a stacked area graph. The values of each group are plotted above one another enabling comparison of the different shaded areas. It is predominantly used to depict the change of a constituent part of a whole over a period of time. Each shaded region represents one constituent of the whole. The diagram below represents a stacked area graph wherein the series represents the constituent part of the whole that changes with time.

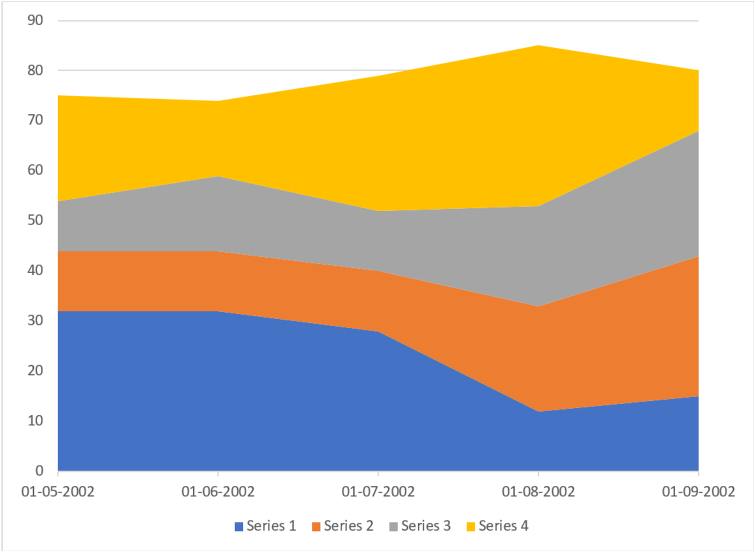


Figure 4.9: Typical Stacked Area Graph (Own Figure). Source: Microsoft Excel

The advantages of using a stacked area graph are that the data can be comprehended at a glance and shows how a part changes in relation to whole over a period of time. It is the best way to depict magnitude of trends over a period of time and it shows all the important quantities and their total in one graph [71]. The disadvantages of using a stacked area chart are that only a small number of data can be compared else it becomes complicated and the value of data plots need to be read in relation to the previous plot making it difficult for the human eye [71]. Hence in conclusion, stacked area chart shouldn't be used in situations where there are multiple data that needs to be compared with its exact values.

ANALYSIS: CAUSE-EFFECT DIAGRAM

The cause-effect diagram, also known as a fish bone diagram (or Ishikawa Diagram), identifies the different causes of an event. These causes are sorted into categories and presented visually looking like a fish bone. The problem is displayed at the head of the fish and the different causes are displayed at the bones as represented in the image below.

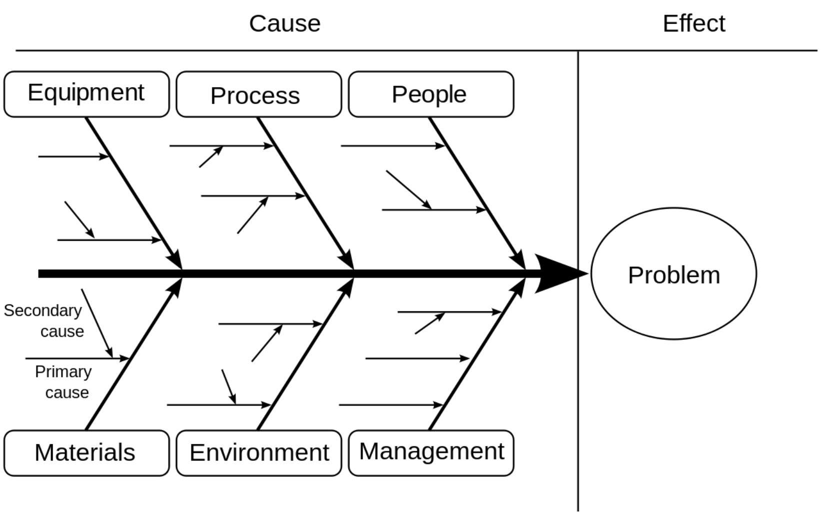


Figure 4.10: Ishikawa Cause-Effect Diagram. Retrieved from [72]

It is the most common tool used during brainstorming to identify the root causes to a problem. The main categories on the fish bone diagram lead to identifying certain causes that would otherwise be left out. These main categories form the primary bones from which the causes radiate forming the smaller secondary bones. The primary categories need to be decided in advance by all the participants of the brain storming session. The most commonly used categories are; Environment, People, Machine, Material and Method. Whilst preparing a fish bone diagram it is important for the participants to focus on the causes and not the symptoms. Every possible cause needs to be listed by repeatedly asking the question 'Why' [**?**]. The delineating of the causes to a problem will help in identifying methods to mitigate the problem and planning interventions to solve the problem [73].

A fish bone diagram has a lot of advantages making it a popular tool to use. It helps in bringing every possible cause to the table without the chance of overlooking any. The visual representation helps in easily comprehending the problem and the primary categories help in focusing on listing out the potential causes. Once the causes have been identified, the relationship between different causes can be established and the innate weaknesses are brought to fore that need amending [73]. Another important advantage of this process is that subordinate relationships can be depicted, which further enhances problem solving [74]

Like any other tool, the Fish bone diagram has its dis-advantages. Its simplicity, though considered a strength, can be a shortcoming in situations where the problem in question is very complex. This will make presenting the causes very difficult without missing the subtle details. As interesting as visual brainstorming sessions can be, this process would require a huge canvass to ensure all causes are being listed on the sheet. This can end up becoming cluttered and lead to further complexity in comprehending [73].

4.5. Conceptual Model for Continuous Productivity Improvement

This section explains in detail the conceptual model that was designed for the purpose of this research. The model was designed with the help of previous studies related to work sampling and its applications in productivity assessment as well as the findings from the previous research phases. The underlying theory and the tools used for constructing this model was explained in section 4.4.

4.5.1. Assumptions of Work Sampling

As mentioned earlier, the conceptual model was designed with the aim of incorporating the work sampling technique into the PDCA cycle for continuous productivity improvement. Before starting a work sampling study, it is vital to have an understanding about the underlying assumptions in this technique. The three fundamental assumptions that must be made before conducting a work sampling study according to Thomas *et al.* are listed below:

1. It is assumed that reducing time spent on delays or waiting will increase productive time (direct or indirect).
2. Time is related to output and productivity.
3. Waiting time is also related to productivity

The first two assumptions seem logical and the third assumption is derived from them. However, it must be realized that these are only assumptions, even though they seem to align perfectly with the equation for turnaround productivity proposed in section 3.4.4.

4.5.2. PDCA cycle for Productivity Improvement

Although the work sampling technique measures work proportions, it is not just the workforce utilization that can be calculated. The proposed activity categories include the avoidable unproductive category '*Reworks due to mistakes made earlier*'. The proportions of these can be used to calculate the effectiveness measure that was part of the proposed turnaround productivity equation. Hence, through this conceptual model, both proposed 'Workforce Utilization' and 'Effectiveness' measures can be calculated. However, in order to completely assess productivity, work efficiency measures have to be calculated separately and then combined with the results from the work sampling study.

As mentioned earlier, a work sampling framework will cover the *Plan* and *Do* phases of the proposed model. This framework was developed with the help of few pre-existing detailed studies regarding work sampling. The Check phase will include a description of how to make use of the proposed quality tools that were chosen in section 4.4 and Act phase will only include recommendations for ESWI.

Step 1: Plan

- ***Defining the Objectives of the study***

  The first step in the *Plan* phase is to develop the objectives of the study to be conducted. The objectives should represent the information that is of interest from the resulting data of the study [47]. A generalized objective for a work sampling study would be to:

  > "*Quantify the time expended by craftsmen on productive and non-productive activities in order to determine productivity barriers and opportunities for improvement.*"

  Once the PDCA cycle is repeated, the objectives can be tailored based on the results from the previous studies. For example, management will want to determine the specific factors causing reworks. In this case, more focus has to be given into the activity category definition of reworks. Only once the objectives have been clearly defined, the activity categories can be decided upon. A more narrowly defined study to produce even more specific results (for example, variations in a specific kind of activity) will require a comprehensive knowledge of the activities and one may also face difficulties in sampling [49].

- ***Defining the Population of the study***
  Once the objective of the study has been defined, the next step is to decide on the study population. The study population has to be determined based on the craft and job location [49]. For the generalized objective mentioned in the previous section, the population would be inclusive of all craftsmen. It should be noted that foremen and supervisors should not be part of the population since they do not contribute to directly productive work. It may also be possible that the objective is focused on a single discipline, in which case the study population has to be determined accordingly.

  Another point to be kept in mind is that the population on which the study is conducted should not be too small. This may cause discomfort for the craftsmen being observed and the Hawthorne effect mentioned in 4.1.2 may begin to creep in. It is also wise to have an idea of the site layout and plan the study population accordingly. A less densely populated area may be avoided for the purpose of work sampling study but only on the assumption that craftsmen in this area would have similar work proportions [49].

- ***Determine the Sampling method***
  The most common method for sampling is using random routes. This involves an observer sampling on a random route through the site so that every craftsman has an equal chance of being observed [50]. However Thomas Jr argues that there are two disadvantages to this method. Firstly, the observer may not be able to familiarize with the craftsmen, their designated work face and daily tasks [50]. Secondly, it is possible that the random route method may include both critical and non-critical activities and the results may be misleading[50].

  Thomas Jr proposes two other approaches for sampling. One, is the crew approach, that only studies the activities of specific crews performing critical activities and another approach which is a modified approach of the first one, involving one crew per specific task under the same trade in order to tackle the limitations of random routes [50]. Gouett *et al.* argues that anonymity of work sampling study can be used to gain trust of the workforce. However, familiarizing may give induce a feeling within the workforce that the management may use work sampling results for employment decisions [49]. Moreover, in a turnaround context, a distinction between critical and non-critical activities may not be feasible. Hence, the random route method is proposed for sampling.

- ***Define Activity Categories***
  The activity categories in theory should be customized for every project based on the study objectives [49]. This research focuses solely on turnarounds and the relevant activity categories have already been defined, investigated and modified in section C.1 for the purpose of this research. More activity categories can be added (removed) based on previous studies. It must be kept in mind that a study with high number of defined activity categories may be prone to error [49].

  Although the activity categories proposed are mostly self-explanatory, an understanding has to be reached as to which activities would fall under the *Directly Productive* and *Indirectly Productive* activities. This is something of extreme importance in order to get realistic work proportion results. The management must put considerable efforts along with the observer(s), in order to arrive at consensus regarding this.

- ***Determine Minimum Sample size***
  Work sampling, though in a broader scale measures proportions of time spent on different activities, what is actually measured is the 'behavior' of craftsmen at particular points in time. The behavior determines the activity that the craftsman is indulged in. The work sampling technique is driven by the statistical assumption that a sufficient number of observations of this sorts made would help in calculating percentage of the time spent by a craftsman on average on various activity categories [54]. Hence, determining the minimum sample size is of vital importance in a work sampling study and this can significantly affect the reflection of the actual site conditions [54].

  Sampling error is the range of the deviation of the measured mean from the actual mean [49]. These errors are quantifiable using statistical equations. However, in a planned statistical sampling study, usually a random value is chosen to limit the error to and then the minimum required sample size is determined [49]. The general accepted values in most industries are a ±5% error with, a confidence level of 95% [54]. In layman terms, a confidence level of 95% indicates that there is a potential of being wrong 1 out of 20 times i.e if the study were to be repeated over and over again, the results would match the results of the actual population 95 percent of the time. A margin of error of ±5% indicates that the measured parameter will be within 5 percent points of the true value of the population. The following equation is popular for determining sample size based on the margin of error desired and anticipated activity category percentages [54]:

$$n = \frac{(Z_{\frac{\alpha}{2}})^2 p(1-p)}{d^2} \tag{4.2}$$

In the above equation, 'n' is the sample size, '$Z'_{\frac{\alpha}{2}}$ (= 1.96 for 95% confidence level) is the standard normal variable corresponding to a confidence level of 'α' (= 0.05 for 95% confidence level). The value 'p' is the anticipated activity category percentage and 'd' is the error between the true and estimated percentage. The value of 'p' is usually taken as 50% (0.5), which is assumed to be the worst case scenario, meaning, the sample size will be overestimated. The minimum sample size calculated using these values will result in 384 observations.

The minimum sample size can be obtained by considering data as binomial or multinomial distribution. However, equation 4.2 is applicable only to sampling exercises when the sampling characteristic follows a binomial distribution [49]. Since work sampling usually has more than two activity categories, a multinomial distribution is to be considered. Thompson proposed the following equation to determine the minimum sample size in case of multinomial distributions:

$$n_0 = \max\left\{\frac{(Z_{1-\frac{\alpha}{2m}})^2 \frac{1}{m}(1-\frac{1}{m})}{d^2}\right\} \tag{4.3}$$

For a given confidence level, equation is used to calculate the maximum number of observations in the worst case scenario (n_0) at varying number of categories 'm' (regardless of the number of categories in the study) [49]. The sample sizes for varying confidence levels for estimating multinomial distributions were presented by Thompson. This is presented in the table below [75] (Retrieved from [54]):

α	d^2n_o	n_o(d=0.05)	m
0.5	0.44129	177	4
0.4	0.50729	203	4
0.3	0.60123	241	3
0.2	0.74739	299	3
0.1	1.00635	403	3
0.05	1.27359	510	3
0.025	1.55963	624	2
0.02	1.65872	664	2
0.01	1.96986	788	2
0.005	2.28514	915	2
0.001	3.02892	1212	2
0.0005	3.35304	1342	2
0.0001	4.11209	1645	2

Figure 4.11: Sample Size for varying confidence levels and Error d=0.05 [75], retrieved from [54]

It can be seen that for an α value of 0.05 (95% confidence level), the corresponding value for the minimum sample size (n_0) is found to be 510 observations.

However, these estimates are based on the assumption of infinite population. As mentioned earlier, the population being measured in fact constitutes of the 'behavior' of the craftsmen at some point in time rather than the craftsmen itself [49]. It is the constantly changing behavior of the craftsmen that is being sampled and hence a true population size cannot be determined. To tackle overestimation of sample size and to avoid the collection of redundant samples, a finite population correction factor has to be applied as shown below [54]:

$$\text{Minimum Sample size per hour} = \frac{1}{\frac{1}{n_0} + \frac{1}{N}} \tag{4.4}$$

In the above equation, 'n_0' is calculated from values presented in figure 4.13 and 'N' is the number of workers under the study. The required number of samples are calculated for a one hour period. Since it is nearly impossible for a single observer to reach the required sample size for a particular hour period (say 10 to 11 am) in one day, the sampling can be distributed evenly over several study days and then the results are summed up. Given in table C.1 are the minimum sample sizes per hour depending on the number of craftsmen calculated as per equation 4.4 for a confidence level of 95% and margin of error ±5% (adapted from [54]).

- ***The Observer***
  Errors that can occur in a study are either random errors or systematic errors (the bias that consistently occurs in a study) [54]. The sources of systematic errors in a work sampling study were discussed by Thomas and Holland which included human limitations, variations between observers, observer bias, observer fatigue and procedural deficiencies [47]. These challenges faced during work sampling study highlight the importance of having well trained observers for the purpose of the study. Gouett *et al.* suggest that a good observer has the following qualities (adapted from [49]):

  - Have a comprehensive knowledge of the work site.
  - Have a very good understanding as well as memory regarding the defined activity categories.
  - Easily able to identify different trades, tasks and activities.
  - Adhere to the concept of instantaneous observation.
  - Unbiased and committed to finding accurate results.

  In the *Check* phase of the PDCA cycle, when the results of the work sampling is to be analyzed, there is no one better than the observer himself in terms of knowledge of on site conditions. Hence, the observer is the most important analyst in identifying productivity barriers and improvement opportunities. However, the observer must have a sufficient knowledge and experience in turnarounds for being able to recommend solutions.

- ***Host Craft Information Session***
  The final step to be taken in the *Plan* phase is to host a craft information session. Through this, the workers feel part of the process and is crucial in minimizing the Hawthorne effect mentioned in section 4.1.2. Gouett *et al.* suggest the following three key factors are to be stressed at the craft information sessions [49]:

  - Craftsmen should be informed that work sampling does not involve continuous observations. Work sampling is believed to be more readily accepted by workforce than techniques making use of stopwatches.
  - Workforce should be made aware of the methods of the study, the expected results as well as the benefits to workers.
  - It must be stressed that the data collection process in completely anonymous. The workforce should understand that it is the productivity of the entire workforce that is being measured and not individually.

The craft information session will give the feeling to the workforce that they are part of the improvement process. While limitations exists regarding variations in nature and capabilities of different craftsmen, an information session will only help in reducing the degree of errors that can occur in a study.

STEP 2: DO

- ***Execute the Work Sampling Study***
  The observations are to be made with the help of a data collection form. The form should contain spaces to fill in general information such as date,observation period, study type, weather and so on. This data will also be of additional help in the *Check* phase in order to identify barriers and opportunities for productivity improvement [49]. Figure C.1 depicts a typical data collection form that should be used for an work sampling study. Observations can be recorded with the help of tally marks. Using tally marks is a fast and easy way for recording observations. As proposed previously, the observer should walk around in random routes and record observations. A few recommendations regarding executing the work sampling study follows.

  – Data Collection challenges [54]

    1. Observations must be halted in case of weather breaks and lunch breaks.
    2. Identification of activities of crafts in confined spaces might be challenging and must be done in consultation of the supervisor.
    3. Tracking of craftsmen and consistency of observations may be an issue in cases of large groups while reaching the minimum number of observations may be difficult in cases of smaller groups.
    4. Differentiating indirect labor such as management, safety officers and engineers may be difficult.

  – Craft Identifiers
    Craft identifiers can be used to differentiate craftsmen based on their discipline. The use of color strips on the helmets are one means [49]. The use of numbers is also seen as an alternative. The data collection form presented in C.1 includes the segregation of observation based on craft identifiers, as an example.

  – Recording Observations
    The observer should approach a craftsman and instantly identify the activity category and the craft. This should be done within a distance of 15 to 30 meters from the crafts person [49]. This distance is not too far nor too close to the craftsman and is appropriate in order to correctly identify the activity without causing discomfort to the craftsman [49]. The observations should not be recorded directly after identification of activity. It is recommended that observations are recorded in a quiet area where the observer is not within the site of the craftsmen. This is to avoid discomfort on the worker [49]. However, it should be kept in mind that this shouldn't be done by sacrificing accuracy of data collection.

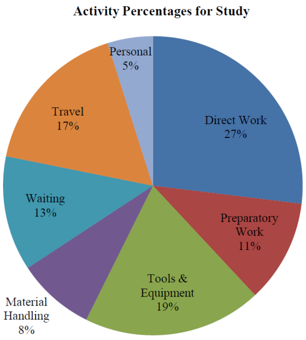
  – Random Start Locations and Times
    The observer must go to a random start location, of a randomly selected route just before the first observation of a day. Then at the beginning of the hour, the observer starts to move in the predefined route and record observations. If the entire site cannot be covered withing one hour, the observer must use a new collection form from the beginning of the next hour [49]. However, if the site can be covered within an hour, the observer must start at random times and sometimes even predetermined times (for example, in the one hour period just before lunch, the later minutes of the hour should be observed) [49].

STEP 3: CHECK

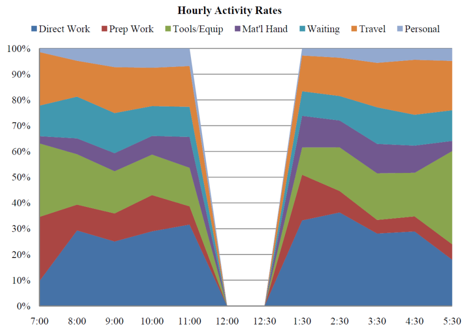
- ***Presenting the results***

  The next step is to present the results of the work sampling study which will facilitate the managers to identify shortcomings in work proportions. There are numerous ways in which the data collected from the study can be presented. The objective of presenting the results should be to make it easy for management to understand and analyze the data put forward. Three alternatives for visual representation were proposed in section 4.4.3.

  When the entire workforce is studied, a pie chart or a stacked area chart will be most appropriate. Initial studies where the activity proportions are of most interest must make use of pie charts for visual representation. This is easy to understand and will enable the management to quickly identify areas of opportunities. A more in-depth visual representation would be based on the hourly rates. This will enable the management in identifying variation patterns over a standard work shift. This will be more appropriate for a detailed analysis.



(a) Pie Chart



(b) Stacked Area Chart

Figure 4.12: Visual representation alternatives. Retrieved from [49]

When the study is differentiated between different disciplines, a stacked bar chart will be most effective. This facilitates easy analysis of work proportions in different crafts through a single chart. The stacked bar chart was also found to be the most recommended in literature.

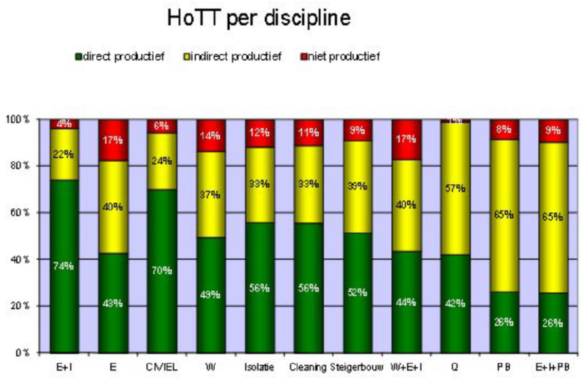


Figure 4.13: Visual representation based on discipline. Retrieved from [76]

- ***Interpreting Data***
  The next step is to analyze the results that are presented. Interpreting the data correctly is one of the most difficult parts of work sampling [49]. As mentioned earlier, the observer will be the best person to analyze the results since he/she would have developed close knowledge regarding site issues over several days of observation [47]. The observer along with the management should be able to analyze the results of the study and identify barriers and opportunities to improve productivity. For this purpose, the Ishikawa diagram was proposed in section 4.4.3.

  Analysis using Ishikawa diagrams ensures that analysts work systematically which reduces the chances of overlooking important causal factors [55]. While the 'effect' is derived from the results, the (root) 'causes' are to be found by the analyst team. Brainstorming, '5-why method' or similar in listing probable causes into the Ishikawa diagram. During the initial studies the objective, in theory, should be closely related to the general objective presented in the beginning of this section.

  Figure 4.14 represents the causes for low wrench time percentages as an example to demonstrate a typical cause-effect diagram (adapted from [55], [49]). The aim of presenting a diagram of this sort is not to identify the root causes that affect wrench time percentages. Rather, it is to understand the degree of influence a contractor can have on the wrench time measures. The causes marked red are those that root from the contractor alone, while blue represents the causes that can root from either the contractor or plant owner/client and gray representing those that root from the plant owner alone. The identified causes from literature are just a few of the many possible causes that can have a negative influence on wrench time percentages. It is seen that a fair share of causes root from the contractor side alone and hence improvements in those areas are completely in the hands of the contractor. Identification of root causes at this point is not the focus of this research.

- ***Using the proposed Turnaround Productivity equation***
  Equation 3.7 was proposed as the definition of Turnaround productivity. This equation can be used for tracking productivity in this phase. The variations in productivity measure according to the implementations made from the preceding *Act* phase can be analyzed.

  However, there are a few things that have to be taken care of before doing so. Before the equation can be used for tracking, it is important to either benchmark or baseline the productivity measure. This is because it is pointless to calculate something without knowing the expected/favourable value. While benchmarking simply speaking involves measuring and comparing something with standard accepted results, baselining helps in assessing the current state using a set of test data. Since equation 3.7 was proposed as a part of this research, baselining seems like the only choice.

  Baselining in turn requires additional data regarding current state of the three elements of turnaround productivity (i.e. Workforce utilization, Work efficiency, Work effectiveness). The conceptual model will help in baselining workforce utilization measures. However, discrepancies regarding effectiveness measures still exist and will be discussed in the next chapter. Moreover, there may exist other tools for visual representation and analysis of turnaround productivity than the ones proposed.

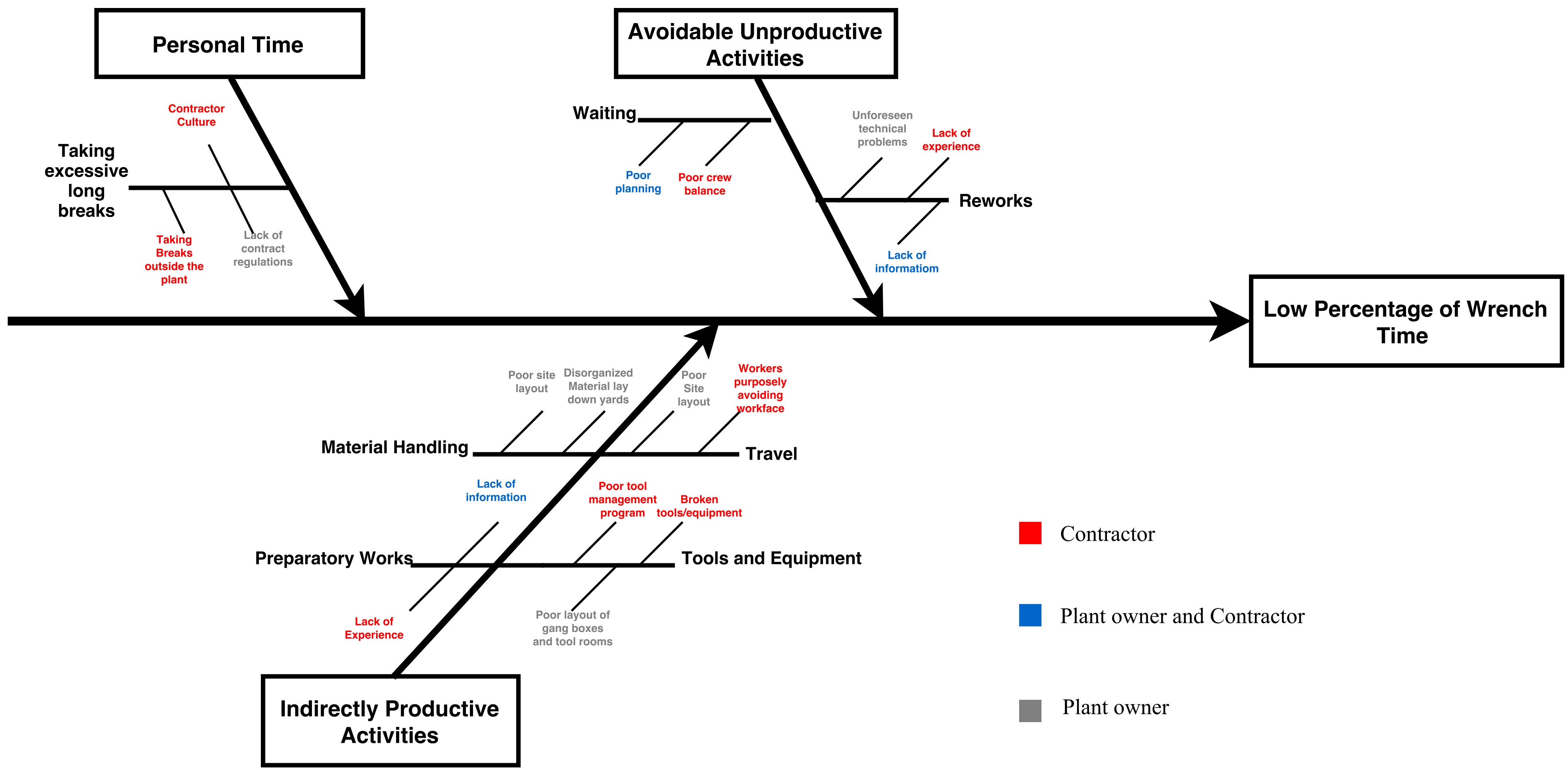


Figure 4.14: Ishikawa fish-bone diagram for Root cause analysis of low wrench time percentage (Own Diagram)

STEP 4: ACT

Once the root causes of the problems are identified by the analyst team, the next step is to plan and implement measures to take care of the identified causes. The order of steps to be taken in this phase are as follows [49, 54].

- Analyze alternatives
- Plan Implementation of improvement
- Implement Improvements

The implementation of the improvements should form the base for the next *Plan* phase, since the effects of the implementations have to be analyzed. The objectives of the next study will also change accordingly. This phase largely depends on the results and their interpretations from the preceding phases. Hence, due to the specificity of this phase, more recommendations regarding the aforementioned steps cannot be put forward.

4.5.3. TQM PRINCIPLES REVISITED

While '**continuous improvement**' and '**process and analysis**' have been emphasized enough already while developing the proposed conceptual model, intrestingly, elements of other TQM principles (as discussed in section 4.4.1) can also be seen within the model. The first principle '**management commitment**' is of utmost importance to the implementation of such a model. The proposed model can only be effective over a rather long period of time and hence the management must be committed to productivity improvement and moreover workforce utilization improvements, before its implementation. The second principle which is '**training and education**' is also seen as an important element of the model. Observers should be well trained and should possess good knowledge about worksite as well as turnarounds. '**Teamwork**' is also key to the success of the model. The workforce, the observer, management and other relevant personnel should all be included as part of the improvement process. The only area where the model falls behind in terms of TQM is the '**interaction with the customer**'. Interaction with the customer, although will definitely aid in improvement, may not be easy in reality to achieve, at least for the purpose of implementing such a model. Due to the organizational complexities involved in a turnaround setting and due to the fact that the proposed model was developed for self-assessment and tracking, the customer could not be included as part of it. However, it is possible that at some point in the future, results from implementing the model may be used for in-depth discussions on a much bigger scale than just self improvement.

4.6. CHAPTER CONCLUSIONS

This research phase started with the proposal that improvement efforts (with regards to the defined productivity) should start at the workforce utilization level. The percentage of wrench time was the measure proposed for workforce utilization in the turnaround productivity equation. Work sampling was found to be a popular technique in literature that was related to wrench time measurements. It is a form of work measurement study which involves dividing the work into a set of productive and unproductive activity categories. While the work sampling seemed appropriate as a starting point for productivity improvement, investigation regarding this had to be done. For this purpose, first the activity categories for a craftsman in a typical turnaround were defined with the help of literature. After that, a qualitative survey was designed in order to investigate the opportunities for improvement in these categories. The survey was conducted within ESWI and ABC, a smiliar technical service provider. The respondents were asked to rate the opportunities of improvements based on their perception. The analysis of the data acquired from the survey confirmed that the respondents did believe there were considerable opportunities for improvement in most of the proposed activity categories, confirming the relevance of the work sampling technique as a starting point towards improving turnaround productivity.

Once it was confirmed that opportunities for improvement in the defined activity categorties were believed to exist, the focus of the research shifted towards developing a conceptual model that will help in implementing a work sampling study at ESWI. Continuous productivity improvement is the main objective underlying within the model. Although the conceptual model revolved around workforce utilization measures, recommendations on how to incorporate the equation for turnaround productivity into the model were discussed. This would effectively convert the model into a productivity tracking tool. However, there are still lots of unexplored domains with regards to analysis and relationships between the elements of the proposed equation still to be investigated.

5

Research Phase 3

The final phase of the research was conducted in order to assess the practicality and the validity of the research findings within ESWI. The first section elaborates on the validation procedure that was conducted within the organization and the next section delves into the practicality of the proposed model.

5.1. Validation of Conceptual Model

The developed conceptual model had to be tested within ESWI, for the purpose of validation and to gain further insight into the feasibility of implementing such a model. The various elements of the proposed model had to be checked for feasibility and (or) validity. This section gives a brief explanation regarding the validation procedure, followed by the conclusions from it.

5.1.1. Validation Overview

The first element that had to be tested was the derived equation for turnaround productivity (Equation 3.7), which is of high importance for this research as well as the proposed conceptual model. After the equation was derived, the focus shifted to the first component of turnaround productivity. However, the model itself can be redesigned as a continuous productivity improvement model once favorable targets are achieved in workforce utilization measures. This equation will be used for productivity tracking and hence, is of utmost importance.

The *Plan* and *Do* phase in the conceptual model mainly consisted of a series of steps to be followed in order to conduct a work sampling study. These recommendations were based on previously conducted studies. However, these steps are only basic recommendations and a separate research is required in order to develop and test an ESWI specific work sampling study. Hence, these steps were not part of the validation. Nevertheless, the feasibility of conducting such a study had to be validated. Moreover, the *Plan* phase consisted of a step where the activity categories had to be defined. These categories were earlier proposed from literature findings and were investigated through the qualitative survey for opportunities for improvement. Hence, these too were included as part of the validation.

The aforementioned elements were the most crucial components of this research as well as the model. They needed to be discussed in detail and hence a total of 4 expert interviews were conducted within ESWI for the purpose of validation. The other elements that were to be tested were the proposed tools for visual representation and analysis as well as the underlying theory i.e. the PDCA-cycle. These were checked for feasibility and validated with the help of a focus group meeting. The overview of the validation procedure is presented in the table below.

Table 5.1: Validation Overview for various elements of the Conceptual Model

Element	Description	Comments
Equation	Derived based on the findings from literature.	Important turning point for the research. Validated through expert interviews.
Plan	Recommendations from literature. Steps on how to plan the work sampling study.	Activity categories validated through expert interviews. *Plan* steps are only basic and separate investigation required for ESWI specific study.
Do	Recommendations from literature. Steps on how to execute the work sampling study.	Feasibility validated through expert interviews. Execution steps are only basic and separate investigation required for ESWI specific study.
Check	Quality tools proposed for analysis of results	Validated through focus group meeting.
Act	Specific to the results from preceding phase	n/a
PDCA-cycle	Theory that forms the basis of the conceptual model	Validated through focus group meeting.

The following sections will elaborate on the design and outcomes of the interviews as well as the focus group meeting.

5.1.2. EXPERT INTERVIEWS

Three components of the conceptual model were under scrutiny in the expert interviews. Firstly the definition for turnaround productivity, then, the work sampling technique and finally the proposed activity category definitions. Separate structured interviews were conducted with 3 project managers (PM1, PM2 and PM3) and one head of work preparation (WP) as part of the validation procedure. All the interviewees had a minimum experience of 20 years in the field. The interviewees were first familiarized with the research findings and then presented with a set of open questions which are detailed below along with their responses and inferences. These questions were aimed at getting more insight in the accuracy of the proposed definition, activity category as well as the feasibility of the work sampling technique within ESWI.

1. **Do you agree that the focus on workforce is appropriate while measuring productivity in a turnaround context?**

   PM1, **PM2** and the **WP** agreed that the focus should in fact be on the workforce while productivity measures are considered. **PM2** also underlined the importance of this focus on workforce, by revealing that ESWI recruits a large share of their workforce from outside suppliers for numerous turnarounds i.e. assessment of the workforce becomes crucial. However, **PM3** disagreed, stating that there are more aspects that are to be considered while measuring productivity. He claimed that focus should also be on work preparation and engineering.

   This argument is valid considering the fact that ESWI deals with work preparation as well as execution of turnarounds. Having said that, this research solely focused on the execution phase of turnarounds, since it was seen in the exploratory phase that there is already a well established system in place to track the progress and efficiency of work preparation within ESWI and productivity measurement was concluded to be not critical in the work preparation phase. Moreover, a separate productivity measurement for the execution phase will help in identifying site related issues easier compared to a measurement that includes components of work preparation and engineering.

2. **Are there any factors that are not considered in the proposed definition? If so, please rewrite the equation.**

PM1 and **PM2** agreed that the three components of the derived equation are adequate. Following up from the answer to the previous question, **PM3** feels that there are more components regarding work preparation and engineering are missing from the equation. **WP** suggested that a factor for additional works is missing from the defined equation. He says that while 'burned hours' calculated include the hours spent on additional works, the 'earned hours' only include those hours that are planned for. Meaning, the efficiency is underestimated in cases of additional work that are not reworks. He defended his point by stating that turnarounds encounter a lot of additional work and hence they should be incorporated into the productivity equation.

Incorporating an additional work factor to the proposed equation will be difficult. In that case, the time spent separately on additional work has to be measured along with the additional earned hours. Since the burned hours already include the total time spent, it will be easier to incorporate additional hours earned into the earned hour calculation. **WP** agreed that the calculation of earned hours for additional work separately is in fact feasible with current way of working, following a detailed discussion regarding this.

3. **Is there any component in the proposed equation that should be modified/redefined (in terms of measurement) ?**

   While **PM2** and **PM3** agreed that the currently defined measurements for the three components are appropriate, **PM1** and **WP** put forward their concerns regarding these. **PM1** suggested that current work efficiency measure already includes hours spent on reworks and that the effectiveness component may lead to calculating the burned hours value twice. **WP** suggested that rework hours are difficult to quantify. He stated that there are all kinds of reworks happening in a turnaround at all times and these are usually not based on unit rates, rather, they are based on material or a fixed number of craftsmen.

   Both arguments seem to make fair points. Considering **PM1**'s comment, it can be said that workforce utilization and effectiveness measures are not to be considered as numerical values of importance. Rather, they should be seen as separate factors that are to be multiplied with the work efficiency value in order to quantify productivity. Both these factors, in theory, should be equal to unity in the most ideal conditions. However, in reality, this is not the case. While effectiveness measure still can be somewhere close to a value of 1, workforce utilization measure can never be in the close vicinity of unity. This is because the ideal wrench time percentage is not the highest achievable value, rather a value that ensures correct balance between directly and indirectly productive activities. Hence, benchmarking each value separately becomes important.

   WP stated that rework hours are extremely difficult to measure separately. He relates this to the large number of possible reworks in a turnaround and the culture of treating reworks differently during the turnaround execution. Moreover, he stated that planning for reworks is not possible. The activity category 'reworks due to earlier mistakes' was proposed in the defined set of activity categories as part of the work sampling study. If the assumptions of the study holds true, then the percentage of time an average craft worker spends on reworks can be calculated using the work sampling data. However, distinguishing reworks from planned work and additional work may not be possible for an observer. Further investigation has to be done in order to facilitate the observer in the work sampling study to identify reworks.

4. **The research proposes work sampling technique in a continuous cycle where wrench time has to be calculated over a period of time before a certain value can be set as a baseline. Only then it would make sense to use the proposed definition of productivity. Do you think that the current working culture at ESWI is suitable for the implementation of this method?**

   While all the interviewees agreed that it is feasible, there were quite a bit of concern regarding this. **PM3** suggested that up until now, work sampling has never be a point of attention since most contracts where all the hours were reimbursed. He suggested that ESWI should get accustomed to the work sampling technique. Supporting this, **WP** stated that implementation of such a model will be very time consuming and the decision to conduct such a study should only begin once there if enough evidence that it will be helpful.

Both the interviewees had similar thoughts and were right about the fact that the procedure will take long periods to be effective and for being accustomed to. Having said that, it must be realized that there is absolutely no quick way of tracking workforce utilization measures. Since this is one of the three components of the proposed productivity equation, the management must be prepared for commitment before starting the study. While the study may take long periods to be effective, the advantages of such a study clearly outweigh the resources spent. Pilot studies are the best solution to this problem. Pilot studies will help understand and analyze the current state of the matter under scrutiny which can help in deciding whether the focus should really be on that matter.

5. **Would you add any other category to the proposed category list? Do you think this level of detail is enough for defining the activities in order to measure workforce utilization ?**

All the interviewees were satisfied with the proposed activity category definitions. **PM1** suggested that initial activity categories should be defined broadly. He recommended that once the activity category with the most opportunity has been identified, it has to be further split into sub-categories in the following studies. **WP** suggested that, from a practical point of view, the level of detail is already higher than required. However, the focus should always start with avoidable unproductive activities since these are the major barriers to work flow that can be 'avoided', so to say. For this sole reason, the avoidable unproductive activity categories were defined in more detail compared to the rest. Nevertheless, as mentioned while developing the conceptual model, the activity category definitions can be tailored based on the objectives of the study, from cycle to cycle.

An important finding through this question was the fact that the activity category "*reworks due to mistakes made earlier*", which was defined for the sole purpose of measuring the effectiveness value, turned out to be impractical. Views of the interviewees suggested that it will be difficult to differentiate work that falls within this category from planned/additional work. Moreover, there were suggestions that this propotion shouldn't be measured based on statistics. It was mentioned by **WP** that for such works, certain number of workers are assigned and hence, the number of manhours can be recorded more accurately, provided the effort is made to do so.

Conclusions

The expert interviews helped greatly in identifying few major faults in the research findings. The equation, though correct from a scientific viewpoint, proved to be confusing to the interviewees from a practical viewpoint. Their suggestions led to the modification of the proposed equation elaborated in the recommendations that follow. Also, the methodology proposed for measuring the effectiveness of the workforce turned out to be impractical. Although a clear substitute could not be found, few recommendations are provided based on the insight from the interviews in the coming section. Moreover, the interviews suggest that work sampling, although feasible, may take a lot of efforts in being correctly implemented within the organization. Even though the interviewees unanimously agreed that the goal of such a model is convincing and attractive, there were major concerns over the path to be taken to reach that goal.

5.1.3. Focus Group Meeting

The focus group meeting was conducted in the context of the proposed quality tools and the PDCA-cycle. The questions were aimed at get more insight into the feasibility as well as the aptness of the proposed tools/theory. The focus group consisted of 4 Project Managers (PMs) within ESWI, who have had significant experience in turnarounds. Each member at least 20 years of experience in the field. The questions were mostly 'yes/no' type questions, with a couple of questions asking to make choices. Additional spaces were provided for reasoning the choice or for making general comments. The meeting began with a presentation of all the research findings up to this point. The presentation lasted for about 20 minutes, with all the relevant findings presented to the focus group. After the presentation, each member was given a validation questionnaire to be filled and were reminded that there weren't to be any sorts of discussion to ensure that the members did not influence each other. The questions asked and their responses are detailed below:

1. **Are there any similar theories for continuous improvement currently implemented at ESWI for the purpose of self-assessment/improvement ?**

	PM1	PM2	PM3	PM4
Yes				
No	✓	✓	✓	✓

All the members agreed on the fact there there are currently no similar methods implemented at ESWI for continuous improvement/self-assessment. Notably, **PM2** provided an additional comment stating that the PDCA-cycle has been previously used within ESWI before.

2. **Do you agree that the proposed PDCA cycle would help improving wrench time proportions ?**

	PM1	PM2	PM3	PM4
Yes	✓	✓	✓	✓
No				

All the members unanimously agreed that the proposed conceptual model will be effective in tracking and improving wrench time percentages. However, **PM1** additionally stated that the effectiveness of the model will depend on the level of organization involved in implementing the model.

3. **Which of the following ways of implementation do you think the proposed model will be most feasible and practical ? (Multiple choices possible)**

	PM1	PM2	PM3	PM4
For all the T/As being carried out by ESWI	✓	✓	✓	✓
For a particular discipline		✓		
For each customer separately		✓		

All the members agree on the opinion that implementation of the proposed model for all the turnarounds carried out by ESWI will be feasible and practical. However, **PM2** was aligned to the opinion that the model can be implemented in such a way that the results can be segregated based on discipline as well as customer, while also facilitating overall results.

4. **Out of the three visual representations proposed, which one do you think will be more easy and practical to analyze the changes between two work sampling studies ?**

	PM1	PM2	PM3	PM4
Pie Chart			✓	
Stacked Column Chart	✓			
Stacked Area Chart		✓		✓
Other	none			

Two members preferred the stacked area chart while one preferred the pie chart and the other the stacked column chart. No member recommended any other forms of visual representation.

5. **Are you familiar with the Ishikawa Cause-Effect Diagram?**

	PM1	PM2	PM3	PM4
Yes	✓	✓		
No			✓	✓

It was seen that familiarity with the Ishikawa diagram was split evenly among the members.

6. **Do you have any suggestions for a substitute tool that can be used in place of the Ishikawa Cause Effect Diagram to identify improvements/ barriers to work flow? (Please also mention if the tool(s) is currently being implemented at ESWI for the similar purposes)**

	PM1	PM2	PM3	PM4
Yes				
No	✓	✓	✓	✓

Neither of the members provided a substitute method that can be used instead of the Ishikawa diagram. However, **PM4** suggested that it is a common practice within ESWI to analyze the causes and effects of various issues but is not done with the help of any tools.

INFERENCES FROM FOCUS GROUP VALIDATION

It was seen that ESWI doesn't currently deploy any continuous improvement model similar to the conceptual model proposed. All the members of the focus group agreed that the proposed conceptual model will be effective in improving workforce utilization measures. Since this measure is not being measured currently at ESWI, tracking and assessing work proportions will provide more insight into shortcomings regarding this. This is at present inaccessible to ESWI. Hence, once ESWI are able to identify these shortcomings, they will be able to act upon it. The model is developed in such a way that this is done periodically and the effects of actions are analysed in subsequent runs.

The conceptual model was proposed as a model for tracking and improving wrench time proportions alone. Possibilities of making use of the proposed equation for turnaround productivity were not mentioned in the presentation to avoid confusion and deviation of focus from the basic elements of the model. The concern put forward by **PM1** regarding the level of organization could have been because the presentation did not stress on the 'team commitment' that is required to implement such a model. Nevertheless, it has already been mentioned in the preceding sections that the management, workforce, observer and several other personnel should all be involved in conducting the study i.e. there is not really one level of organization involved in the implementation of the model.

Coming to the ways in which the model can be implemented, the entire focus group agrees that the model should be implemented for all the turnarounds that are carried out by ESWI. Since **PM2** chose all the options, it can be inferred that he is aligned to the opinion that the study, while done for all turnarounds, should also be able to produce results based on discipline as well as customer. This is certainly possible, however, each discipline will require a minimum sample size which may not be easy to achieve, especially if the results are to be further divided based on the client.

Coming to the quality tools proposed in the model, firstly the three tools for visual representation of results were tested for practicality and ease of understanding. The three tools were presented as alternatives rather than choices based on the type of study. This is because although each chart was proposed for a certain kind of study while developing the model, in theory, they can be used over one another to present results of any kind of study. Two members suggested that the stacked area chart would be appropriate, while the other two were split among the remaining tools i.e. pie chart and stacked column chart. The majority of the group chose an option that is not pie chart, meaning, the PMs do acknowledge the importance of variations of work proportions over a standard work shift. It can be seen that the repondents are indeed interested in knowing the variations of time spent on each activity category, may it be based on time or discipline, even if this is not currently facilitated at ESWI.

Lastly, the Ishikawa diagram was tested for familiarity among the members. The members were also asked to list any substitute method that they think is appropriate instead of the Ishikawa diagram. While the half the group were familiar with the tool, neither of the members proposed a substitute tool for analyzing causes. Nevertheless, **PM4** suggested that analyzing causes are done without the help of any tools within ESWI. However, the proposed Ishikawa diagram will ensure that all root causes regarding the problem at hand will be listed with minimum chance of missing out on causal factors. Validation suggests that current analysis methods at ESWI are restricted to brainstorming sessions, which by no means is wrong but definitely less systematic and possibly less effective compared to the fish bone diagram in analysing causes/effects.

5.1.4. RECOMMENDATIONS BASED ON THE VALIDATION PROCEDURE

- Conceptual Model for Continuous Improvement
  - The proposed model revolves around wrench time measures. The investigation regarding the relevance of this mesure was tested based on the perception of personnel within the organization alone. Clearly, more evidence (numerical backing) is required before the management can commit to implementing such a model within ESWI. Baselining is something that cannot be overlooked because it is not possible to understand how you have improved if there is no understanding about what you have improved from. Pilot work sampling studies are to be used for the purpose of baselining.
  - The proposed model focuses on workforce utilization measures. However, it can also be incorporated with the proposed equation in order to analyze the effects of the improvements implemented, on turnaround productivity as well. Having said that, initial studies are to remain focussed on workforce utilization measures since ESWI are yet to be accustomed to these measures and their analysis. During this time, work efficiency measures are to be measured and analyzed separately based on the existing methodology at ESWI.
- Turnaround Productivity Equation
  - The turnaround productivity equation has been developed with the help of extensive literature study. While majority of the respondents interviewed agreed to this equation, there are still question marks surrounding it. Based on the recommendations from the expert interviews, the equation had to be slightly modified as follows:

$$T/AProductivity = \left(\text{\% of Productive Time}\right) \times \left(\frac{\text{Earned Hours}}{\text{Burned Hours}}\right) \times \left(1 - \text{\% of Rework}\right) \quad (5.1)$$

    The workforce utilization and the effectiveness measure proposed in equation 3.7 has now been modified to 'percentage of productive time' (sum of wrench time percentage and indirectly productive time percentage) and '1-percentage of reworks'. This equation takes care of any concerns regarding accounting for the total hours burned multiple times because compared to equation 3.7, where both the workforce utilization measure as well as the effectiveness measure contained burned hours, the modified equation considers these components as values (factors) between 0 and 1, which is to be multiplied with the calculated efficiency. Moreover, this equation will be easier for a personnel from ESWI to comprehend, since it involves factoring an already calculated measure i.e. work efficiency.
  - The first factor i.e. percentage of productive time should include both direct work as well as indirect work percentages. Although the proposed activity definitions seperates these, considering the modification of the workforce utilization measure to a factor compelled this proposition of including indirect work percentages as well. Both these percentages can be found out and analyzed separately with the help of the proposed conceptual model. Hence, the most ideal and practically impossible to achieve value that can be achieved in this measure will be unity.
  - The modification of the second factor was made for different reasons compared to workforce utilization. While the initial equation required the calculation of burned hours and hours spent on reworks seperately, the new measure only requires the percentage of reworks. It was proposed that if the assumptions in the work sampling theory are accepted (which has to for the conceptual model to be valid), it is possible that percentages of reworks can also be calculated. However, validation suggested that this is impractical. The percentage of rework hours should be calculated based on the hours burned and the hours spent on reworks. The rework hours are to be calculated

based on the number of workers assigned to execute the job(s). Having said so, taking into consideration the large number of reworks that can occur in a turnaround (based on insight from the validation), this research has failed to propose a practival and sound methodology for measuring the effectiveness measure.

5.2. PRACTICALITY OF THE CONCEPTUAL MODEL FOR CONTINUOUS PRODUCTIVITY IMPROVEMENT

The qualitative survey was conducted in order to investigate the opportunities for improvement in workforce utilization, which is one of the two newly proposed components of productivity in the earlier stages of this research. After having successfully confirmed the opportunities for improvement, a conceptual model for continuous productivity improvement was designed, which mainly revolved around the work sampling technique which will enable the calculation of the proposed workforce utilization factor.

Once the work sampling study is conducted, the percentages of time spent by the average workforce on each of the defined activity categories can be seen in terms of percentages. In order to calculate the workforce utilization value, ESWI should consider the total percentage of directly and indirectly productive activities. This value along with the efficiency calculated with the existing methodology and the proposed effectiveness measure will give a final value for turnaround productivity. A dummy example of the expected outcome after running the *Do* phase of the model is presented below. Assuming that the work efficiency is 90%, total percentage of productive time around 75% (based on the data from Buro Walravens [55]) and assuming 5% of the hours burned were used for reworks, the calculations of the three components is presented below.

Workforce utilization factor (75%)	=0.75*
Work Efficiency (90%)	= 0.9*
Effectiveness factor (1-[5%])	= 0.95*
Turnaround Productivity value	= 0.75 x 0.9 x 0.95 = **0.64***

The aforementioned values will prove to be useful in the *Check* phase of the model. If realistic achievable benchmarks are set for each of the three components, a benchmark can also be set for the final productivity value (product of the benchmark values). Acting downwards, ESWI should first check if the calculated productivity value is satisfactory based on the benchmark value. If found unsatisfactory, the three components have to be seperately checked with their respective benchmark values to see where the contractor is behind in terms of productivity. It is possible that ESWI are short of achieving the required values for more than one component, in which case, the management has to make the decision as to which component is to be given more priority in terms of improvement and necessary improvements have to be implemented in the *Act* phase. Hence, the success of the model will largely depend on the quality of the work sampling study and the benchmarking of the three components. The values calculated in the next run of the PDCA cycle should be compared with these values to analyse the results of the *Act* phase.

This value can also be viewed as factored efficiency, which is obtained by factoring the currently measured efficiency value with workforce utilization and effectiveness factors. The factored value is definitely better than the current value since current value can give a false sense of success. As can be seen from the example, a 90% value for efficiency is very good and rather hard to achieve. Suppose if the workforce utilization factor is found to be say 50%, then the factored efficiency reduces to 0.43*, which is definitely on the lower side and can be considered as the “actual” efficiency. Hence, the productivity value can be considered as a numerical value depicting the true efficiency of the workforce.

* - only for the purpose of showing example values. It is assumed that the three components are mutually exclusive.

5.2.1. SUGGESTED LEARNING PROCESS

From the numbers mentioned abover, currently only work efficiency is available to ESWI. The graph in the next page (source: internal data) depicts the typical way work efficiency data related to turnarounds is represented for analysis currently at ESWI. It can be seen that earned and burned hours for each day are represented using bars and the cumulative data is represented with the help of two separate curves. While these kind of graphs facilitate knowing how the efficiency of the work is changing over time, they do not depict where exactly the efficiency is being lost. To be clearer, the analysts simply rely on the information gathered on-site/elsewhere to understand where the efficiency is dwindling. This is where the proposed conceptual model can be most useful, since it includes work sampling, which facilitates understanding resource (input) utilization. This would help ESWI in recognizing the areas for improvement within the defined activity categories, which in turn will help improving the efficiency. The proposed effectiveness measure will also act as an additional measure of quality of work which, as literature suggests, is an important factor to be considered in the context of productivity.

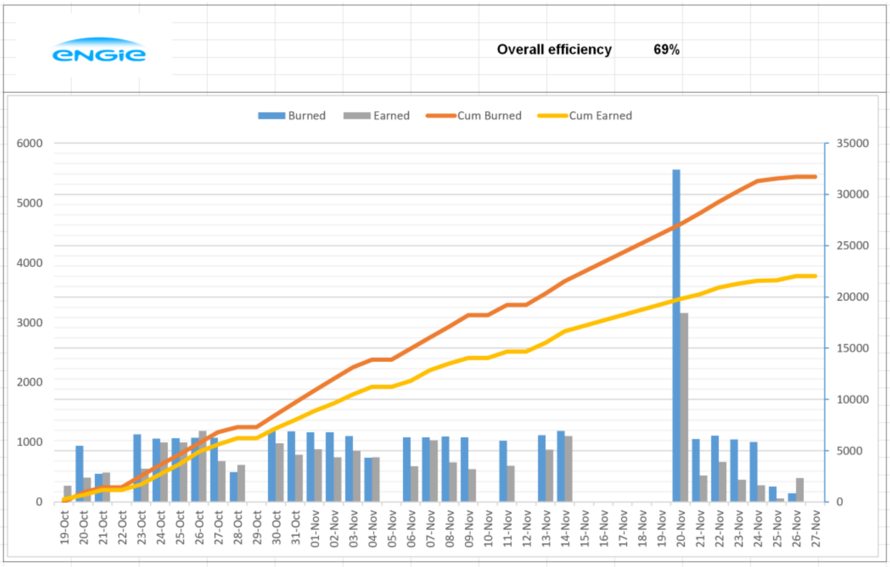


Figure 5.1: Current way of representing work efficiency data within ESWI. Source (Internal Data)

However, it must be realized that such a model will have to be implemented through a learning process, rather than directly relying on its outcomes for making management decisions. As concluded from the validation, since ESWI are not accustomed to many of the research findings, it is not possible to directly implement the proposed model within the organization. It has to be implemented through a learning process in order to achieve its full potential as well as to implement it correctly. Moreover, the learning process can be used to assess the need/feasibility of such a model in the first place. The proposed learning process based on the recommendations from experts is briefly explained below:

1. **Stage 1**: The model is to be used onlyor informative purposes. At this stage the final value of the equation is virtually useless. Recording each f element of the proposed equation separately could be the initial starting point. Out of the three components of the proposed turnaround productivity, efficiency data is to be analysed using the existing methodology. Work sampling outcomes will provide insight into the resource utilization factor. Since work sampling would provide the proportions of time spent on the various activity categories, at this stage, ESWI would be able to realize if there really exists a problem within the time utilization of the workforce. This could prove to be useful in deciding whether the proposed model is worth pursuing for in the future,given that the conceptual model revolves mainly around the work sampling study.

   Another point to be noted is that the proposed PDCA cycle cannot be implemented at this stage since ESWI would not be able to recognize the problems that exist within their management methodology based on just data collected on several days. The main aim here is to gain more insight into the workforce utilization in turnarounds. At this stage ESWI has the freedom to conduct the work sampling study based on discipline, time periods or even based on different crew type. This will help ESWI identify area(s) where this factor is most unsatisfactory. This will also help in further developing the model for implementation. It is suggested that the work sampling study should be given priority to be conducted in turnarounds that are found to be progressing with lower efficiencies. This might also help in establishing a relationship between the resource utilization and efficiency factors.

   Recording the effectiveness measure at this stage is also of importance because at present this measure is not being recorded within ESWI. This stage can be used to establish a method to record the hours spent on reworks, which is necessary in calculating the effectiveness measure and hence implementing the proposed model.

2. **Stage 2**: The model is to be used as a major argument. In the second stage, ESWI would be proficient in calculating the three components of the productivity equation. The main aim of this stage is to benchmark the three components of the productivity equation. This should be done by the management team along with the observer(s) of

the work sampling study since the observer will be able to provide more insight to what the workforce is actually going through during the execution of a turnaround. Speaking of benchmarking, past successful projects can act as a source for efficiency benchmarks. Wrench time standards based on industry are available through various consultancies that specialise in such calculations. One option is to purchase these to zero in on a benchmark value for the proposed workforce utilization measure. Another option is to rely on the pilot studies conducted within the organization. However, this would mean ESWI must be able to calculate the work sampling outcomes with extreme precision and the management must be able to make effective analysis based on this data. Moreover, the management must realise the right number of studies to be conducted in order to achieve this value. Although the uncertainties may be higher with the second option, it might prove to be the cheaper one.

Once the benchmarks are obtained, these calculation can be used in order to support management decisions related to turnarounds. The PDCA cycle cannot be fully implemented at this stage as well since there is yet no confirmation as to the effect of calculating these values. ESWI must try and run the cycle at fixed intervals in order to assess its effectiveness. This interval can again vary depending on the need for improvement based on the progress of the turnaround(s). This stage should also be used to further develop the model in order to reach an ESWI specific model. Many of the components of the model are solely based on findings from literature and although these were validated within the organization (in the following section), it is possible that there exists some other tools/ components that best suit ESWI.

3. **Stage 3**: The model will have direct contractual consequences. This is the stage for which the model was ultimately designed for. With the help of the tailor made model for continuous productivity improvement and the benchmarks, ESWI will be able to self-assess and hence self-improve with respect to turnaround productivity. The numbers acquired from the model will finally have meanings that is established and ESWI will be able to act based on this number. It is also possible that the model is discussed with the customer in order to provide further assurance regarding the job that ESWI is to deliver. At this stage, ESWI will be able to analyse the progress of the turnaround at the work as well as the workforce level and will be able to quickly identify and act upon the shortcomings.

5.3. ADVANTAGES OF THE CONTINUOUS PRODUCTIVITY IMPROVEMENT MODEL

- Identifying how exactly work efficiency loses are incurred is a major advantage over the current analysis method. Knowing the percentages of time spent by the workforce on the various categories will facilitate ESWI in understanding the major reasons for work efficiency losses easily. This is certainly an upgrade on the current analysis method because with the aforementioned percentages presented in front of them, the analysts will now be able to focus more on the critical category(s), saving the time spent on figuring out where exactly the efficiency is getting affected. The analysts without spending much time in identifying the problems, can go deeper and make use of the proposed RCA method i.e. the fishbone diagram to identify the root causes of the identified problem(s). With the current methodology, the effects of improvement implementations can only be analysed from the entire work efficiency numbers. The proposed model is advantageous in this aspect as well because once the necessary measures are taken, the analysts can see if the problem still exists in the activity category(s) under scrutiny by assessing the relevant percentages in the subsequent runs of the proposed PDCA cycle.
- Analysis per discipline is another key application of this model. As mentioned earlier, ESWI is responsible for works from various disciplines in a typical turnaround and although an efficiency graphs like the one in figure 5.1 may be created separately for each discipline, they may not be of much use in terms of improvement. It is possible that each discipline faces a different problem related to efficiency losses/time utilization. The proposed model can identify these with the help of separate runs in each discipline.
- Although the proposed productivity equation will eventually produce a numerical value within the range [0,1], it is far away from implementation. This is because, at the moment, this value cannot be meaningfully interpreted within ESWI. However, this value, once baselined after a series of pilot studies, can eventually be used as an overall measure for productivity. This will certainly be more attractive to the customer compared to the work efficiency value due to the underlying quality factor. A drawback behind the final productivity value is that this value alone may not provide a clear picture of the overall workforce productivity until clear standards have been established within the organization i.e. up until such a point in time, the efficiency and effectiveness values have to be analysed separately. This is mainly due to the fact that the relationships between the three factors of the equation have not been investigated. However, the resource utilization factor can be multiplied to the work efficiency value to give a factored efficiency value. This value will definitely be lower than the initial efficiency value but will push ESWI as an organization towards resource utilization improvements.

5.4. CHAPTER CONCLUSIONS

The final research phase was aimed at validating the research findings from the preceding phases within the organization. This was done with the help of 4 expert interviews and a focus group meeting. The validation procedure led to a modification in the proposed turnaround equation for better understanding from a practical viewpoint. The proposed methodology for effectivess was also found to be impractical and a substitute methodology could not be found from the interviews since these interviews were only for the purpose of validation. However, recommendations on how the proposed effectiveness value can be measured has been laid down.

The conceptual model, although validated to be feasible, couldn't be tested real-time within the organization. There were concerns regarding the implementation of the model since the organization as a whole are yet to familiarize with the work sampling procedure which forms the basis of the model. Moreover, the need for measuring the workforce utilization has only been confirmed through a qualitative study and hence, the need for such a model has also been not confirmed within the organization. The first stage of the suggested learning process for the implementation of the model, is also for these purposes. Although the scientific part is well defined and validated, the practical difficulties in implementing the model are yet to be addressed. The validation procedure suggests that implementation is possible in practice but it cannot be achieved easily.

6

Discussion, Conclusions and Recommendations

This is the final chapter of this report and is aimed to provide concluding remarks for the research that was carried out. The chapter will be divided into discussions regarding research findings and the limitations, followed by conclusions and recommendations for ESWI as well as for future research.

6.1. Discussion

6.1.1. Research Findings

This research was conducted in order to answer the following research question:
"How can ESWI improve in terms of productivity in Turnarounds?"

The first step in answering the aforementioned question was to split it into 5 sub-research questions, which were defined in such a way that they were to be answered in a particular sequence to arrive at an answer to the main research question. Answering one was required in order to answer the next and this sequence guided the research methodology that was followed in this research. The sub-research questions were divided among three research phases.

In the first research phase a preliminary literature study was conducted in the domains of turnaround and the concept of productivity in order to familiarize with these topics. Exploratory interviews were conducted within ESWI in order to gain more insight into current management methodologies for tunrarounds as well as to identify the current position of productivity in the organization. The exploratory interviews aided in gathering internal data, which further aided in understanding current turnaround management methodology, organization and other relevant information. Productivity was seen as a concept that is restricted to work efficiency measures in the organization. This was confirmed by the exploratory interviews. However the recent shift in turnaround contract trend highlightens the importance of productivity related improvements. The lack of understanding and an established definition for the term was seen as the main reason behind stagnant improvement efforts.

Side by side, a definition for productivity in the turnaround context for ESWI had to be developed in order to compare it with the actual productivity presently at ESWI. In order to do so, initially an extensive literature study in the domain of productivity was conducted. Subsequently a definition in the form of an equation was derived based on the findings from the literature study as well as literature on turnarounds. The focus of this equation was on turnaround execution and its workforce. The proposed equation included three components workforce utilization, work efficiency and effectiveness, out of which, only work efficiency calculations were found to be currently measured and analysed within ESWI.

The next research phase was aimed towards the improvement of turnaround productivity. It was seen that work efficiency had a well established methodology for measurement and tracking The workforce utilization measure was proposed as a starting point for improvement, since ESWI would have more control over this measure than efficiency measures, while effectiveness measures were proposed to be maintained above a certain level at all times. Since the focus had narrowed down further towards workforce utilization measures, relevant theories were investigated in literature. Work sampling was found to be a popular method of work measurement study and its underlying principles seemed to match with the proposed workforce utilization measure. Further investigation into work sampling led to the definition of activity categories that form the foundation of such a study. This was also done with the help of literature. The work sampling study will only be practical if there is really a need to conduct it. In order to investigate the opportunities for improvement in the proposed activity categories, a qualitative survey was designed and conducted within ESWI and ABC, an organization that provide similar technical services as ESWI. The data obtained from the survey was analysed using appropriate statistical inferences. Survey results concluded that respondents percieved opportunites for improvement are significant enough to not be ignored. Having confirmed the presence of opportunities to improve workforce utilization, the next objective was to translate the findings up until this point into a solution for practical implementation. A conceptual model for continuous productivity was developed for this purpose. The underlying theories behind the model was TQM and particulary, continuous improvement, which is one of the principles of TQM. To ensure continuous improvement, Deming's PDCA-cycle was chosen as the backbone of this model. The *Plan* and *Do* phase included recommendations to plan and execute a work sampling study. The *Check* phase included proposed quality tools found in literature for the purpose of visual representation and analysis of results. The *Act* phase is specific to the results of the preceding phase and hence only basic steps regarding this were put forward in the model.

The final step of the research was to test the feasibiliy and the validity of the proposed model within the organization. Various elements were split among expert interviews and a focus group meeting for the purpose of validation. The validation procedure gave rise to a slight modfification to the proposed definiton of productivity. Conclusions drawn from this validation procedure gave more insight into certain limitations of this model. However, the validation prodedure also helped in identifying barriers to implementing the proposed conceptual model. These are reflected in the recommendations in the coming section. A learning process for the testing and implementation of the proposed model was also suggested, since, the main concerns during the validation procedure were related to the practicality and the implementation of the model within the organization.

6.1.2. LIMITATIONS OF RESEARCH

This section acknowledges the limitations of the conducted research:

1. A significant drawback of this research is its qualitative nature. Much of the important research findings were based on existing studies. While in few cases a qualitative approach was the best way to go, the same cannot be said for few others. For example, exploratory interviews along with literature study for initial investigation seems appropriate. However, the investigation regarding improvement opportunities was done by conducting a qualitative survey. While inferences can be made from the qualitative survey, there is a lack of numerical backing.
2. The conducted survey was filled out by 45 respondents from ESWI and ABC company (based on availablity) which is a low number and it was resricted to only PMs, CMs and PLs to variations in perceptions of other personnel. However, this might have affected the accuracy of the survey data, although the data was found to be of statistical significance.
3. While the three components of the productivity equation were established with sufficient backing from literature and validation, the relationships between the three components have not been discussed. How changes in one measure may affect the other or the recommendations on how to make use of the data using the equation has not been put forward. Although the conceptual model was developed for continuous productivity improvement, it focuses solely on workforce utilization measures at the beginning and only basic recommendations regarding incorporating the equation into the model to convert it into a continuous productivity improvement model (true purpose) were discussed in the form of a learning process.
4. The effectiveness component of the proposed equation has a lot of question marks surrounding it. First and foremost, there is no real effectiveness measure that can be quantified. However, based on literature findings, it was concluded that productivity should include this component. Speaking of measuring, it is still uncertain if it is possible to calculate the percentage of time an average craftsman spends on reworks. Although, in theory, it should be possible through work sampling, there is no evidence in literature regarding this. Validation led to the conclusion that the proposed methodology for measuring this value is impractical. The research has failed to provide a concrete method for measuring the proposed effectiveness component.
5. The fact this entire research was conducted from a contractor perspective can also be considered as a limitation. Although the research aimed at providing the technical service provider with recommendations on turnaround productivity improvement, it has failed to take into consideration the perspectives of the different stakeholders that exist within the turnaround.
6. The quality tools proposed as part of the conceptual model are not exclusive for the purposes mentioned in the model. There may be different tools/techniques that may prove to be more appropriate, eventhough the proposed tools were positively validated within ESWI.
7. Wrench time measures are not new to the industry. Investigation led to the findings that many organizations deploy the work sampling technique as part of productivity improvement. However, the research did not compare the current state of ESWI with wrench time standards that already exist.
8. Even after the early shift in focus towards workforce productivity, the research has failed to address the viewpoints of actual workforce associated with turnarounds. The research has probably missed out on some valuable insight that could have changed the course towards the conclusions of the research.

6.2. CONCLUSIONS

This section provides the conclusions to the conducted research. In this section, answers to the five sub-research questions are sequentially stated. Based on these conclusions, the main research question is answered.

1.How are turnaround maintenance services currently handled by ESWI?

In the turnaround context, ESWI as a contractor is involved mainly in work preparation and execution. The technical capabilities of ESWI restricts them to turnaround activities of certain nature and not the entire turnaround execution. These activities are collectively managed by applying principles of project management such as planning, scheduling and so on. The turnaround specificity is taken care by turnaround specific management softwares. The established management methodology has been found to be satisfactory, considering that there hasn't been any significant improvement efforts in recent times.

2.How can turnaround productivity be defined with reference to ESWI?

ESWI should have its focus on improving the productivity of the workforce i.e.only for work execution. Starting productivity measurement and tracking at the lowest level in the organization may prove useful later in setting the foundation for identifying barriers to productivity that exist at higher levels of the organization. Out of all the relevant actors in the turnaround, ESWI would have the most control over their own workforce. Turnarounds are characterized by large amount of highly intense workforce during execution. Meaning, workforce productivity is a crucial measure in the turnaround context. The proposed definition for turnaround workforce productivity is as follows:

$$T/AProductivity = \left(\text{\% of Productive Time}\right) \times \left(\frac{\text{Earned Hours}}{\text{Burned Hours}}\right) \times \left(1 - \text{\% of Rework}\right)$$

In the above equation, the first component (the percentage of productive time) is a measure related to resource utilization, the second component is the measure of efficiency and the final component is related to effectiveness.

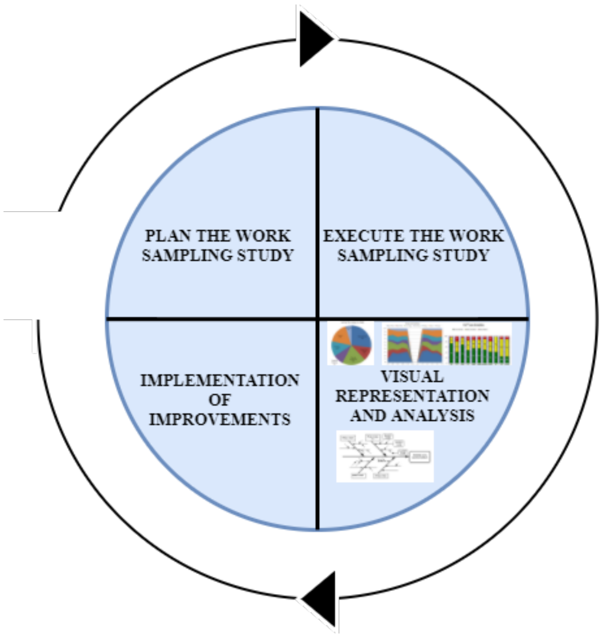
3.What is the position of productivity in the turnaround context at ESWI?

Productivity is seen to be a concept that is both vague and unexplored in the turnaround context at ESWI. Current productivity measures are restricted to work efficiency measures during execution, which is only a single component of the proposed turnaround productivity. There is a clear obscurity regarding the definition of turnaround productivity in the organization, resulting in a lack of subsequent improvement measures. However, the recent shift in turnaround contract trend towards a unit rate setting calls for exploration into productivity.

4.How can improvements be made in the proposed turnaround productivity?

Productivity improvements could start at the workforce utilization factor in the proposed turnaround productivity. Work sampling was seen to be a popular work measurement technique found in literature to calculate productive time proportions. It is driven by the statstical assumption that a sufficient number of observations of workforce behaviour can be used to calculate productive as well as unproductive work proportions of an average craftsman. The qualitative investigation regarding the various activity categories defined confirms that there is percieved considerable opportunities for improvement in reducing unproductive time and increasing productive time in turnarounds.

5.How can the theoretical improvements be translated into practice at ESWI?



A conceptual model was proposed for the purpose of answering the final sub-research question. The underlying theory behind the model was Total Quality Management which thrives for continuous improvement. In order to make it practical, the PDCA cycle was selected as the structure of the model. While the *Plan* and *Do* phase contains recommendations to conduct a work sampling study, the *Check* phase includes quality tools found in literature for the representation and the analysis of the results from the work sampling study. The Act phase involves the implementation of improvements based on the results from the preceding phase. The effectiveness of implementation will be analysed in the *Check* phase of the next cycle. The model, although proposed for workforce utilization measurement and improvement, also contains recommendations on incorporating additional measures to implement it as a continuous productivity improvement model. Although validation suggested that it is feasible to implement such a model within the organization, its practicality raised questions. In order to fully realise this model, it has to go through various stages of a learning process which was suggested based on the insights received from the validation procedure.

6.2.1. ANSWER TO THE MAIN RESEARCH QUESTION

How can ESWI improve in terms of productivity in Turnarounds?

Improvement can only begin by truly understanding what is to be improved. Hence, the first step in improving turnaround productivity is to have a well established definition for it. It was seen the productivity is currently restricted to efficiency measures within ESWI, which contradicts findings from literature which conclude that productivity should be seen as a combination of both efficiency and effectiveness. A turnaround productivity equation has been formulated and validated within the organization. Based on this equation, a continuous productivity improvement model has also been designed, the feasibility of which, has also been tested within ESWI. Although the implementation of proposed model is feasible based on the validation procedure conducted for the purpose of this research, it requires further ESWI specific investigation and management commitment.

6.3. Recommendations for ESWI

- ESWI should conduct in-depth investigation regarding the need for implementing the proposed continuous productivity improvement model, to substantially strengthen the conclusions from the qualitative survey. Pilot work sampling studies or any other methods should be deployed to obtain sufficient numerical backing regarding the scope for improvement in the workforce utilization measure.
- The first two phases of the proposed model include recommendations on how to conduct a work sampling study. Although most of the necessary domains are covered, these recommendations should be further investigated in order to develope an ESWI specific and more detailed work sampling framework. Only then, the conceptual model can be initiated. The study should also include investigation into methods for distinguishing direct works and indirect works related to reworks from the ones related to planned work. The practicality of a work sampling study should also be assessed in this investigation.
- The proposed effectiveness measure comes with numerous limitations as discussed previously (refer section 6.1.2). However, since this measure is only a factor in the proposed equation, it is possible that the effectiveness factor can be redefined. Since effectiveness includes an element of quality, a new effectiveness factor, if found better suited, is recommended to align the organization goals and culture.
- The concept of productivity should also be discussed with different customers in order to understand the expectations and perceptions of a client. This involvement of the client will help in further redefining the proposed turnaround productivity equation. In the future, this productivty measure can be used as assurance for the client, provided that the re-design of the equation actively involved client.
- The proposed conceptual model has only been tested among a few personnel within ESWI. Its applicability within the organization must be further tested among other relevant personnel. Feasibility studies and financial studies must also be considered.

Practical Relevance of Research

The researh defined turnaround productivity with reference to ESWI with the help of literature. The conceptual model was also designed based on previously conducted studies. Hence, the practical relevance of such a research comes into question. However, the research also had investigations within the company and the research findings were developed in such a way that it will help ESWI the most. The findings, conclusions and recommendations presented in this research can be used as a foundation for making productivity tracking and assessment a reality. This will most certainly be useful for ESWI given the unit rate contract setting associated with turnarounds. Moreover, the stride towards self-assessment and improvement would make ESWI more attractive to a customer.

6.4. Recommendations for Future Research

- The proposed equation for turnaround productivity has been developed from a contractor perspective alone. Moreover, a fair share of research findings were from investigations and data collected from just one organization. A more detailed research into the organiszational complexities and different perspectives related to turnarounds will help in defining a more genralised equation for turnaround productivity.
- A similar research can be conducted from a client perspective alone and the similarities/dissimilarities between the research findings of both can be assessed.
- The proposed conceptual model is rather general and if presented alone may not look as a turnaround exclusive model. Further investigation regarding the development of the model into a turnaround specific model is suggested.
- The relationships between the three components have not been identified in this research. This is important in further developing the equation and subsequently the conceptual model.

Scientific Relevance of Research

Since the main focus of this research was to provide ESWI with recommendations on turnaround productivity, the scientific relevance of this resarch is lesser compared to its practical relevance. The proposed equation for turnaround productivity can be considered as the element with the most scientific relevance in this research. It can be further investigated from a contractor perspective or can be exploited for the purpose of defining a genral turnaround productivity formula. The conceptual model, although general in terms of applicability, can also be used and further modified based on the objectives of the research that is being conducted.

6.5. Critical Reflection

Looking back at this research, mentioning a few points as part of reflection is worthwhile. The research was aimed at providing ESWI with recommendations to improve productivity in turnarounds, an event that the organization specializes in. However, initial exploration led to the conclusion that the concept of productivity was restricted to work efficiency measures alone within the organization. This contradicted the literature findings regarding the concept of productivity which clearly implied that productivity should be a measure of both resource utilization as well as quality of work, meaning, efficiency and effectiveness respectively. Hence, an equation for turnaround productivity was derived based on literature findings and then compared with the one that existed within ESWI. It was seen that although components of the derived equation did exist within the organization, they were not considered under the same umberella i.e. productivity.

The path chosen for deriving the equation was through literature study. A validation could have been done at this point in the form of interviews (or similar), which would have further solidified the proposition that this is in fact the equation apt for ESWI. This validation could have also led to further findings and changed the course of the research entirely. Waiting to validate this important finding of the research till the end could have been avoided. Although enough literature backing was present, practicality was completely ignored at this point of the research.

Given all the findings until this point, which was mostly from literature and internal data, it was decided to look for ways to improve turnaround productivity, based on the derived equation. Although there exists a well established methodology for work efficiency measurement and tracking within the organization, identifying how efficiency losses are incurred, are restricted to mostly experiences gained first hand from the worksite. This led to the focus being narrowed down to the resource (workforce) utilization component of the turnaround productivity equation (wrench time percentage). Literature findings suggested that the effectiveness measure was not a straight forward one and there was no clear cut definition for this term. However, the research failed to give equal importance to both these components. Since majority of this research relied upon literature, it was assumed that solely focussing on the wrench time measures, for the purpose of improvement, would produce more useful outcomes compared to a study that was spread across the two newly defined components of the productivity equation i.e. wrench time and effectiveness.

Work sampling method was found to be an well-known and accepted technique for wrench time calculations through literature. Although many literary sources conclude that work sampling data alone be used as a measure for productivity, earlier conclusions suggested that this shouldn't be the case. Work sampling data was proposed as a source for the workforce utilization measure. Further studies into work sampling led to the activity category definitions of the turnaround workforce. It was hypothesized that time spent on these activity categories could be improved, hence, improving the workforce utilization. This hypothesis was confirmed through a qualitative survey which led to the conclusion that improvement opportunities did in fact exist according to the respondents of the survey, which were limited to PMs, CMs and PLs within ESWI and another similar technical service provider ABC. Although the responses received proved to be of statistical significance, they were limited. The idea behind restricting the respondents to just PMs, CMs and PLs was done in order to limit the variations in perceptions between different relevant players within the organization. However, the perception of the workforce, who actually execute the work, was a crucial component which the research lacks.

Having confirmed the improvement opportunities, a conceptual continuous improvement model was designed as part of recommendations to ESWI. The conceptual model included the work sampling method as well as recommendations regarding analysis of the data acquired from it, along with the use of the proposed turnaround productivity equation. The model was validated within the organization with the help of 4 expert interviews as well as a focus group meeting. The validation, although partly successful, led to the conclusion that the model cannot be practical until significant efforts are put into implementing it. Moreover, the research failed to provide numerical backing regarding the improvement opportunities that were the reason behind developing the model in the first place. Although the validation committee seemed interested in it, they were unsure of how useful the model could be for the organization, let alone its practical impact.

The inexperience of the author in the field of turnarounds and the limited time frame for the research led to the decision of relying upon existing literary sources for most of the findings of this research. Although the work sampling method was not tested in a turnaround setting, the validation respondents agree that it is possible to implement the proposed model (which includes work sampling) in practice. Another drawback of the research is that the perception of the workforce was not included as part of the research. A DILO (Day In the Life Of) method or similar would have given significant insight into what the workforce really goes through during a turnaround, since the main focus of the research had shifted to the workforce. The backbone of the entire research is the proposed productivity equation which is recommended to be used in the future for turnaround events in order to truly understand their resource (workforce) utilization as well as quality of work. In the new contract setting, it is vital that these aspects are to be given more importance with regards to improvement. Measuring and truly understanding these should be the starting point of the strive towards improvement for the contractor. This research has provided a foundation for this. However, if the same research were to be conducted again, more time would be expended for the purpose of understanding the difference between literary findings and practicality.

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A

Literature Study

A.1. Literature Study on Turnaround Management

A.1.1. Turnaround/Shutdown Projects

There are few definitions of Turnarounds/Shutdowns that can be identified from literature. Most of the definitions describe the turnaround process in a similar way i.e. there are no extreme differences between various available definitions, a few of which are stated below:
" Engineering events during which new plant is installed, existing plant overhauled and redundant plant removed. " [6]
" Planned periodic shutdown of a refinery's processing unit (or possibly the entire refinery) to perform maintenance, inspection and repair of equipment that have worn out or broken in order to ensure safe and efficient operations and replace catalysts that have deteriorated. " [4]
Those projects that involve shutdowns of major equipment are expensive both in terms of direct costs as well as in terms of lost production [5]. Often, improvements in equipment or processing scheme can only be implemented when the equipment (plant) is not under operation [4]. Due to the high combined costs and potential impacts (both positive as well as negative) on the business , turnarounds are mostly associated with intense top management attention [5].

Activities during a Turnaround/Shutdown

The activities that are carried out during a planned Turnaround can fall under either maintenance related activities or improvement activities[4]. Maintenance activities may involve routine as well as special inspections, installations of replacement equipment for parts of worn out instruments and replacement of catalysts or process materials that have been depleted during operations [4]. Improvement activities may include installation of new upgraded equipment or technology to improve the refinery processing, installation of new major capital equipment or systems that might cause a significant alteration in the refinery process and the product output [4].

What differentiates Turnaround projects from regular EPC projects?

Although at first glance turnaround projects seem like *Engineering,Procurement* and *Construction* (EPC) civil projects, there are significant differences [7]. The main difference would obviously be that turnarounds have a dynamic scope compared to a more or less static scope of an EPC project. Unlike EPC projects which usually have well-define scope from drawings, specifications, contract and more, it is common for turnaround scopes to be changing up to the last minute before project execution [7]. The reason for this can be varying market conditions leading to last minute budget/time or start date changes,or a planning input that would only be identified during last minute operations or issues relating to availability of specialized equipment [7].
A few other differences between turnaround and EPC projects are listed below [7]:

- EPC projects are usually planned and scheduled well in advance of execution whereas in turnaround projects, planning and scheduling can only be finalized once the scope has been approved (generally near the shut down date).
- Manpower staffing requirements are more or less stable in an EPC project but they can vary substantially in a turnaround project. Once again this arises due to more scope fluctuations in the latter.
- Project schedules can be updated either weekly or on a monthly basis in case of EPC projects. Due to the short time period available for turnaround execution, schedules must be updated every shifts, daily.
- Schedule can be accelerated in an EPC project in order to correct slippages in the critical path. Since turnaround schedules are compressed, there may be little or no opportunity to correct the critical path by accelerating the schedule.

COSTS INVOLVED IN A TURNAROUND/SHUTDOWN

As mentioned earlier, turnarounds involve both direct costs as well as costs due to lost production which make them expensive [5]. *Direct costs* are calculated by adding up all the manpower, equipment, material and service costs throughout the entire life-cycle of the turnaround i.e. from preparation to termination [6]. *Indirect costs* in a turnaround project are those costs that are incurred in order to support the project and not directly associated to a work order. These may include supervision costs or certain equipment rental costs. Also, there are *Potential costs* that may include costs due to emergent work, overrun, throughput and more [6]. The image (Figure A.1) below depicts the total turnaround cost as business cost which includes direct costs, potential costs as well as costs due to loss in production.

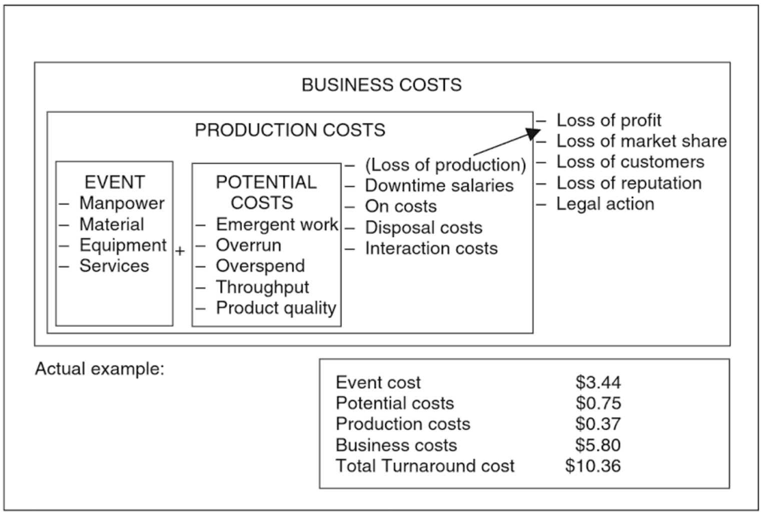

Figure A.1: Total Costs in a Turnaround Project
Retrieved from *Turnaround, Shutdown and Outage Management: Effective Planning and Step-by-Step Execution of Planned Maintenance Operations* [6]

A.1.2. TURNAROUND MANAGEMENT IN PRACTICE

Shutdown projects and project strategies flow from a thorough understanding of what most influences the business i.e. what are the dominant patterns such as growth, cost avoidance, safety, efficiency and so on [5]. These influences are a mixture of both internal (i.e. you have some degree of control) as well as external (must be forecast/predicted) factors [5]. Planning and Scheduling for major shutdown is a specialty, i.e. the management of major shutdown efforts are usually separated from management of other maintenance work [5]. According to Levitt, the most effective approach to maintenance shutdowns is long term [5]. With so much revenue at stake, it is the process sector that continues to strive for longer intervals between successive turnarounds ranging from the traditional twelve/ twenty four months, to, in some cases, up to as much as eight years [6]. The turnaround procedure is a continuous process from one major scheduled maintenance to the next. It starts well before the plant is taken off-line and continues for a period of time after the scheduled major work has been completed [8].

THE PHASES OF A TURNAROUND/SHUTDOWN

The Project Management Body of Knowledge (PMBOK) consists of several techniques and strategies for efficient management of projects, much of which can also be applied to maintenance as well as project driven shutdowns [5]. In order to use these techniques effectively, project managers divide the shutdown into different phases [5]. In general, the entire turnaround management process can be divided into 4 or 5 phases. [4] and [5] describes 5 phases of turnaround management whereas [6] reduces this number to 4. A typical turnaround/shutdown project can be broadly classified into the following 4 distinct phases [4]:

- Phase 1: *Initiation Phase*
  This phase answers the questions "what?" and "why?" [5]. The need for a turnaround is identified and an appropriate response to that need is determined and described [4]. The initiation phase is also characterized by defining objectives, setting policy and appointing the necessary personnel to set up the preparation team and gather basic data [6]. Issues of feasibility and justification are also addressed in this phase [4].
- Phase 2: *Preparation Phase*
  This phase answers the question "How?" [5]. This is a major phase of the process and probably longest in terms of the time put into it. A small team of people work over a long period of time (months or even years) and this phase

should basically encompass all areas of shutdown management and consider budgets, activity definition, scope planning, schedule development, risk identification, staff acquisition , procurement planning among other functions [4]. The final stage of the preparation phase involves communicating the requirements of the Turnaround to every single person who will be involved at any level [6].

- Phase 3: *Execution Phase*
  The size of the work group involved in this phase is the largest. However, the period of time they are involved is the shortest and the most intense [5]. Basically, the execution phase of a turnaround project is characterized by the performance of a large volume of tasks by a large number of people of varying skills and from different disciplines, in a limited space and at different levels simultaneously, which takes place under time (sometimes severe) and financial pressure [6]. Execution can be further divided into smaller sub-phases [6] all of which will fall under either 'shutting the facility down', 'doing the work' or 'bringing the plant back to operation' [5]. Performance measures are also taken and analyzed in order to check whether the turnaround is going according to plan. Corrective measures (in case of unsatisfactory performance levels) as well as unplanned work (due to uncertainties revolving the equipment/plant conditions) are also carried out in this phase [4].
- Phase 4: *Termination Phase*
  There are two separate elements involved in terminating the project. The first is to ensure that the plant is handed back in a fit condition and the second one being de-briefing every member of the Turnaround Organization in order to capture the lessons to be learned from the event as a future reference so that the subsequent turnarounds will be executed more effectively [6]. Trinath Sahoo claims that the closing process is the most often skipped in shutdown management [4]. However, he does not fail to highlight the importance of not just ensuring that the plant is returned in an acceptable condition but also gathering information for future turnarounds.

There were two other phases identified in literature. The first one was the *Controlling Phase*. This phase basically is the project phase where performance measurements are taken and analyzed in order to determine if the turnaround is staying true to the project plan. If found otherwise, corrective actions must be taken [4]. For the purpose of this research, the controlling phase will be assumed to be included in the execution phase (since the activities in these phases generally happen simultaneously). Another phase that was identified from literature was the *Interim Phase*. This stage is where all the files are reviewed in order to decide what is to be restored and what is to be discarded. A narrative for the lessons learned is also written up in this stage [5]. This stage is important because as explained earlier, turnarounds are cyclical [8] and the preparation phase of the next turnaround will depend on the quality of performance in this stage. Even though this is the case, for the purpose of this research, activities in this stage are considered as part of the termination phase.

THE TURNAROUND ORGANIZATION

"The team is the key to the success of a shutdown" [5]. Although this statement holds true for almost any kind of project, the importance of effective team work by the turnaround team should by no means be underplayed. Turnaround organization is a matrix organization that gets personnel for other departments apart than the regular staff on a temporary basis in order to function [4]. A matrix organization is a mixed organizational form in which traditional hierarchy is overlaid by some form of lateral authority, influence, or communication [77]. The matrix organizational structure is one way to gather competence together from different parts of an organization in order to undertake important renewal efforts [78]. The organization developed is temporary in nature, since it is built around the turnaround project or a specific task to be done rather than on organizational functions. The turnaround team can be sub-divided into smaller teams whose basic functions are detailed in Table A.1 [4].

When it comes to turnaround/shutdown projects, one of the most important personnel involved is the turnaround manager. All shutdowns should have a shutdown manager and he is given total control over the project [5]. A few other important personnel involved in a turnaround organization along with the turnaround manager are listed in Table A.2 with a brief description of their respective functions/role in the project [5]:

Table A.1: Turnaround Organization.
Adapted from *Process Plants: Shutdown and Turnaround Management* [4]

Sub-team	Description
Turnaround steering committee (TASC)	Generally consists of the facility's senior management. Provides direction and guidance to the core team to ensure that business needs are met. Ensures that the turnaround's scope and budget are aligned.
Turnaround working committee (TAWC)	The Turnaround working committee is led by the Turnaround manager and the entire turnaround team maybe divided into sub-teams mentioned below. The turnaround manager and the respective team leaders make up the Turnaround working committee.
Planning team	Led by a lead planner who is ideally an experienced manager, leader, team player, and have effective problem solving skills, good communication ability at all levels and so on. The team must be highly experienced and be able to communicate well with all sections/external agencies
Quality team	Usually already in place in most organizations and can be readily incorporated into the team.
Operations team	The operating staff must be formed into teams of well-defined responsibilities for rapid and safe unit shutdowns and startups. They must be trained to undertake pre-close-up inspections which may prove vital in planning before the actual inspection begins.
Execution team	A few qualities of a good execution team are: understanding the contractor, innovative in exploiting resources, being able to communicate with members from other groups, particularly planning.
Safety team	A few tasks of the safety team are formulating the fire prevention measures/precautions required to be taken during the turnaround, they should outline the training program required for all relevant personnel, anticipate the medical services that would be required in the premises and so on.

Table A.2: A few key personnel in a Turnaround/Shutdown project. Adapted from *Managing Maintenance Shutdowns and Outages* [5]

Role	Description
Turnaround Manager	Chooses the remaining members of the team and makes sure that the team has all the necessary training, experience and resources. Acts as a bridge between the Shutdown team and the top management team. An advisor of the Shutdown Policy team (top management team). Given total control of the shutdown.
Planning Manager	Head of the Planning team. Establishes activities for all jobs in consultation with the shutdown engineer and plant personnel. Detailed knowledge of jobs, techniques and work conditions.
Engineering Manager	Head of the Engineering team. All amendments, hurdles and engineering decisions are directed to the engineering manager. Must recognize outside skills when needed.
Purchasing Agent	Involved in the early planning phases of the project since procurement of large quantity of possible expensive as well as one-time equipment is crucial for the turnaround.
Shutdown Accountant	Will account for how all changes are handled. Sets up the accounts for the Turnaround and provides instructions for charging of various items.
Field Manager	Can be found in some shutdowns and is in charge once the shutdown is underway. Directly works with the Turnaround manager. Uses the MBWA (Managing By Walking Around) technique.
Shutdown Safety Officer	Head of the Safety team. Reviews the hazards of various jobs. Involved early in project to ensure that safety is built-in rather than added in planning. Other functions include inspects PPE (Personal Protection Equipment), the techniques followed (fall protection) and so on.
Shift Boss	Usually an employee of the company. Forepersons in various departments including electrical and mechanical report to the shift boss. Reports to the Turnaround Manager or the Field Manager

A few more personnel involved in a Turnaround/Shutdown project identified in literature: *Technical Support team, Process Support team, Contract manager, Material and logistic manager.*

A.1.3. CHALLENGES FACED BY A TURNAROUND MANAGER

The days of plant turnaround being considered a natural extension of a facility's maintenance cycle are long gone. Turnarounds are complex events that require entire plant cooperation and focus and involve work scopes that are often dominated by safety, environmental and reliability improvements, plant expansions and unit debottlenecks [9]. Industry leaders have identified that the ability to predictably deliver superior turnaround performance profoundly defines the business viability and manufacturing competitiveness [9]. Levitt claims that sometimes, the value of lost production is in an order of magnitude greater than the direct costs of the project itself [5]. A few challenges, apart from the obvious partially defined scope of work (general characteristic of such projects), that a typical turnaround manager faces listed in literature are elaborated below:

- Drain on Resources: A turnaround is a drain on the company resources (especially in terms of personnel since Turnarounds usually require much more personnel than the normal number of workers employed on the plant and hence external resources need to be brought in [6].
- Hazardous to Plant Reliability: Although turnarounds form a major part of the maintenance strategy of a plant, the purpose of which is to protect the reliability of the plant, it is possible that if not planned, prepared and (or) executed properly, the turnaround can act as a potential hazard to the plant reliability [6].
- Safety challenges: Turnarounds increase the potential for harm to people, property and the environment. The reason to this is quite clear. Compared to normal plant operation, where there is an experienced team (relatively small) of personnel performing familiar tasks using well defined procedures, shutdowns/turnarounds involve large number of unfamiliar strangers using inherently hazardous procedures and equipment working upon the plant that is shutdown and taken apart[6].
- The risk of overspend and overrun are always part of any kind of project. In case of shutdowns/turnarounds, the possibility of occurrence of unforeseen problems leads to higher risks of cost and time overruns, even if the company acts prudently and take these into consideration by adding cost and time contingencies into the turnaround plan [6].

Turnarounds are also exposed to additional challenges which includes environmental, operability, quality and even community affairs targets [9]. Hence, the real challenge for turnaround management is to achieve an optimum balance between the company's business and financial goals and the plant's operational and mechanical integrity needs [9].

A.1.4. WHY IS THERE A NEED FOR TURNAROUND PROJECTS?

Even after numerous strenuous challenges faced by turnaround managers (few of which are mentioned in the previous subsection), while also rendering a plant non-operational for a certain duration of time, it is seen that such kind of projects are executed in the process industry all across the globe. This raises the question as to why there is a need for such kind of high labor-intense, expensive projects in the first place. Most of the reasons boil down to improved performance of the plant [5]. A few reasons are listed below:

- Maintenance needs: One of the most common drivers for a shutdown is a need for maintenance (equipment, plant or both). Large scale assets will require maintenance work which can be carried out only when the plant has been taken off line and made safe for the performance of such work [6]. This kind of maintenance needs can stem from inspection, Non-Destructive Testing, past experience and history or even gut feelings at times. A few objectives of shutdown maintenance is to increase reliability, increase repeatability, increase or augment life span [5].
- Changes in market demand: New products are constantly being invented and plant outputs must be modified in order to meet the ever-changing market demands. Shutdowns are designed to meet this objective as well [5].
- Profit Enhancement: Turnarounds can positively affect operational efficiency as well as energy efficiency of a plant or industrial process. Such revamp/refit projects are done in order to improve the return on investment from physical assets [5].
- Changes in law can also be a reason as to why there is a need for turnarounds. Legal requirements including regulatory changes, safety improvements, consent decrees can change quickly. Hence, many industries have had multiple shutdowns to adapt to the news rules and regulations [5].
- Customer's request for increased production might call for a turnaround [5].

A.2. LITERATURE STUDY ON SUCCESS FACTORS AND CRITERIA IN PROJECT MANAGEMENT

A.2.1. PROJECT SUCCESS

In order to understand project success, it might be wise to first have a simple and clear definition of the term *project*. According to the PMBOK (Project Management Body of Knowledge), a project is defined as *"a temporary endeavour undertaken to create a unique product, service or result"*. The term *success* can have different perceptions from the different stakeholders involved in a project. A constraint is *"something that limits the project, the organization or its team and* *serves as a bottleneck"* [79]. These are aspects that impact the project team's ability to meet the customer needs as well as project requirements [79]. Traditional definition of success in the project management context confined it between the constraints of time, budget and quality or the so called "Iron Triangle" [80]. However, over the years, this traditional view has been found to be insufficient, with researchers trying to define project success and criteria that go beyond the constraints of the iron triangle. First, it was realized that success required trade-offs between the constraints of the iron triangle in different project environment and context, and hence, customer acceptance of the project was included in the success criteria [81]. Various researchers such as [82],[83] and [84] suggest that project success goes beyond just meeting these criteria. [85] insists that what makes the measurement of project success difficult is the fact that there is lack of a universally accepted definition of project success, and also the fact that the concept of success remains vague among stakeholders. Over the years, quite a few number of researches have been conducted in order to better define project success in varying environments. [80] for example, puts forward new boundaries of measuring success which includes constraints that fall under the iron triangle, information system , benefits of the organization and benefits of the stakeholder community. Elsewhere, one of the latest examples of project success definitions defines it as *"Achieving the desired business value within the competing constraints"* [81]. Kerzner argues that business value should become the driver for success because because as the number of constraints increase, it becomes more likely that not all of them are met.

A.2.2. DIFFERENTIATING SUCCESS CRITERIA AND FACTORS

The term *Criterion* is defined as *"a standard on which a judgment or decision may be based"* [86]. The roots of project success criteria emerge from the Iron Triangle as explained in the previous section. As mentioned earlier, researchers have been trying to define various project success criteria that are beyond the constraints of time, budget and quality. It is due to the realization of the fact that there exists different perspectives of project success [87]. Lim and Mohamed, explain this through the two views of project success, namely the micro view and the macro view. While the macro viewpoint addresses the question whether the original project concept is achieved or not, the micro viewpoint considers achievements in smaller components of the project [87]. They argue that both viewpoints are to be considered regarding project success [87]. Moreover, the success criteria varies from project to project depending on many factors such as size, uniqueness and complexity and hence it is impossible to create a universal project success criteria checklist [88]. [87] defines success factors as the set of circumstances, facts, or influences which contribute to project outcomes but do not form the basis of the judgment of project success although they facilitate or hinder it. According to [89], relevant success criteria should be identified first and then factors that can increase the chances of meeting those criteria should be determined, after which, the appropriate project management methodology which would deliver those factors should be selected.

A.2.3. CRITICAL SUCCESS FACTORS

Critical Success Factors is a concept that has been in the picture for quite some time now, with the earliest mention of such factors tracking back to Daniel in the early 1960s [90]. Their application extend across various fields such as management information systems (MIS), control systems, planning systems and so on. Critical success factors analysis has also been a concept well exploited in the Project Management field over the years [91]. These factors usually vary from industry to industry [90]. There are some varying definitions of CSFs across various applications [90]. Given in the table below are a few definitions of CSFs found across literature.

Table A.3: A few definitions of Critical Success Factors found across literature

Literature	Definition
Bullen, C. V., & Rockart, J. F. (1981). *A primer on critical success factors.*	CSFs are the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department or organization. CSFs are the few key areas where "things must go right" for the business to flourish and for the manager's goals to be attained.
Leidecker, J. K., & Bruno, A. V. (1984). *Identifying and using critical success factors.* Long range planning, 17(1), 23-32.	Critical Success Factors (CSFs) are those characteristics, conditions, or variables that when properly sustained, maintained, or managed can have a significant impact on the success of a firm competing in a particular industry. A CSF can be a characteristic such as price advantage, it can also be a condition such as capital structure or advantageous customer mix; or an industry structural characteristic such as vertical integration.
Boynton, A. C., & Zmud, R. W. (1984). *An assessment of critical success factors.* Sloan management review, 25(4), 17-27.	Critical success factors are those few things that must go well to ensure success for a manager or an organization, and, therefore, they represent these managerial or enterprise areas that must be given special and continual attention to bring about high performance. CSFs include issues vital to an organization's current operating activities and to its future success.
Somers, T. M., & Nelson, K. (2001, January). *The impact of critical success factors across the stages of enterprise resource planning implementations.* In System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on (pp. 10-pp). IEEE.	Critical success factors can be viewed as situated exemplars that help extend the boundaries of process improvement, and whose effect is much richer if viewed within the context of their importance in each stage of the implementation process.

The use of the CSF concept as a methodology for information systems was first introduced by John Rockart. He made use of this concept in a mechanism for defining a CEO's information needs. Rackart and Bullen later broadened the definition pf CSFs and proposed that they be used as an MIS planning tool [92]. However, their application extends beyond MIS. For example, M.C. Mruno and B.R. Wheeler suggested that CSFs can be used in developing strategic plans [92]. Along with developing a set of strategies, CSFs can also used to identify critical issues that are associated with implementing a plan [92]. Another notable example would be C.R. Anderson's observation that CSFs can be used by managers and organizations in order to achieve high performance [92].
CSFs are related to the specifics of a particular manager's situation, meaning, they must be tailored to the industry, to the company and to the manager [93]. They tend to change from manager to manager according to the individual's space in the organizational hierarchy or they can change as the industry's environment changes (as the company's position within the industry changes)[93]. They can also change when a particular problem arises for a particular manager [93]. Hence, it is safe to say that CSFs are neither a standard set of measures nor are they limited to factors which can be reported on by just historical, aggregated, accounting information [93].
Although the CSFs approach has been established and popularized over the last few decades, the majority of related studies focus on the traditional iron triangle i.e. cost, quality and schedule as criteria for measuring project success [94].
According to Leidecker and Bruno, the concept of CSFs has been applied at three levels of analysis namely firm-specific, industry and economic socio-political environment [90]. Firm-specific analysis tries to focus on providing the link between possible factors, whereas, industry level analysis tries to focus on certain factors in the basic structure of the industry which can have a significant influence on the company's performance operating in that particular industry [90].
The third level of analysis goes beyond industry boundaries in order to scan the environment (economic socio-political) to provide sources of success determinants for the firm and/or the industry [90].
Elsewhere, Bullen and Rockart suggested that there are 5 prime sources of CSFs. They are as follows [93]:

1. The Industry: Each industry has a set of CSFs that are determined by the characteristics of that particular industry.
2. Competitive strategy and Industry position: A company's position in the industry based on its history and current competitive strategy dictates some CSFs.
3. Environmental Factors: These are factors over which the organization has minimal control. The sources of these factors vary from fluctuations in the economy and national politics to population trends, regulatory trends and energy sources.

4. Temporal Factors: These are areas of activity within an organization that become critical for some period of time due to something “unusual". Normally these areas would not generate CSFs.
5. Managerial Position: Each functional managerial position has a generic set of CSFs associated with it.

A.3. LITERATURE STUDY ON PRODUCTIVITY

Productivity is one of the key components of every company's success and competitiveness in the market [95].The success of a business does not only depend on the quality of a product but its strive to continuously improve productivity in order to remain competitive [20]. Before diving into the topic ‘Productivity in Turnaround/Shutdown Projects', it is important to have a clear idea about the concept of productivity as a whole. Hence, firstly, various definitions and other concepts related to productivity available through literature will be scrutinized. Then, it is possible to look into productivity in Turnaround projects, in order to establish what exactly is meant by productivity for the purpose of this research.

A.3.1. UNDERSTANDING PRODUCTIVITY

The issues surrounding the definition as well as the measurement of productivity have been the topic of research for various disciplines including economics, engineering and operations research [2]. The concept of productivity, generally defined as the relation between output and input, has been available for over two centuries and applied in many different circumstances [10]. A couple of general definitions of productivity found in literature are cited below:
“It is the ratio of output to input for a specific production situation." [2]
“A ratio of output over input that indicates the efficiency of a productive system." [20]
The definitions mentioned above are as simple as it can get, but these definitions only form the base of a concept that is being exploited by researchers and industries across the globe. In fact, these definitions give rise to more than one question like *How can productivity be measured?*, *What is the relation between the input and the output?*, *How can the input and the output be quantified?*, *What are the consequences of having different outputs and inputs?* and many more. This ambiguous nature of the general definition sparks further research into the concept.
According to [10], productivity is closely linked to the use and availability of resources on one hand and, to the creation of value on the other. Although, so far the term productivity seems to be easy to understand, its ambiguous nature has caused much confusion and there are several implications for this [10]. For example, the term productivity is often mistakenly used synonymous to measures of production. However, increased production doesn't necessarily mean increased productivity [10]. Improvements in productivity can root from the five below mentioned relationships [10]:

- Output and input increases, but the increase in input is proportionally less than the increase in output.
- Output increases while input stays the same.
- Output increases while input is reduced.
- Output stays the same while input decreases.
- Output decreases while input decreases even more.

Another important point to be noted is that there exists different kinds of productivity. The main reason behind this being that almost any transformation process within a manufacturing company is fed with several types of input (e.g. labour, capital, material and energy) and emits more than one output (e.g. product A, product B)[10]. Based on this reason, productivity can be classified into two, namely, partial productivity(output related to one kind of input) and total productivity(output related to multiple types of input) [10]. It must also be comprehended that productivity can mean different things due to the existence of various hierarchical levels within a company [10].
Four terms that are similar to the term productivity are profitability, performance, efficiency and effectiveness and it is worthwhile to have a clear distinction between these terms [10]. These terms are explained in detail below[10]:

- Profitability: Profitability is the overriding goal for the success and growth of any business, and is generally defined as a ratio between revenue and cost (i.e. profit/assets). Although we can see a component of productivity in it, profitability can change for reasons that have little to do with productivity, such as inflation and other external conditions that may bear no relationship to the efficient use of resources. A company can recover more than the cost of its input by raising prices for its output, which would increase its profitability even when its productivity is decreasing. Hence, cost recovery is what distinguishes productivity from profitability. Given below is a diagram (Figure A.2) which tries to illustrate the relationship between the two.

- Performance: Performance is a term which includes almost any objective of competition and manufacturing excellence. As illustrated in the diagram below (Figure A.3), various performance objectives can have a large effect on the productivity in an operation. Performance objectives should be seen as factors affecting productivity rather than as a part of the concept of productivity.

- Efficiency and Effectiveness: Effectiveness is simply defined as *'doing the right things'* whereas efficiency is defined as *'doing things right'*. Efficiency is strongly linked to resource utilization and hence mainly influences the input

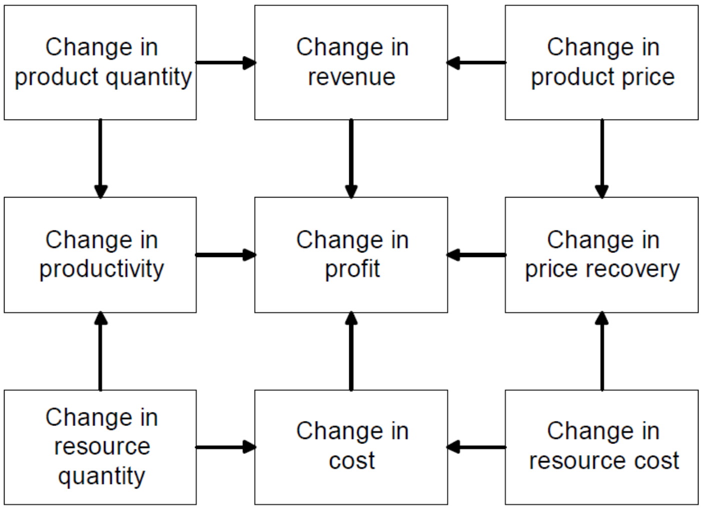

Figure A.2: Productivity's relation to Profitability
Retrieved from *"Profitability = Productivity + Price Recovery" Harvard Business Review* [96]

of the productivity ratio. It is also easier to quantify efficiency in various terms (money, time and so on). However, when it comes to effectiveness, quantification becomes difficult in most cases. It is often linked to the creation of value for the customer and affects the output of the productivity ratio. A single focus on efficiency proves to be unfruitful when it comes to positively affecting productivity. It is the combination of high values of both efficiency and effectiveness in the transformation process that leads to high productivity i.e. is it possible for an effective system to be inefficient or an efficient system to be ineffective.

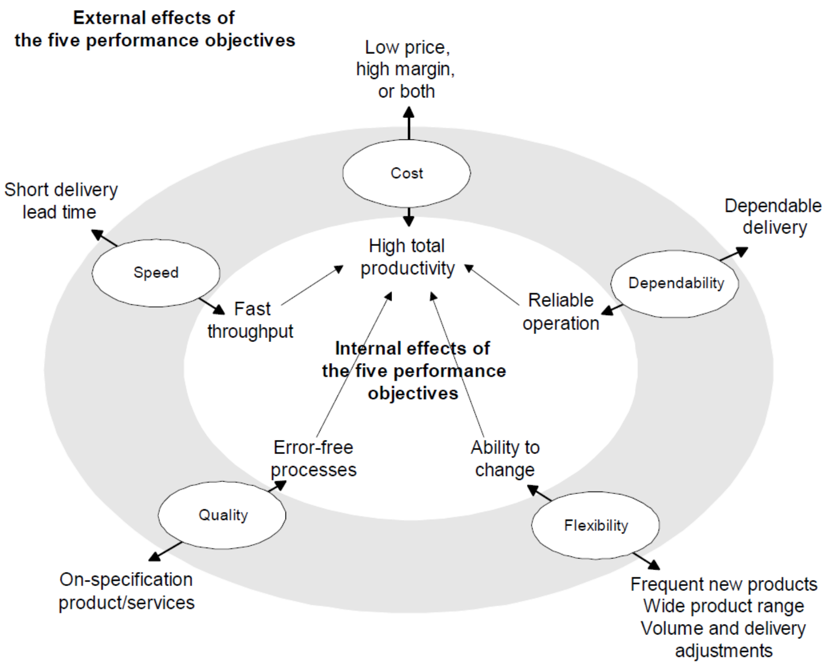

Figure A.3: Productivity's relation to Performance Objectives
Retrieved from *Operations management.U.K: Pearson Education Limited* [97]

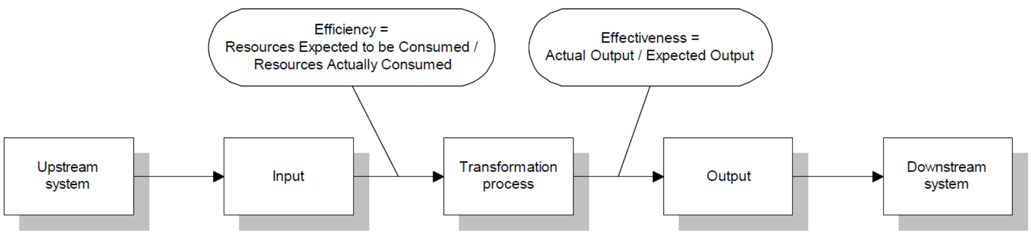

Figure A.4: Efficiency and Effectiveness
Retrieved from *Planning and measurement of in your organization of the future, Norcross, USA* [98]

THE TRIPLE-P MODEL

The relationship between productivity and the previously discussed terms are schematically depicted by Stefan Tangen in the Triple P model (Figure A.5) developed to give an idea of how the different terms are to be used. The major differences between the five terms i.e. Productivity, Profitability, Performance, Efficiency and Effectiveness can be easily grasped from the model.
Productivity constitutes the central part of the model, following the straightforward definition of productivity i.e. the ratio of output quantity to the input quantity. Profitability is also the ratio of these quantities but includes/influenced by price related factors (i.e. price recovery). Performance not only encompasses productivity as well as profitability but also non-cost factors such as quality, speed, delivery, etc. Effectiveness is to be used when the focus is aligned towards the output whereas efficiency represents the how well the resources are utilized.

MEASURING PRODUCTIVITY

The measurement of productivity has always been something that has left researchers thinking a bit more considering the lack of a standard/norm related to this concept. The term 'Productivity' is a multidimensional term [19]. This view is supported by the following statements which made about productivity by Stefan Tangen [19]:

1. Those who use the term productivity rarely define it.
2. There is a lack of awareness of the multiple interpretations of the term, as well as the consequences, to which such discrepancy leads.
3. There are both verbal and mathematical definitions and approaches.

Hence, the meaning and the measuring technique can vary, depending on the context within which the term 'productivity' is used [19]. Though the term is widely used, it is often misunderstood, leading to productivity being disregarded or

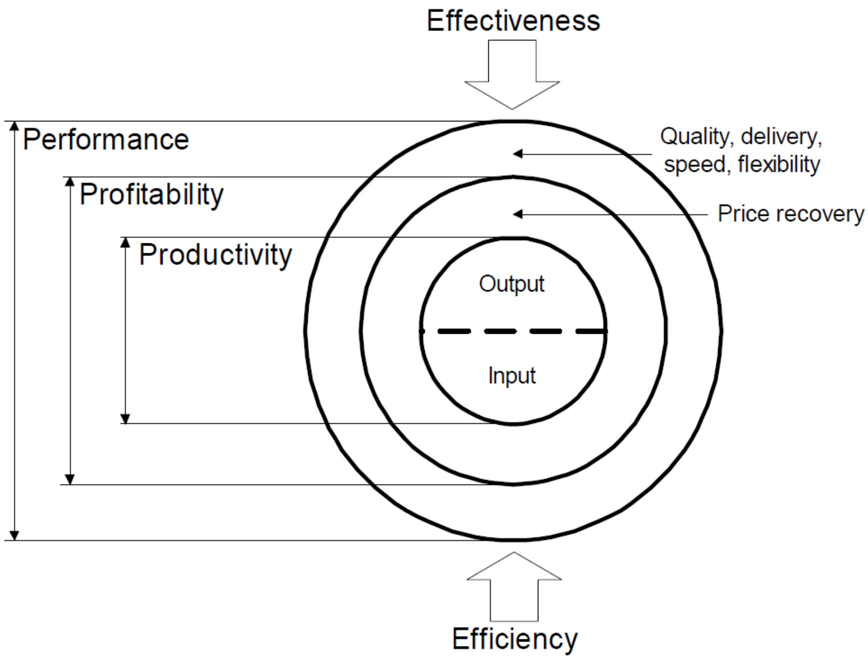

Figure A.5: Triple-P Model
Retrieved from *A theoretical foundation for Productivity measurement and improvement of Automatic Assembly Systems* [21]

even to contra productive decision making [19]. As mentioned earlier, two traditional types of index productivity measures can are distinguished as *Partial Productivity* (ratios of output to a single source of input, such as labour, capital, material or energy) and *Total Productivity* (ratio of total output to the sum of all input factors) [12].
When it comes to partial productivity measures, the advantage is that it is easier to understand and measure in reality. The required data are easily obtained and partial productivity indices are calculated with not much difficulty [22]. Another advantage when it comes to partial productivity measures is that it is possible to recognize a specific partial productivity measure in an important smaller area, function or department, meaning partial measures can detect improvements and the reasons behind them more easily when compared to broader measures. [12]. A major objection or disadvantage of partial productivity measures is that it considers only one production factor and any improvement efforts might affect another partial productivity measure which considers another production factor, which, in turn, might hamper the total productivity although an increase in the former partial productivity measure is seen [12]. An example to this is a problem known as capital-labour substitution, which means that labour productivity can be improved at the cost of capital resulting in a decline in the total productivity. Hence, partial productivity measures tend to overemphasize the increase in productivity [23]. Furthermore, partial productivity measures do not have the ability to explain the overall cost increases, making them misleading if used alone [22].
Total productivity measures provide a good picture of the overall productivity of a process or a company. An advantage of these measures is that they take into account the relationship between various production factors [12]. Having said that, pitfalls of total productivity measures include the fact that they are more difficult to understand and to measure or even quantify [23]. Hence, in practice, they are not always accurate [12]. Total productivity measures are more or less based on a number of carefully made assumptions and can produce varying results based on the weightings given to various factors [12]. A few other difficulties faced when total productivity measures are considered are tracking the activities that improve productivity and also retrieving the data that was used in calculating the total productivity [12].

B

Qualitative Survey

The qualitative survey questionnaire used for the purpose of this research can be found in this section. Following that, the overall survey results and SPSS outputs are presented.

Direct Work Rate/Wrench Time/ Hands-on-tool time in Turnaround Execution

Hello,
My name is Arjun Jayakumar and I am a Master student in Construction Management and Engineering from TU Delft, Netherlands. I am currently working on my graduation thesis at ENGIE Services West Industrie B.V.
The research focuses on productivity in Turnaround execution. As part of my study, I would like to conduct this survey regarding wrench time/hands-on-tool time. This survey will be vital for my research and I kindly urge you to fill this survey. The survey would take only a few minutes. Your inputs will be of utmost importance for my research. I will be more than happy to share the outcome of the thesis with you if required.

****

Important point to be noted: All the questions are with regards to turnaround/shutdown maintenance only and not any other kind of projects.

* Required

1. **Email address** *

____

Personal Details

* Your personal details will not be part of the thesis. I just require them for my analysis.

2. **Name** *

____

3. **Organization** *

____

4. **Role** *

____

5. **Experience (in years)** *
Mark only one oval.

- ◯ 1-5 years
- ◯ 5 - 10 years
- ◯ 10-15 years
- ◯ 15-20 years
- ◯ More than 20 years

Wrench Time/ Hands-on-Tool Time

Wrench time is a measure of crafts personnel at work, using tools, in front of jobs. Wrench time does not include obtaining parts, tools or instructions, or the travel associated with those tasks. It does not include traveling to or from jobs. It does not include time spent obtaining work assignments. Obviously, it does not include break time. It is a measure of direct work in terms of time.

6. **How much percentage of a standard shift do you think is associated with Wrench Time?**
   Mark only one oval.

	1	2	3	4	
0-25%	◯	◯	◯	◯	75-100%

Indirectly Productive Activities

These activities do not contribute directly to the maintenance jobs themselves, but they are meant to help accomplish the wrench time tasks in an indirect way by providing the right circumstances for the workers to be directly productive. Three categories of activities are defined :

1.Preparatory Works (receiving preparatory instructions, setting-up works, discussing material/tool needs, etc.)
2.Material Handling (transporting materials to work areas, unloading materials, etc.)
3.Tools and Equipment (locating tools, putting on safety equipment, connecting electrical supply to tools/equipment, etc.)

7. **In which of these following categories of activities do you think time can be improved/saved?** *
   Mark only one oval per row.

	No room for improvement	Little room for improvement	Considerable room for improvement	Lots of room for improvement
Preparatory Works	◯	◯	◯	◯
Material Handling	◯	◯	◯	◯
Tools and Equipment Handling	◯	◯	◯	◯

8. **Are there other categories of indirectly productive activities than the ones mentioned above? If yes, please mention**

____
____
____
____
____

Unproductive Activities/Delays

These are activities that do not contribute to the maintenance job at all. These can be categorized as
1. Waiting
2. Travel
3. Personal activities.

9. **Given below are a list of delays that cause unproductive waiting periods in turnarounds. Rate them on a scale of 1-4 based on their frequency of occurrence in Turnarounds (1 = rare, 2 = occasional, 3 = common, 4 = frequent)** *

Mark only one oval per row.

	1	2	3	4
Waiting for Permits				
Waiting for Instructions				
Waiting for Materials				
Waiting for Tools/Equipment				
Waiting for Quality Assurance/Quality control				
Waiting for other Sub-contractors				

10. **Are there any other causes of waiting periods other than the ones mentioned above? If yes, please mention**

11. **Unproductive work can also present itself in the form of reworks that occur due to correcting mistakes made earlier in a particular task. How often do you encounter these kind of works?**

Mark only one oval.

	1	2	3	4	
Rare					Frequent

12. **In which of these following categories of activities do you think time can be improved/saved?** *

Mark only one oval per row.

	No room for improvement	Little room for improvement	Considerable room for improvement	Lots of room for improvement
Personal Time (Toilet breaks, smoke breaks, lunch breaks, etc.)				
Travel Time (Travelling in and out of work area, lunch, etc.)				

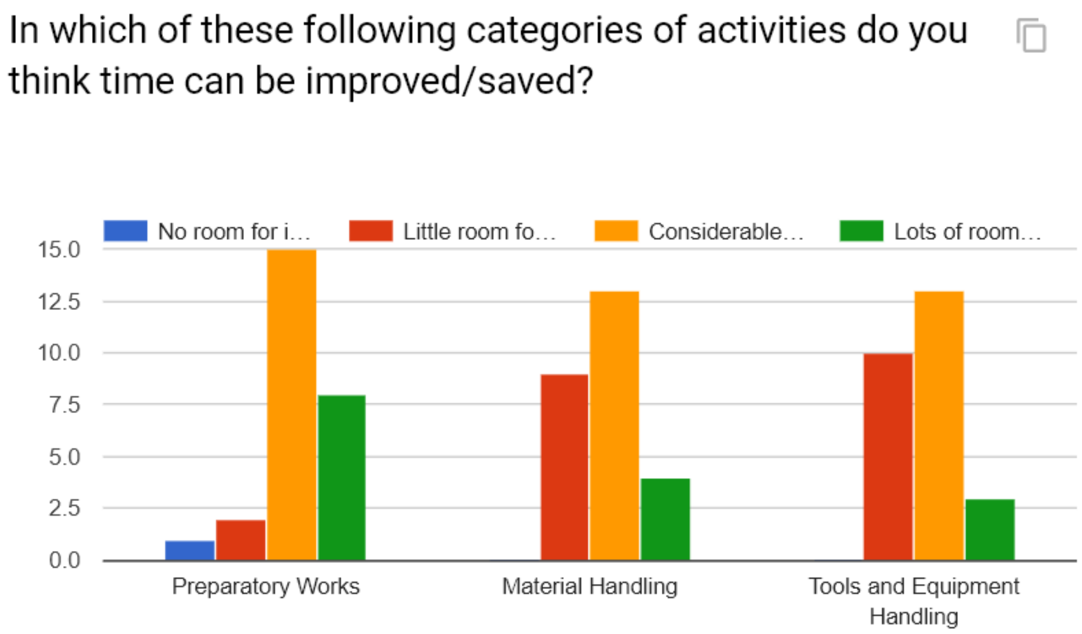

Figure B.1: Survey Data: Indirectly Productive Activities

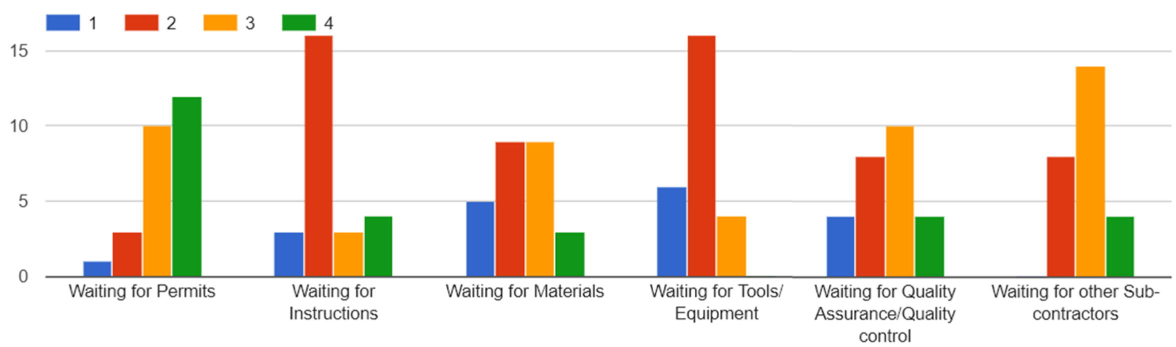

Figure B.2: Survey Data: Avoidable Unproductive Activities- Waiting

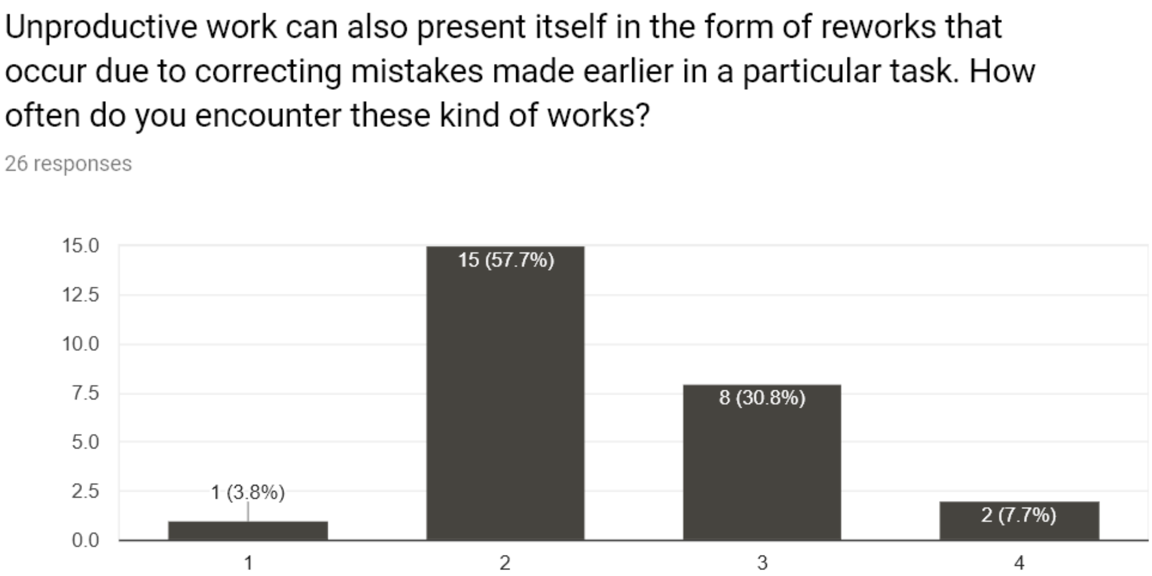

Figure B.3: Survey Data: Avoidable Unproductive Activities- Reworks

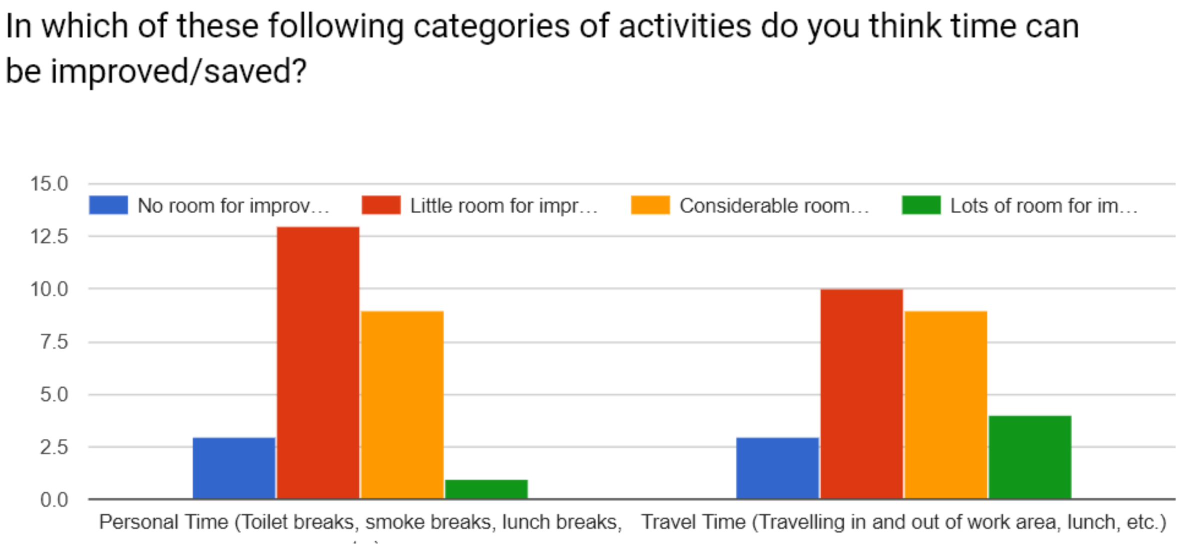

Figure B.4: Survey Data: Unavoidable Unproductive Activities

Report

Median

Comapny	Percieved Wrench Time percentage	IP-Preparatory Works	IP-Material Handling	IP-Tools and Equipment Handling	UA-Waiting for Permits	UA-Waiting for Instructions	UA-Waiting for Materials	UA-Waiting for Tools/Equipm ent	UA-Waiting for QA/QC	UA-Waiting for Sub-contractors	Unproductive Activities - Reworks	OUA-Personal Time	OUA-Travel Time
Engie	2.00	3.00	3.00	3.00	4.00	2.00	2.00	2.00	3.00	3.00	2.00	2.00	3.00
ABC	3.00	3.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00	3.00	3.00	2.00	2.00
Total	2.00	3.00	3.00	3.00	3.50	2.00	2.50	2.00	3.00	3.00	2.00	2.00	3.00

Figure B.5: SPSS output:Central Tendency Measures

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of IP-Prep Work, IP-Material Handling and IP-Tools & Equipment are the same.	Related-Samples Kendall's Coefficient of Concordance	.011	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of UA-Waiting Permits, UA-Waiting instructions, UA-Waiting Materials, UA-Waiting Tools Equip, UA-Waiting QA/QC and UA-Waiting Sub Contractor are the same.	Related-Samples Kendall's Coefficient of Concordance	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of OUA-Personal Time and OUA-Travel Time are the same.	Related-Samples Kendall's Coefficient of Concordance	.083	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure B.6: SPSS output:Kendell's Coefficient of Concordance

Test Statistics[a]

	Percieved Wrench Time percentage	IP-Preparatory Works	IP-Material Handling	IP-Tools and Equipment Handling	UA-Waiting for Permits	UA-Waiting for Instructions	UA-Waiting for Materials	UA-Waiting for Tools/Equipm ent	UA-Waiting for QA/QC	UA-Waiting for Sub-contractors	Unproductive Activities - Reworks	OUA-Personal Time	OUA-Travel Time
Mann-Whitney U	58.000	40.500	59.500	36.000	53.000	53.000	55.000	67.500	64.500	59.500	45.500	57.500	51.500
Wilcoxon W	178.000	85.500	104.500	81.000	98.000	98.000	175.000	112.500	184.500	179.500	165.500	177.500	96.500
Z	-.624	-1.795	-.529	-2.061	-.945	-.998	-.783	.000	-.189	-.539	-1.462	-.652	-1.022
Asymp. Sig. (2-tailed)	.532	.073	.597	.039	.345	.318	.433	1.000	.850	.590	.144	.515	.307
Exact Sig. [2*(1-tailed Sig.)]	.599[b]	.108[b]	.640[b]	.064[b]	.411[b]	.411[b]	.482[b]	1.000[b]	.861[b]	.640[b]	.194[b]	.558[b]	.347[b]

a. Grouping Variable: Comapny

b. Not corrected for ties.

Figure B.7: SPSS output:Mann-Whitney U test

C

WORK SAMPLING

Date		**Start Time**						
Observation #		**Stop Time**						
	CRAFT	E&I	ELEC	MECH	PIP	CIV	CLE	Comments
	IDENTIFIER	Red	Blue	Green	Black	Orange	Brown	
DP	Directly Productive							
IP	Preparatory Works							
	Materials Handling							
	Tools/Equipment Handling							
AUP	Waiting for Permits							
	Waiting for Materials							
	Waiting for Instructions							
	Waiting for tools and equipment							
	Waiting for QA/QC							
	Waiting for sub-contractors							
	Reworks							
UUP	Personal Time							
	Travel							

Figure C.1: Work Sampling Observation Form. Adapted from [49], [54]

Table C.1: Minimum Sample size per hour based on the number of workers. Adapted from [54]

Number of Craftsmen	Minimum Sample Size per hour
0-50	46
51-100	84
101-150	116
151-200	144
201-250	168
251-300	189
301-350	208
351-400	225
401-450	240
451-500	253
501-550	265
150-200	144
551-600	276
601-650	286
651-700	296
701-750	304
751-800	312
801-850	319
851-900	326
901-950	332
951-1000	338

For number of N > 1000, the equation given below should be used in order to find the minimum sample size per hour (95% confidence interval, margin of error ±5%) [54]:

$$(MinimumSamplesizeperhour) = \frac{(N \times 510)}{(N + 510)} \tag{C.1}$$

C.1. MODIFIED LIST OF ACTIVITY CATEGORIES

The modified list of activity categories based on the input from the open questions of the qualitative survey is given below:

1. *Directly Productive Activities*

2. *Indirectly Productive Activities*
    - Preparatory Works
    - Material Handling
    - Tools and Equipment Handling
3. *Avoidable Unproductive Activities*
    - Waiting
        - Waiting for permits
        - Waiting for instructions
        - Waiting for materials
        - Waiting for tools and equipment
        - Waiting for quality assurance/quality control
        - Waiting for sub-contractors
        - **Waiting for operations**
        - **Waiting due to unforseen events**
    - Reworks due to mistakes made earlier
4. *Unavoidable Unproductive Activities*
    - Personal Time
    - Travel Time

D

Other

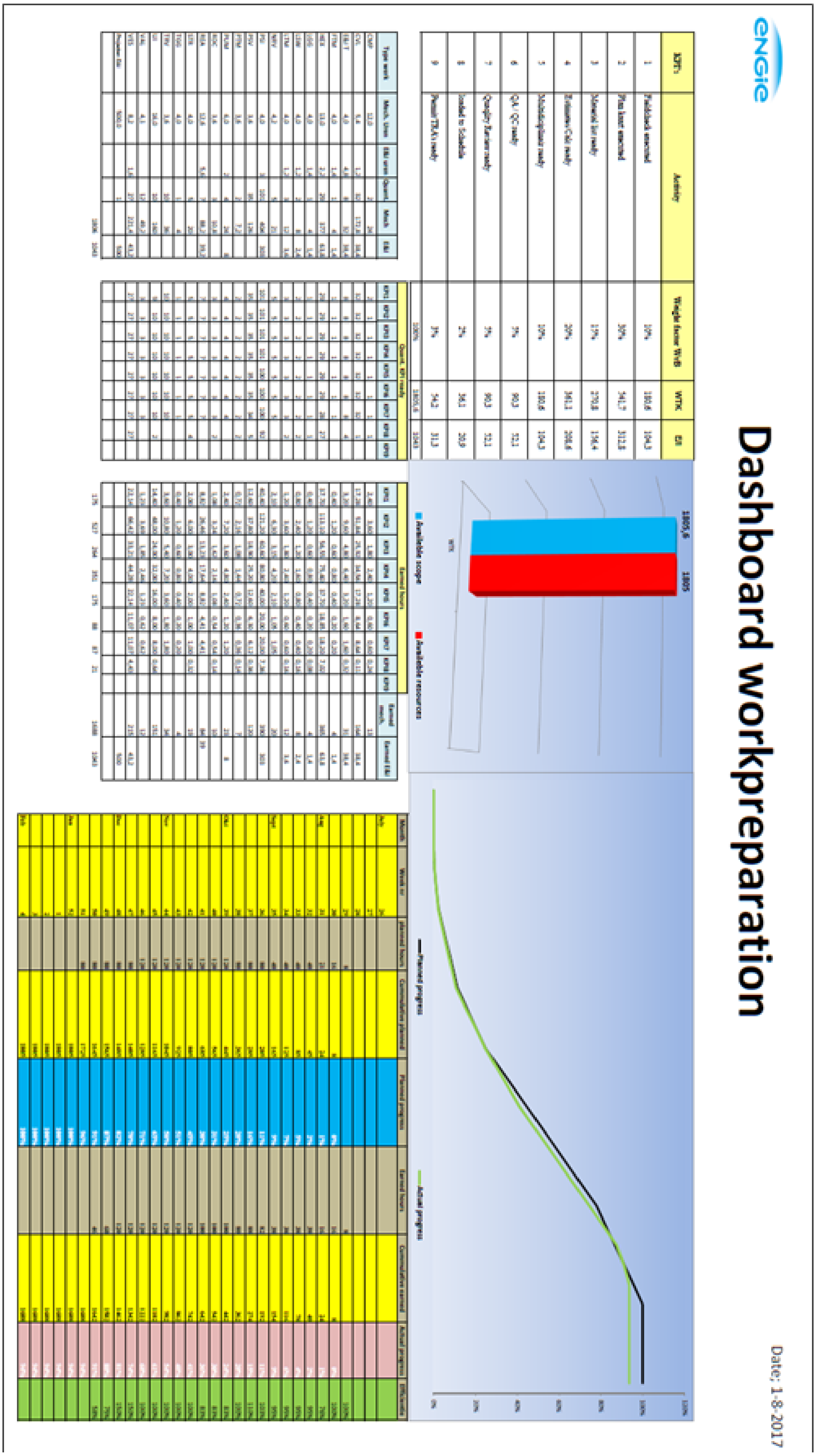

Figure D.1: Work Preparation dashboard depicting work preparation efficiency. Source: Internal Data

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