A TOOL TO ASSESS AND IMPROVE THE CONSTRUCTION WORKER PRODUCTIVITY

Nishan Madusanka Karunarathna

188023K

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

June 2019

A TOOL TO ASSESS AND IMPROVE THE CONSTRUCTION WORKER PRODUCTIVITY

Disanayaka Mudiyanselage Thalakubure Gedara Nishan Madusanka Karunarathna

188023K

Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

June 2019

DECLARATION

I declare that this research "A tool to assess and improve construction workers' productivity" has been carried out solely by me and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where stated otherwise by reference or acknowledgment, the work presented is entirely my own, and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

Also, I at this moment grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or another medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:……………………… Date:…………………………

The above candidate has researched for the Master's thesis under my supervision.

Names of the supervisor: Dr. C.S.A Siriwardana

Signature of the supervisor: …………… Date: …………………….

ABSTRACT

Construction workers are the basic unit of the construction industry. The behaviour of construction workers is considered variable, which impacts on worker productivity. Therefore, obtaining the highest levels of performance is crucial to be competitive in the construction industry. The scarcity of skilled workers, increase of many high-rise building projects and changes in the economic and political conditions aggravated the need of seeking strategies to improve the performances of construction workers.

In the construction industry, contractors attempt to improve the workers' productivity with the aim of profit. Few frameworks which are connected were developed using different kind of research techniques. Firstly the existing productivity measurement techniques were thoroughly studied.

Furthermore frequent and critical errors and reworks in the building construction, causesof delay, factors affecting sub-contractor performance were identified and studied. In this study, the main focus is to setup relevant assessment frameworks to assess the productivity of Sri Lankan construction sites. To have a complete productivity assessment, a new framework was put forward considering an Initial and Detailed Assessment.

The initial assessment was developed to get a relative measure of productivity according to the external conditions other than labour and management. As the first step, critical factors that affect productivity were identified. Then, a few surveys were carried out to categorize and weight the factors. Detailed Assessment will be fulfilled on the basis with Activity Analysis to investigate root causes and improvements for the poor performance. It will mainly focus on sub-contractor performance on progress, direct work percentage and. worker performance benchmarking.

Further errors and rework reduction framework and sub-contractor assessment framework was connected to detailed assessment. Developed sub-contractor assessment is mainly a factor based assessment. It is reinforced with onsite data to cross check the performance and assessment value. Activity analysis results, crew wise errors and rework amount, attendance records and other available management records in different divisions in the site are connected to the sub-contractor assessment process

Analyzing the nature, frequent areas, and trends was identified as a key to minimize the repetitive errors. In a large construction site mainly high rise building construction projects most of the towers are having typical floors. In the framework which is a major part in detailed assessment, possible errors and reworks were identified under three main stages structural, masonry and finishing.

Finally, the developed frameworks are incorporated into a template which can easily be plugged into a web tool. An initial version of the web-tool ("Enhancer"- enhancer.lk) was developed. The "Enhancer" tool can analyse the performance using a set of developer productivity tools. The tool can suggest best practices according to the inserted data and information. Furthermore, it can work as a helping hand for productivity improvement.

The developed productivity improvement framework was implemented in a building construction project in Sri Lanka, and it was able to contribute to the productivity improvement process. Additionally, six presentations and knowledge and research finding sharing sessions were successfully carried out and received very good feedback from the experts who were in the audience.

Keywords: Productivity, Sri Lankan, Construction, Productivity, Workers, Activity Analysis, Sub-contractors, Performance improvement

DEDICATION

This whole work which I have carried out is dedicated especially to my mother and father

And to,

All the construction workers around the world,

who sacrifice their heart and soul

to build a better world for all of us.

Also

Sri Lankan people who, sponsor for the entire education system from every rupee they earn, without knowing the people who get the benefits for all of those!

ACKNOWLEDGEMENTS

I am indeed grateful and thankful to my research Supervisor and Mentor Dr. C.S.A Siriwardana who provided me with immense support to complete this research successfully. An individual who always believed in me and my work, which has been the success of my career.

I express my sincere appreciation to the Research Coordinator of the Department of the Civil Engineering University of Moratuwa; Dr. J.C.P.H Gamage and Prof. A.A.D.A.J Perera who led me towards the successful completion of this research and for the guidance given regarding the research project throughout the period. My heartiest gratitude to all the progress review examiners who gave their valuable comments throughout the period.

Special thanks goes out to Chairman, Chief Executive Officer Mr. Namal Peris, Deputy General Manager of Quality, Safety, and Productivity Mr. Thilak Jayathunga in International Construction Consortium (Pvt) Ltd – ICC, for providing me with the research grant. They also provided valuable and critical comments with regards to the research findings and methodology from an industry perspective. I strongly believe their contribution makes this research a more industry-based study.

During the period of data collection, I was assigned to the Havelock City Phase III project. General Manager of Projects Mr. A.R. Rodrigo and Senior Project Manager Mr. Piyathunaga for guiding us within the research period. As a General Manager, Mr. A.R. Rodrigo personally looked after about the research works. My heartiest gratitude all the Site Managers, Engineers, staff members and skilled and unskilled laborers who gave their valuable support to make this study a success.

I am grateful to all the professionals who assisted me in carrying out the questionnaire surveys and discussions to gather information related to the topic from the stakeholders. Immense gratitude to all my colleagues for their support and encouragement throughout this research study.

Last but not least, I would like to offer my most grateful thanks to my parents, my brothers and my friends, for their endless support and love.

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Overview of Construction Productivity 1

1.2 Current Challenges of Construction Industry in Sri Lanka 3

1.2.1 Threats to Sri Lankan Construction Industry 3

1.3 Research Aims 5

1.4 Overview of the Thesis 6

1.5 Summary of Research Findings 7

2. LITERATURE REVIEW 9

2.1 Basic Definitions of Productivity 9

2.2 Scale of Productivity 10

2.3 Methods to Assess Labour Productivity 12

2.4 Directions for Productivity Improvement 16

2.5 Available Productivity Models 17

2.6 Barriers of IT Implementation into the Construction Industry 19

2.7 Benchmarking Concepts 20

2.7.1 Used Benchmarking Model for the Framework 21

3. RESEARCH METHODOLOGY 25

3.1 Selected Sites for Data Collection 25

3.2 Initial Assessment Methodology 26

3.2.1 Identified Critical Factors 27

3.3 Detailed Assessment 29

3.3.1 Activity Analysis Based Assessment 30

3.3.2 Methodology in Activity Analysis Based Assessment 35

3.3.3 Sub-Contractor Assessment 37

3.3.4 Errors & Rework Reduction Framework 40

4. BACKGROUND STUDY 46

4.1 Identified Delay Causes through Literature 46

4.2 Industry survey 49

5. INITIAL ASSESSMENT 56

5.1 Limitations in the First Version of the Enhancer Tool (enhancer.lk) 56

5.2 Deriving a Quantitative Mark 57

5.3 Identification of Measurable Criteria and Measurable Indicators 57

5.4 Validation of Measurable Criteria and Indicators by Performing a Questionnaire Survey 58

5.5 Related and Probable Cases for each Factor 58

5.6 Contribution from Other Disciplinary Towards Worker Productivity- Fish Bone Diagram 70

6. DETAILED ASSESSMENT 71

6.1 Data Analysis of Activity Analysis 71

6.1.1 Activity Analysis Calculations 71

6.1.2 Root Causes and Improvement Areas 85

6.2 Sub-Contractor Assessment Framework 91

6.2.1 Sub-Contractor Performance Issues - Fish Bone Diagram 94

6.3 Errors and Reworks Reduction Framework Data Collection 95

6.3.1 Criticality and Frequency of Masonry Stage Errors 97

6.3.2 Error Mapping 98

7. OVERALL PRODUCTIVITY IMPROVEMENT TOOL 100

7.1 First Version of the Tool 100

7.1.1 Login Page of the Enhancer Tool 100

7.1.2 Authorization Levels in the Login 101

7.1.3 Overall Productivity Assessment 101

7.1.4 Use Case Structure of the Tool 102

7.2 Initial Assessment Process of the Tool 104

7.3 Detailed Assessment of the Tool 104

7.3.1 Activity Analysis Based Performance Assessment 104

7.3.2 Sub-contractor Assessment 107

7.3.3 Errors and Reworks Reduction Framework 109

7.4 Capabilities of Overall Productivity Improvement Tool 111

7.5 Next Version of the Tool 112

8. IMPLEMENTATION OF THE TOOL 113

8.1 Initial Implementation Works Carried Out 113

8.2 Pilot Implementation in Tiling Trade 113

8.3 Proposed Implementation Method 114

8.4 Productivity Improvement Officer 116

9. CONCLUSION AND RECOMMENDATIONS 117

9.1 Effect of the Management of Tool Time 118

9.2 Overall Recommendations for Productivity Improvement 120

REFERENCES 128
APPENDIX A – Developed Productivity Improvement Posters 137
APPENDIX B – Factor Based Initial Assessment Benchmarking 145
APPENDIX C – Activity Analysis Detailed Category Work Definition 160
APPENDIX D – Sub-Contractor Framework Criteria Ranking Questionnaire 163
APPENDIX E – Error Survey Observation Sheet in Masonry Stage 165

LIST OF FIGURES

		Page
Figure 1.1:	The triple P- model	2
Figure 1.2:	Overview of the thesis	6
Figure 1.3:	Assessment framework overview	8
Figure 2.1:	Process of Activity Analysis	15
Figure 2.2:	Available labour productivity models	18
Figure 2.3:	Barriers to IT Implementation in the construction industry	20
Figure 2.4:	Benchmarking types	21
Figure 2.5:	Framework for setting benchmarks	22
Figure 2.6:	Data collection for benchmarking	23
Figure 2.7:	Data analysis for benchmarking-	24
Figure 3.1:	Process of the initial assessment framework	26
Figure 3.2:	Worker productivity affecting factor categories	27
Figure 3.3:	Activity Analysis development	34
Figure 3.4:	Classification of construction working day	35
Figure 3.5:	Data collection sheet	36
Figure 3.6:	Network structure model of the contractor performance	38
Figure 3.7:	Construction worker performance index	39
Figure 3.8:	Skill will matrix	39

Figure 3.9:	Cost impacts of rework reported in various studies	41
Figure 3.10	Interdependency of construction activities	42
Figure 3.11:	Conceptual model of rework determinants	43
Figure 3.12:	Quality control measures	44
Figure 3.13:	Errors and reworks reduction plan	46
Figure 4.1:	Identified delay cause categories	47
Figure 5.1:	Process of deriving of quantitative mark	59
Figure 5.2:	Variation of responses	61
Figure 5.3:	Fishbone diagram	75
Figure 6.1:	Tiling hourly activity percentage	78
Figure 6.2:	Painting hourly activity percentage	79
Figure 6.3:	Plastering hourly activity percentage	80
Figure 6.4:	Block work hourly activity percentage	81
Figure 6.5:	MEP hourly activity percentage	82
Figure 6.6:	Form work hourly activity percentage	83
Figure 6.7:	Reinforcement hourly activity percentage	84
Figure 6.8:	Responsibility breakdown	89
Figure 6.9:	Fishbone diagram	96
Figure 6.10:	Developed sub-contractor assessment framework	97
Figure 6.11:	Comprehensive view of selected factors	97
Figure 6.12:	Fish bone diagram- sub-contractor performance issues	101
Figure 6.13:	Error mapping	106
Figure 7.1:	Tool front page	107
Figure 7.2:	Login page of the tool	108
Figure 7.3:	Home page of the tool	108
Figure 7.4:	Proposed communication concept structure	109
Figure 7.5:	Use case structure of the tool	110
Figure 7.6:	Data input page for Activity Analysis	112
Figure 7.7:	Activity results for tiling trade	113
Figure 7.8:	Root causes for an excessive non-productive time in trade wise	114
Figure 7.9:	Sub-contractor assessment home page	115
Figure 7.10:	Home page of errors and rework assessment	116
Figure 7.11	Errors and reworks home page	117
Figure 7.12	Summary of the identified errors and reworks	117

Figure 7.13	Data entry sheet for errors and rework quantification	118
Figure 7.14:	Next version of the tool	119
Figure 8.1:	Proposed continuous improvement process for productivity improvement Tool	122
Figure 8.2:	Continuum of leadership shared between CMT and crew leader	123
Figure 9.1:	Activity Analysis results of site A	126
Figure 9.2:	Activity Analysis results of site B	126

LIST OF TABLES

Table 1.1:	Summary of the research findings	7
Table 2.1:	Existing types of productivity models	15
Table 3.1:	Summary of research methodology	25
Table 3.2:	Top 15 factors according to RII	28
Table 3.3:	Category wise ranking	28
Table 3.4:	Summary of detailed assessment process	30
Table 3.5:	Minimum sample sizes per hour	36
Table 3.6:	Common practices of error management	44
Table 4.1:	Identified delays in each category through literature	47
Table 4.2:	Performance comparison	52
Table 5.1:	Indicators for each main factor	61
Table 6.1:	Number of workers observed per hour	76
Table 6.2:	Activity categories and color code	76
Table 6.3:	Trade wise Activity Analysis percentages	77
Table 6.4:	Activity percentages under main categories	78
Table 6.5:	Average non-productive time in each trade	85
Table 6.6:	Tiling worker crew combination	86
Table 6.7:	Painting worker crew combination	87
Table 6.8:	Plastering worker crew combination	88

Table 6.9:	Block Work worker crew combination	89
Table 6.10:	Identified root causes and responsibility breakdown of management party	91
Table 6.11:	Identified root causes and responsibility breakdown of workers	92
Table 6.12:	Selected factors form literature	98
Table 6.13:	Identified construction stages	102
Table 6.14:	Identified errors in structural stage	102
Table 6.15:	Identified errors in masonry stage	103
Table 6.16:	Identified errors in finishing stage	104
Table 6.17:	Frequent and critical errors in masonry stage	104
Table 8.1:	Implementation works carried out using Activity Analysis based Assessment	118
Table 9.1:	Time distribution variation based on the management change	125

LIST OF APPENDICES

Appendix	Description	Page
Appendix - A	Developed Productivity Improvement Posters	146
Appendix - B	Factor Based Initial Assessment Benchmarking	154
Appendix - C	Activity Analysis Detailed Category Work Definitions	177
Appendix - D	Sub-contractor Framework Questionnaire	196
Appendix - E	Error Survey Observation Sheet	204

LIST OF ABBREVIATIONS

Abbreviation	**Description**
CMT	Construction Management Team
PIM	Productivity Improvement Model
SFP	Single Factor Productivity
TFP	Total Factor Productivity
MFP	Multi Factor Productivity
RII	Relative Improvement Index
KPI	Key Performance Index
PIO	Productivity Improvement Officer
CPIO	Construction Productivity Improvement Officer
IT	Information Technology
CWPI	Construction Worker Performance Index
QS	Quantity Survey
QA	Quality Assurance
QC	Quality Check
UPA	Unit Price Analysis
CII	Construction Industry Institute

1 INTRODUCTION

1.1 Overview of Construction Productivity

Productivity is a crucial factor when it comes to the construction industry. The methods of improving productivity have been discussed from time to time by researchers. Having detailed knowledge and thorough understanding is important to improve productivity.

- The factors which affect the productivity
- The gaps and drawbacks which affects productivity in the current construction industry
- The research methods, practical methods and frameworks of productivity measurements

Firstly, gains in productivity means corporations will increase wages while not increasing costs that successively makes more cash accessible for everyday disbursement [1].

- Productivity is a major indicator to realize benefits on price and quality over its competitors [2] [3].
- The term productivity is commonly defined and measured in financial units per inputs as in several cases it looks to be solely sensible method [4].

As a whole through productivity improvement, the following can be achieved,

- Improve the competitiveness
- Increase in profit
- Enhance the satisfaction of workers, staff, and management

Performance is the alternative conception that productivity is commonly confused. Although productivity may be a four-dimensional term, it is still a reasonably specific conception associated with physical phenomena in production. Performance, on the other hand, is a broader conception covering overall economic and operational aspects. "The Triple P Model" within Figure 1.1 explains the ideas of productivity; however, gain and performance are associated with one another. [3].

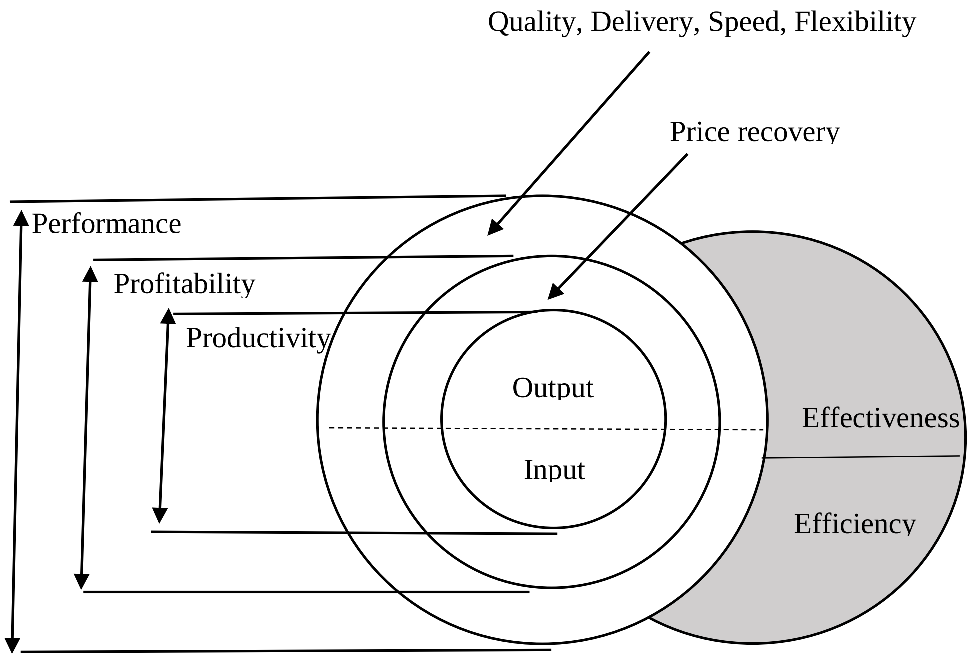


Figure 1.1: The triple P- model

In the modern world, the construction industry is more concerned with productivity. With the industrial revolution, people depended more towards industries, and they found and inventing new technologies by utilizing resources as desired. But current situation is different. Everyone is seeking methods to maximize the number of products with a minimum amount of utilization. This is the real picture of productivity where the industry found it difficult to come up with an accepted definition [5]. But at present every industry is more concerned towards achieving the best productivity and the industry will be investing more to gain that since that will be more profitable than operating with low productivity.

Just like any other business environment, construction industry is highly competitive [6]. Therefore, to achieve higher productivity levels, each company is competing to win over the projects to complete them as soon as possible without the interference of the external factors such as weather, finance ability, and political conditions etc. Thus, to avoid the factors which could affect the productivity of activity, these industries follow different quality control practices. As a result, theoretically productivity should be improved [6].

1.2 Current Challenges of Construction Industry in Sri Lanka

In Sri Lankan construction industry, the situation is very different when compared with the industry in other countries. Even though there a fair improvement in technology and management could be witnessed in Sri Lankan construction industry during the last decade. However, Sri Lanka has a long way to go to achieve more for the growth of the industry [7]. Thus, it is now in a position where the contribution to the GDP is about 6% - 7%, and it is the 4th largest sector in the economy of the country [8]. During the recent times Sri Lankan construction industry is on an upward trend, and the end of the island’s ethnic war in 2009 has revived the economic activity and resulted in a projects boom [8].

The main deficiency the industry suffers nowadays is labour power. It affects the industry in two major ways. First one is the scarcity of labour and the other is higher amount of cost for their wages. Besides that, the problems that the industry suffers other than these are a higher cost of materials, lack of funds and changes in regulations [8]. Commonly the global figure for labour cost can be varied within 30% to 50% of total project cost [9]. But according to industry practitioners in Sri Lanka, it is around 25%. Since labour is the responsible stakeholder, which controls the success and the profitability of a constructor all the time, the industry is targeting to maximize the productivity of labour inputs [10].

1.2.1 Threats to Sri Lankan Construction Industry

At present the labour market in the Sri Lankan construction industry has undergone many changes. There are different variations in the labour market such as directly employed labour from the organization itself and there are labourers who have been working under the sub-contractors. These labourers are mostly local residents, and there is a new trend of hiring labours from foreign countries as well. Most of the foreign labourers are from China, India and Bangladesh. But the wages of such labourers will vary with the ability of their work and the level of productivity**.** However, the workers from outside will grow faster if the local labour market does not perform well. Other than that, due to reasons like new methodologies with those foreign labourers, level of skills they have and level of productivity will directly affect the growth of the foreign market [11]. Therefore, if this trend succeeds, the construction industry will have some economic benefits such that they would be able to hire these foreign labourers for minimum wages while maintaining good productivity [12].

The exposure of labour market to foreign employees will cause positive social and economic impacts to the industry like introduction of new methodologies and a higher level of skills, a higher level of productivity (considering both the time and cost saving).

Spread of foreign labour can cause negative economic impacts like expensiveness of labour and related additional costs (wages, accommodation, travel, etc.), social impacts, and degradation of local labor market.

Social impacts can be an issue with different cultures, behaviours and health and safety problems. Furthermore, foreign labours affect the Sri Lankan economy can be draining off the country's income and collapse of the local construction labour market.

Though the Chinese labour is obtained as a new trend in the market one labour will charge comparatively a higher wage than the wage provided for local labourers. Also, they have to be provided with other facilities like transport, accommodation, travel tickets, etc. which is a huge cost. But the industry is willing to accept those costs since their work is much productive than hiring local labourers and this is affected as a future saving during the time which will be a profit latterly.

1.3 Research Aims

The ultimate objective of this study is to develop an “Overall workers’ productivity improvement framework” which will be a practical and sustainable solution for improving productivity. Set of tools have been developed to cover the developed framework and make it a sustainable and practical solution.

- Identify the current workers’ behaviour in building construction. Investigating workers’ time distribution in Direct work, Preparatory work, Tools and Equipment, Material Handling, Waiting, Travel, Personal
- To perform a comprehensive review of existing worker productivity improvement models
- Identify measurable parameters for productivity
- Develop a simple data collection method which is suitable for measure and improve the productivity
- Identify root causes and provide recommendations to improve the productivity
- Develop an overall productivity improvement tool which can be applied in the construction industry in developing countries
- Integrate the developed productivity assessment frameworks into “Enhancer” web tool (enhancer.lk)
- Investigate the applicability of the developed framework to the industry

1.4 Overview of the Thesis

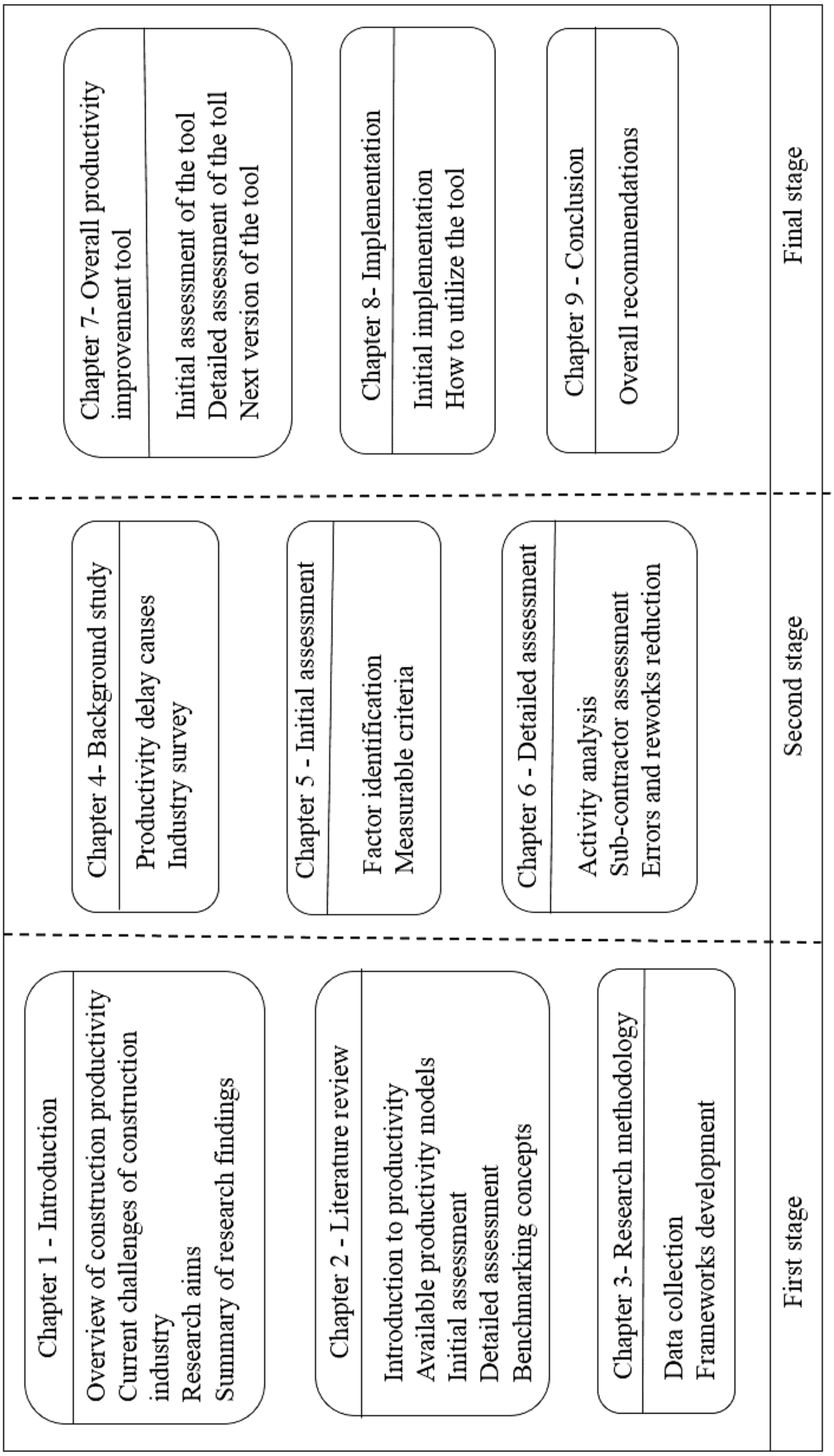


Figure 1.2: Overview of the thesis

1.5 Summary of Research Findings

On-site labour is one of the important that contributes to the performance of a construction project [5]. To improve the productivity of workers,' it is needed to measure productivity [11]. The ultimate goal is to develop an overall workers' productivity assessment framework. To develop an assessment mechanism, the framework was suggested to develop in two parts

Initial assessment

Detailed assessment

Table 1.1: Summary of the research findings

Activity		Deliverable
Initial Assessment	List of factors affecting workers' productivity	• Ranking list of factors affecting workers' productivity • Factor-based initial productivity assessment
	Existing problems and related issues in procedures and method	• Issues and drawback with the current construction industry
	Delay causes in construction	• Categories and delay causes in each category
Detailed assessment	Activity analysis in building construction trades	• Block work, Plastering, MEP work, Tiling, Painting, Formwork and Reinforcement • Root causes for delay work were identified, and the responsible party was identified • Methods for improvement were suggested
	Sub-contractor performance assessment framework	• Sub-contractor assessment framework
	Identification of errors and reworks	• Critical and frequent errors in masonry stage • Errors and reworks reduction framework

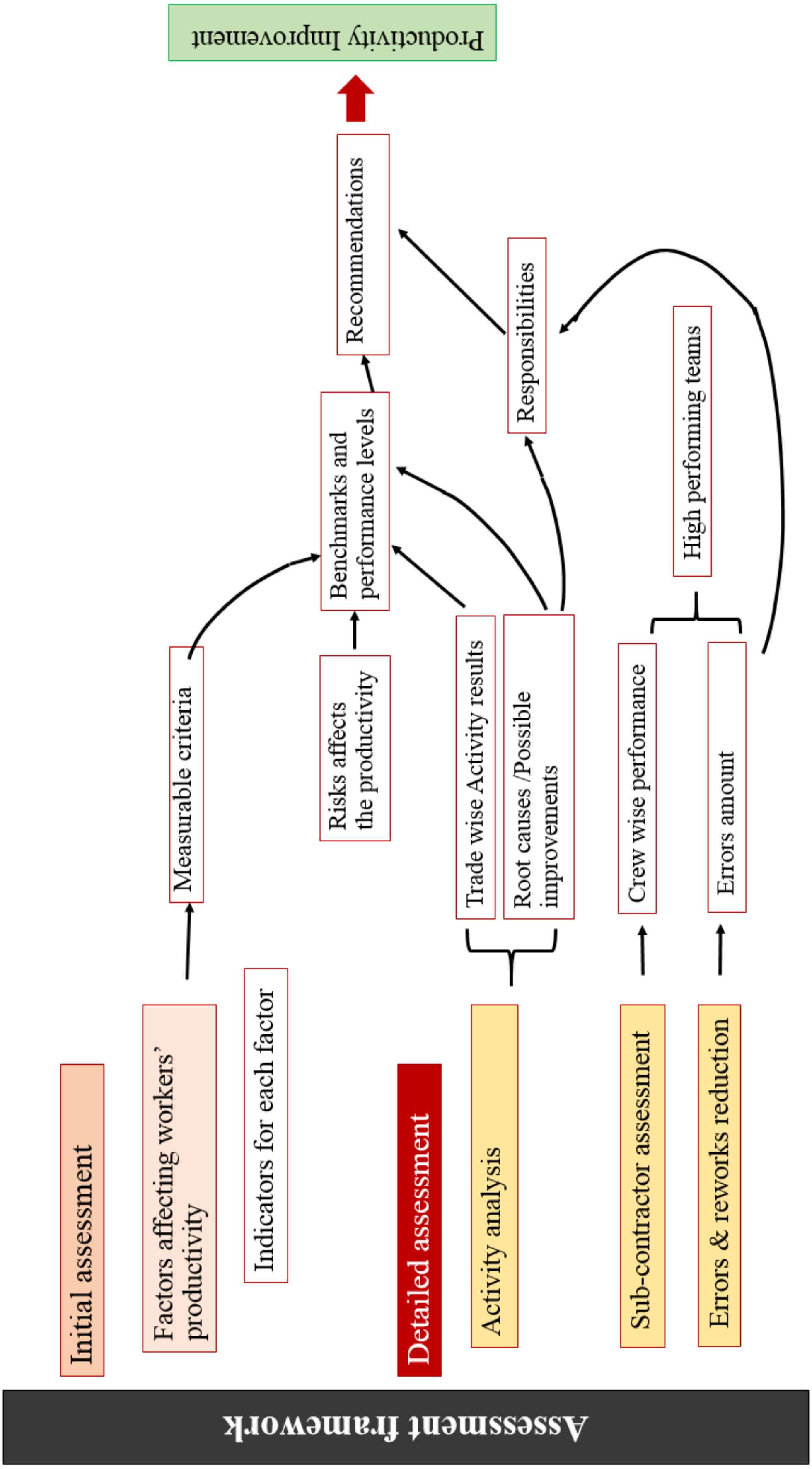


Figure 1.3: Assessment framework overview

2. LITERATURE REVIEW

2.1 Basic Definitions of Productivity

Currently there are different kinds of definitions to measure and quantify productivity. The three different definitions of productivity in construction [13].

1. Single factor productivity
2. Partial productivity
3. Multifactor productivity / Total factor productivity

Construction Owners Association of Alberta introduced "A Framework for Total Factor Productivity Measurement of Construction Projects." In the guide book set of definitions, defined productivity measures in different aspects. Equation 1,2,3,4,5,6,7 and 8 are the equations defined in "A framework for Total Productivity Measurement of Construction Projects" by the Construction Owners Association of Alberta [14].

Single Factor Productivity

Single Factor productivity (SFP) is that most ordinarily used productivity mensuration strategies. SFP evaluates productivity as a quantitative relation of one input issue to output [6]. The factors considered in the equations through SFP are often classified into two broad sections, labour related factors and capital-related factors.

$$\text{Labour productivity} = \frac{\text{Quantity index of gross output}}{\text{Quantity index of labour input}} \tag{1}$$

$$\text{Labour productivity} = \frac{\text{Quantity index of value added}}{\text{Quantity index of labour input}} \tag{2}$$

Partial Productivity

Partial productivity is quantitative between output to one input or more. Capital productivity, material productivity and worker productivity (ration of work output/completed and input worker hours)

Partial productivity over period't': which defined by "Construction Owners Association of Alberta."

$$\text{Human productivity, Hp} = \frac{\text{Vt}}{\text{Ht}}$$

$$\text{Materials productivity, Mp} = \frac{\text{Vt}}{\text{Mt}}$$

As shown in according to CII [15], partial-factor productivity can be used for different types of conceptual estimation for measuring productivity on construction projects.

$$\text{Partial factor productivity} = \frac{\text{Physical output (Units)}}{\text{Labour(\$)} + \text{Equipment(\$)}} \qquad (3)$$

Total Factor Productivity (TFP) / Multi-Factor Productivity (MFP)

Total Factor productivity (TFP) (also called multifactor productivity) is another productivity measuring concern that uses multiple input factors (energy, labour, equipment, materials, and capital) to provide and output [16] [6]. Since this MFP evaluates output against different kinds of inputs, these all factors are considered to take the collective impact on the variation of inputs [17].

Total-factor and total productivity values are computed as follows as defined in "A Framework for Total Factor Productivity Measurement of Construction Projects" by the Construction Owners Association of Albert [14]:

$$\text{Totalfactorproductivity} = \frac{\text{Total output}}{\text{Labour} + \text{Material} + \text{Equipment} + \text{Energy} + \text{Capital}} \qquad (4)$$

$\text{TFPt} = \frac{\text{netoutput}}{\text{Ht+Ct}}$ Where TFP_t is total-factor productivity over period t.

$$\text{Thus, TPt} = \frac{\text{Vt}}{\text{Ht} + \text{Ct} + \text{Mt} + \text{Et} + \text{Ot}}$$

2.2 Scale of Productivity

Productivity in the construction can be defined in different scales. When it comes to construction productivity in the industry level is contributes to each sector of construction building, road, bridge, and other sectors as well. Project-level productivity provides profit, satisfaction to the construction management team and their company while crew level productivity provides more to the workers. Few different levels of productivity can be listed as follows:

1. Industry level productivity
2. Project-level productivity
3. Crew level productivity

Industry Level Productivity

$$\text{Constructionindustryproductivity} = \frac{\text{Gross industry output per annum}}{\text{Labour engaged per annum}} \quad (5)$$

At the industry level, productivity is often used as an indicator of efficiency. It is calculated as the quantity of output created per unit of input. The productivity measured is often expressed as a type of labour productivity or multifactor productivity [15]. Macro-economic productivity measures, like industry-level productivity, offer data relating to living standards, the standing of associate degree economy's productive capability. A comparison of international productivity, and influence of economic policies [18].

According to CII (2013), industry-level productivity is assessed mistreatment to key metrics; total factor productivity (TFP) and labour productivity. TFP is often determined by comparing the products and services created with the input utilized in production operations. Equation half-dozen shows the calculation for TFP, expressed in terms of labour, material, equipment, energy, and capital [15]. Labour productivity at the industry level is often measured as a magnitude relation of total output over the number of labour hours needed to deliver that output (Equation 7) [15]. At the industry level, TFP is most popular over labour productivity.

Project-Level Productivity

Project-level productivity has received the most attention as a result of project boundaries square measure fairly simple to outline, and also the edges of improved productivity square measure simply quantified.[19][20].

In general, a project could be an assortment of activities that are needed for the development of a facility. Then it comes to entail the completion of varied activities, measuring of project level productivity is a lot of sophisticated than measuring of activity-level productivity [18].

CII (2013) lists common measures of productivity that are expressed either as a quantitative relation of output to input or as a quantitative relation of input to output. Issue productivity that is shown below is equation four by is the same as TFP, and it's in the main utilized in abstract estimation to quantify construction productivity.

$$\text{Factorproductivity} = \frac{\text{Physical output (units)}}{\text{Labour(\$)} + \text{Material(\$)} + \text{Equipment(\$)}} \qquad (6)$$

The other productivity measure that can be computed at the project level is labour productivity. Labour productivity can be estimated based on the cost of labour required or on direct work hours (see Equation 10 and 11)

$$\text{Labourproductivity} = \frac{\text{Physical output (Units)}}{\text{Labour(\$)}} \qquad (7)$$

$$\text{Labour productivity} = \frac{\text{Physical output (Units)}}{\text{Direct work hours}} \qquad (8)$$

Success of a project is influenced by the productivity of all task components within the project; so, evaluating solely a couple of work components or activities would not be adequate for the aim of assessing overall productivity [21].

Crew Level Productivity

Measuring the productivity at crew level takes into thought the output of individual activities. [22] [23] and it was outlined because of the quantitative relation of labour-hours to the number of labour in the site.

$$\text{Labour productivity} = \frac{\text{Quantity of work}}{\text{Labour hours}} \qquad (9)$$

2.3 Methods to Assess Labour Productivity

Since the productivity is vital in construction industry, academia have evolved methods to assess the labour productivity in the construction industry. Therefore, different methods have been developed in different areas of the world in such a way that it would matter the most.

Field Rating

Here, the level of productivity is determined as a ratio of working on the total time observed. So, this will give the effectiveness of the work which has been done. First, the sample is taken, and the number of working observations will be divided by total amount, and 10% will be added as an allowance for the supervisory and foreman activities.

$$\text{Field rating} = \frac{\text{Total observations of working}}{\text{Total number of observations}} + 10\% \qquad (10)$$

Since this is a measure, this should have a percentage greater than 60% since there is a 10% allowance directly. If it is considered without that, it will be less than 50% which will not be a satisfactory amount. Hence, this method does not provide any mere causes for these and any problems if there so far. What it does is that only a message will be given if there are some issues [24].

Work Sampling

This method is somewhat sophisticated than the other method. Here a selective sample is taken on static sampling theory. So, this will be done by observation of work in a limited period and thereby arrive at conclusions as to how productive it is. This method is done in the sense of limiting the data collection time by making the limitations of the sample using statistical methods. Other than that, this will be helpful to select a sample from a population where it could include a lot of data if it is done for the whole population and it will be difficult to analyse [24].

In work sampling, a person's productive time will be calculated over throughout the time involved in working. Following is the methodology which has to be followed to achieve the required output.

1. At first identification of the work has to be done in such a way that the work related to an activity can be divided into three categories as Productive, Supportive or Semi-Productive and Non-productive. This can be in accordance to the relationship of the work assigned to that activity.

2. Next step is the development of a format for collecting data. It should be properly understandable and easy to use at sites.

3. Then the observations have to be done to have collective sound data from the sample in such a way that there will be no any bias and the observations should be properly identified with the sub category involved to it.

4. All the observations should be recorded on that format, and it will be taken to calculate the activity percentage in which it belongs to the above-categorized sections. So, the productive time, semi-productive and non-productive percentages will be calculated as mentioned [24].

According to the researches carried out, productive work should be of more than 30%, and it should give the level of productivity of that work. This can be used to identify the areas where the workers should be performed and can be helpful for further analysing them in detail. Thereby the analysis can be used to give recommendations to them.

Unit Price Analysis

In Turkey standard construction unit prices are calculated and published as a Unit Price Analysis (UPA). Here the standard labour hours are calculated before they are revised and put forward as a published work. As a method to assess productivity, the labour figure could be taken, and it can be used to measure how productive the labour according to that. The problem is that in most of the time these will be revised in such a way that the labour figures are at the same. So now there are disputes whether the information given by UPA will be helpful to measure the productivity [10].

Also known as the tool time analysis and this has been considered as the best method to evaluate productivity. In the activity analysis what is performed is an examination of the work time the workers will spend on a task [25]. This will be helpful to provide the answers to the,

1. Identification of respective challenges and find solutions to be implemented to achieve maximum productivity.

2. Will help to know what is happening actually at the site when the workers are working.

3. Maximization of direct work in such a way that is optimizing supportive work and idling work.

4. No any specific work or any disruption to work carrying out.
5. The site will become more towards accepting the activity analysis due to the emergence of craft workers and will lead to higher productivity.

Therefore, now this method has become the most acceptable method by many countries to assess productivity. So, the first thing to be done before the analysis is the determination of appropriate activity categories and selection of tool to support data collection to those categories. The methodology can be listed to five processes as figure 2.1 [26].

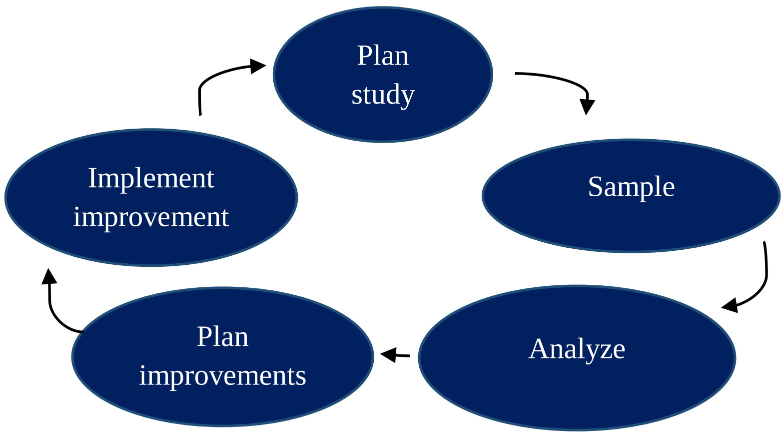


Figure 2.1: Process of Activity Analysis

In the planning phase, the identification of the activities and its activity categories which are Productive, Supportive and Non-productive works has to be identified. The size of the sample has to be determined next. Size of the sample (minimum sample size) and the tool to collect observations can be developed with the aid of 'guide to Activity Analysis by CII. Then the analysis should be done in such a way to identify poor performance. Thereby the improvements can be identified to the non-productive items and the improvements can be implemented [26].

Automated Techniques

With the advancement of time productivity measurement in activities has developed automated techniques. Since the manual techniques will be involved with a lot of time and labor automated techniques were introduced [27]. In many techniques use of video cameras, and Kinect sensors are used to track data of labour intensive construction operations.

With the use of a data processor, digital camera, video recorder, computer, ac transformer, and a wireless modem an automated Real-time productivity Measurement system was developed [28]. By tracking the video, the users of the system will be helpful to monitor the productivity even at the different location since the system is a wireless system. This system can be assessed by project managers, project office, clients and consultants to gather information. This system has features of not disrupting the construction activities, sharing collected data and determining Real-time productivity [28].

In 2009 an algorithm was developed to determine construction productivity by analyzing human poses. By implementing computer vision techniques, artificial intelligence an automated on-site productivity system was developed. In this system captured images of construction activities will be analyzed with the human poses associated [29]. The poses will be identified as effective, ineffective and contributory works and will compare and a real-time productivity figure will be given.

With the use of Machine learning and Vision-based approaches, this method was developed, and the method can identify actions and movements safety and occupational health in a building interior [27].

An Automated Construction Worker Performance and Tool-time Measuring Model Using RGB Depth Camera and Audio Microphone Array System. By this model location information, tool time analysis, site-related information, location information of workers and productivity data can be obtained. In this model real-time RGB Depth data and Audio data will be analyzed by using image processing and signal processing methods and come up with information [25].

2.4 Directions for Productivity Improvement

In thoughts of productivity improvement, it is important to have a background study on the effective and successful ways of productivity improvement. Here are some methods and KPIs which can improve productivity through literature.

a. Develop the project with more practical aspects during the project design period

b. Form a skilled construction worker team

c. Hire special skilled foreign workers

d. Form well organized and capable sub-contractor teams

e. Put construction management and project management theories into practice

f. Use the technology to automate the construction works as much as possible

CRCPM in 2009 revealed key ten targets to be achieved with the aim of construction productivity improvement [30]

1. Construction workers with higher motivation level and satisfaction
2. Guide the staff with best practices guidelines
3. Good relationship among the construction team
4. Use quality tool and equipment and material for construction
5. Improve the direct work percentage through work study methods
6. Good use of construction methods and better work planning
7. Effective use of information technology for site communication
8. Good working relationship among construction site and head office
9. Minimum weather disturbance
10. Minimize problems occurred for construction parties during construction

Following ten measures to improve construction productivity in a construction project in Canada [31].

a) Good practices of construction worker management

b) Effective planning of the project

c) Better construction management

d) Managing all the other external works in construction

e) Through supervision and monitoring

f) Effective communication

g) Well recognize methods of sub- contractor recruiting

h) Constructible and practical project designs

i) Government involvement

j) Effective use of pre-cast products and modular construction

2.5 Available Productivity Models

It could be found that several worker productivity models which are currently in the practice. It has been classified and summarized into the following figure 2.2, then described afterwards.

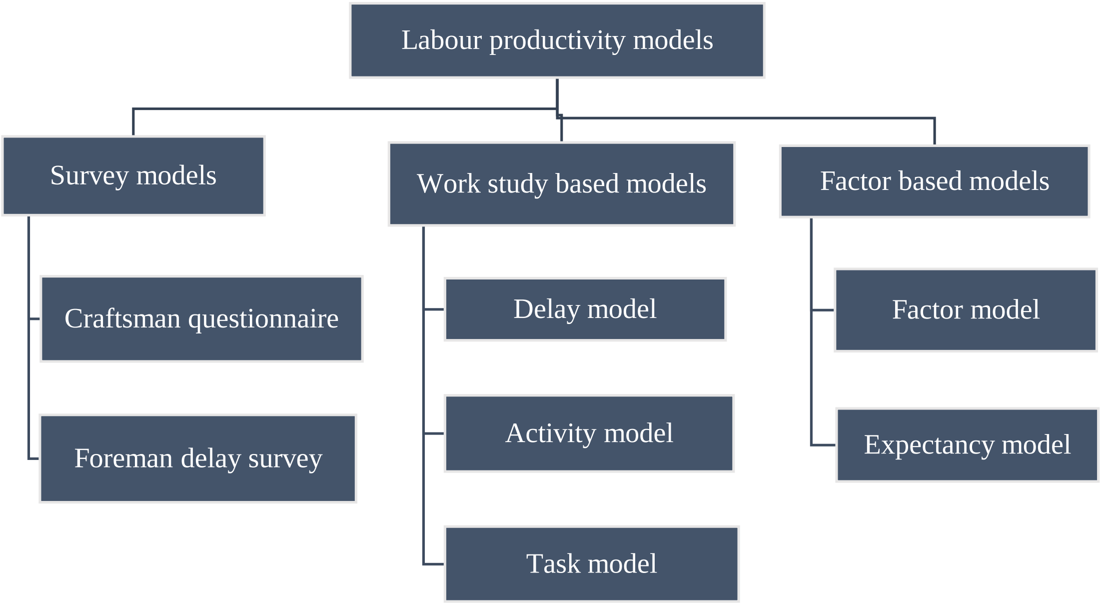


Figure 2.2: Available labour productivity models

Existing productivity models are explained in detailed in table 2.1.

Table 2.1: Existing types of productivity models

		Main objective	details
Survey Models	Craftsman questionnaire	Investigate and understand the productive time and productivity through operatives	Establishes a good basis for self-assessment of operatives. It can be used to verify the benchmarking process as well. Craftsman questionnaire methods were Initially developed, which can supply sensible information on the construction site. [33]
	Foreman/supervisor delay survey	Quantify the delay amount through foreman. Then enhance the productivity of work practices.	This main method of getting relevant information which was initially developed in 1982 [34]. During this technique foreman are separately questioned.

Work study based models	Delay model	Identify and reduce excessive delays. Classify the total available work time into productive time, minor delay time and major delay time	Recommended to carry out time to time for detailed study. Further actions are needed to contribute to productivity after investigation delay causes.
	Activity model	Identification and reduction of unproductive time. Further, classify worker time distribution into direct work, preparatory work, material handling, traveling, waiting, and personal and out of sight.	Can be applied effectively. The construction management team can improve their work practices, daily routines based on the results
	Task model	Identify site efficiency factors and compare the effectiveness of different methods.	This is essentially a benchmarking model requires specific training for effective utilization
Factor-based models	Factor model	Quantification of the influence of factors on productivity	This is suitable for find out effective work practices
	Expectancy model	Highlight the effect of motivation on productivity	Can be used as conceptual support model for understanding worker behavior

2.6 Barriers of IT Implementation into the Construction Industry

Knowledge management could be a vital issue among construction companies. Since effort, sharing, and exploitation data in construction is crucial, data management is thought-about to be one of the key sources of success for the construction projects [35] [36]. Web-based information systems are presently in use in most of the development corporations. This presents three sorts of web-based applications namely to serve the construction industry.

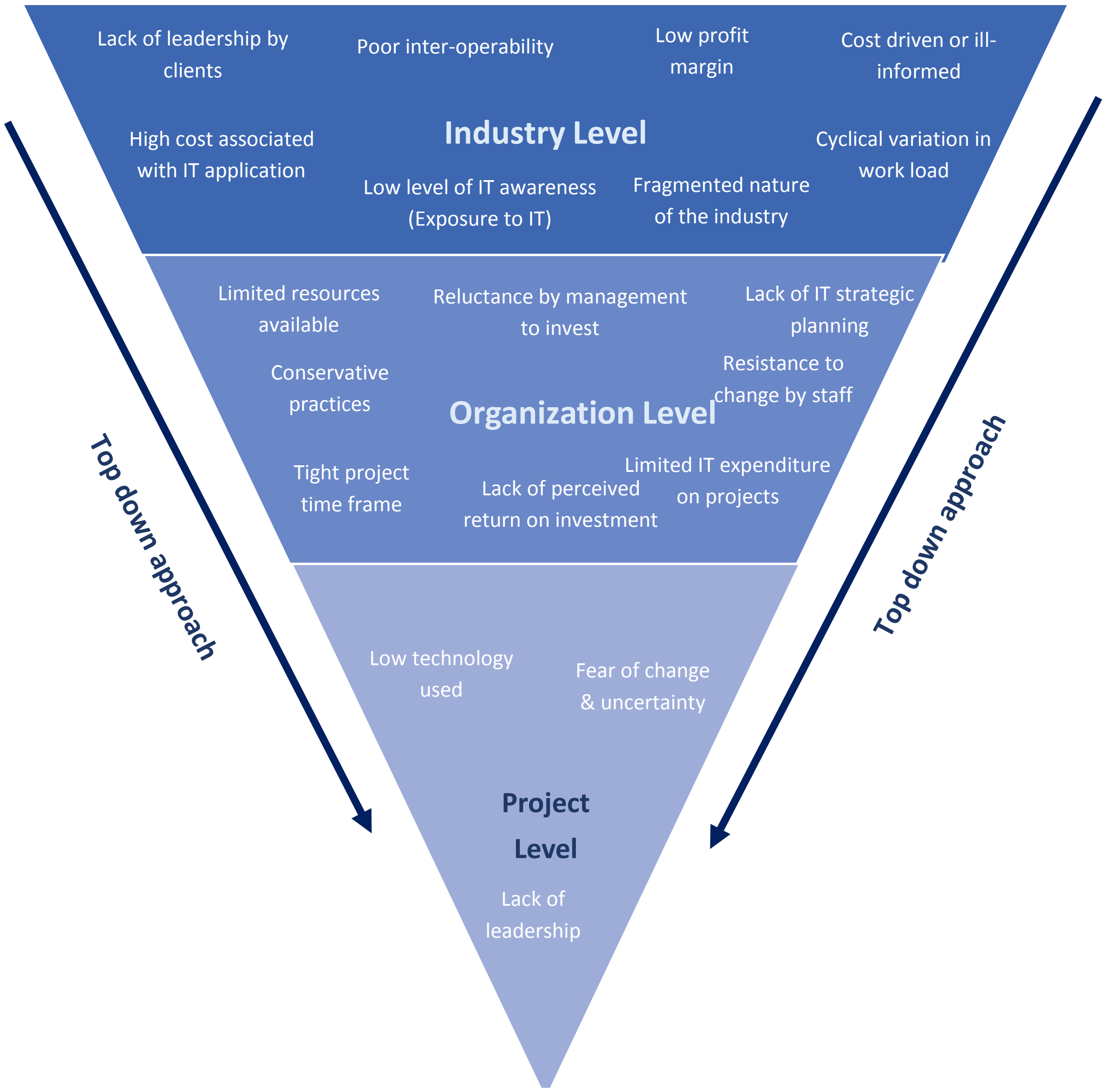


Figure 2.3: Barriers to IT Implementation in the construction industry [36]

2.7 Benchmarking Concepts

Benchmarking is a systematic associate degreed continuous measuring method; a method of continuous measurement and examination of performance, which can facilitate the organization to require action to enhance its performance. Through the literature it can be found out few benchmarking concepts as in the figure 2.4.

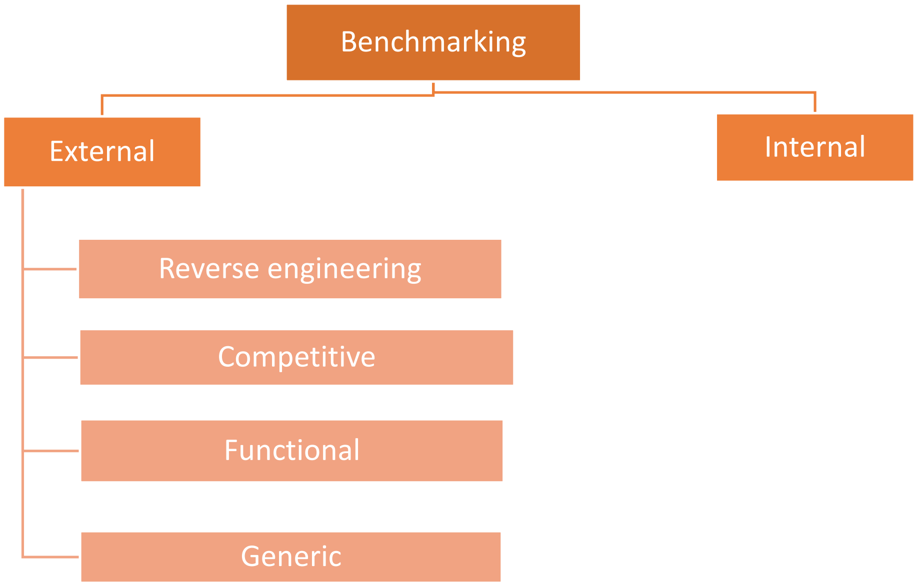


Figure 2.4: Benchmarking types

Internal Benchmarking: Performed inside one organization by examination performance of comparable business units or business processes.

Functional Benchmarking: Associate degree application of method benchmarking that compares a specific business operates in 2 or a lot of organizations no matter the trade kind.

Generic Benchmarking: Benchmarking that is aimed toward uncovering best practices that may be applied in own business method no matter the supply or form of trade.

Competitive Benchmarking: A live of associate degree organization's performance compared to competitive organizations; studies that focus on specific product styles, method capabilities or body ways utilized by company's direct competitors; practices or services.

2.7.1 Used Benchmarking Model for the Framework

In an assessment framework, it is very much important to have the benchmarks to be achieved. Otherwise, the assessment will give the assessment results concerning the ideal conditions. In the activity analysis, the 100% direct work percentage is not practical. To derive benchmarks following method is suggested. The suggested benchmarking process is modified according to a method of previous research [37].

a. Step 01: Identify KPIs for each Criterion

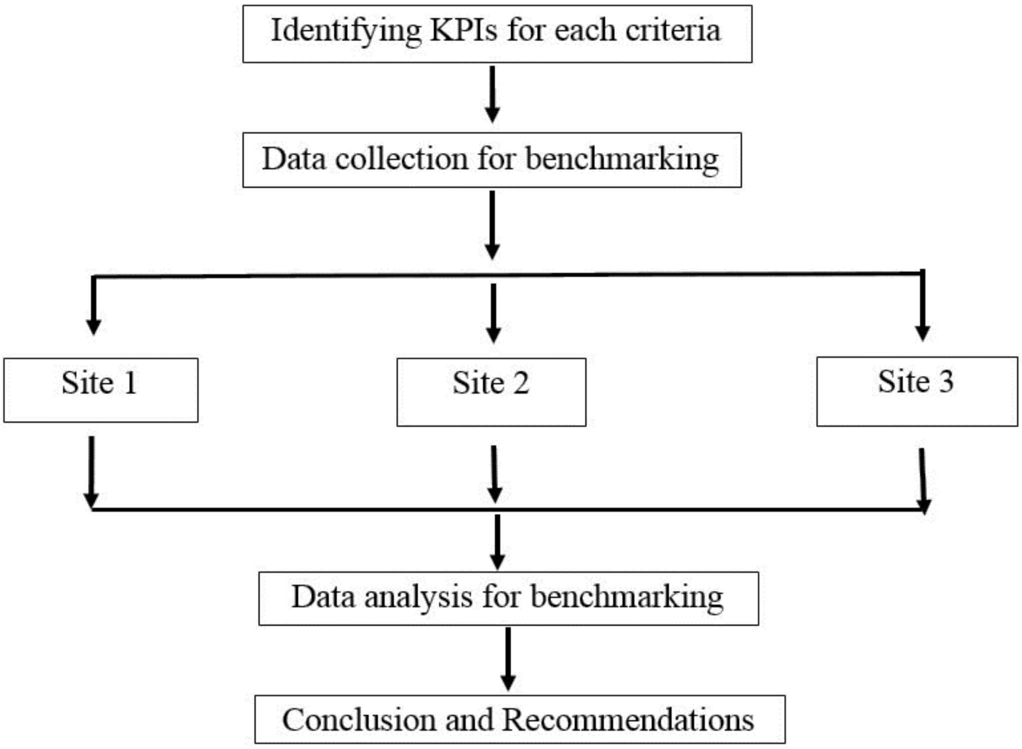


Figure 2.5: Framework for setting benchmarks [37]

b. Step 02: Data Collection for Benchmarking

Representing a few different sites collect the relevant data using several kinds of suitable research methods interview experts, review project documents, site visits quantitative and qualitative methods need to be used.

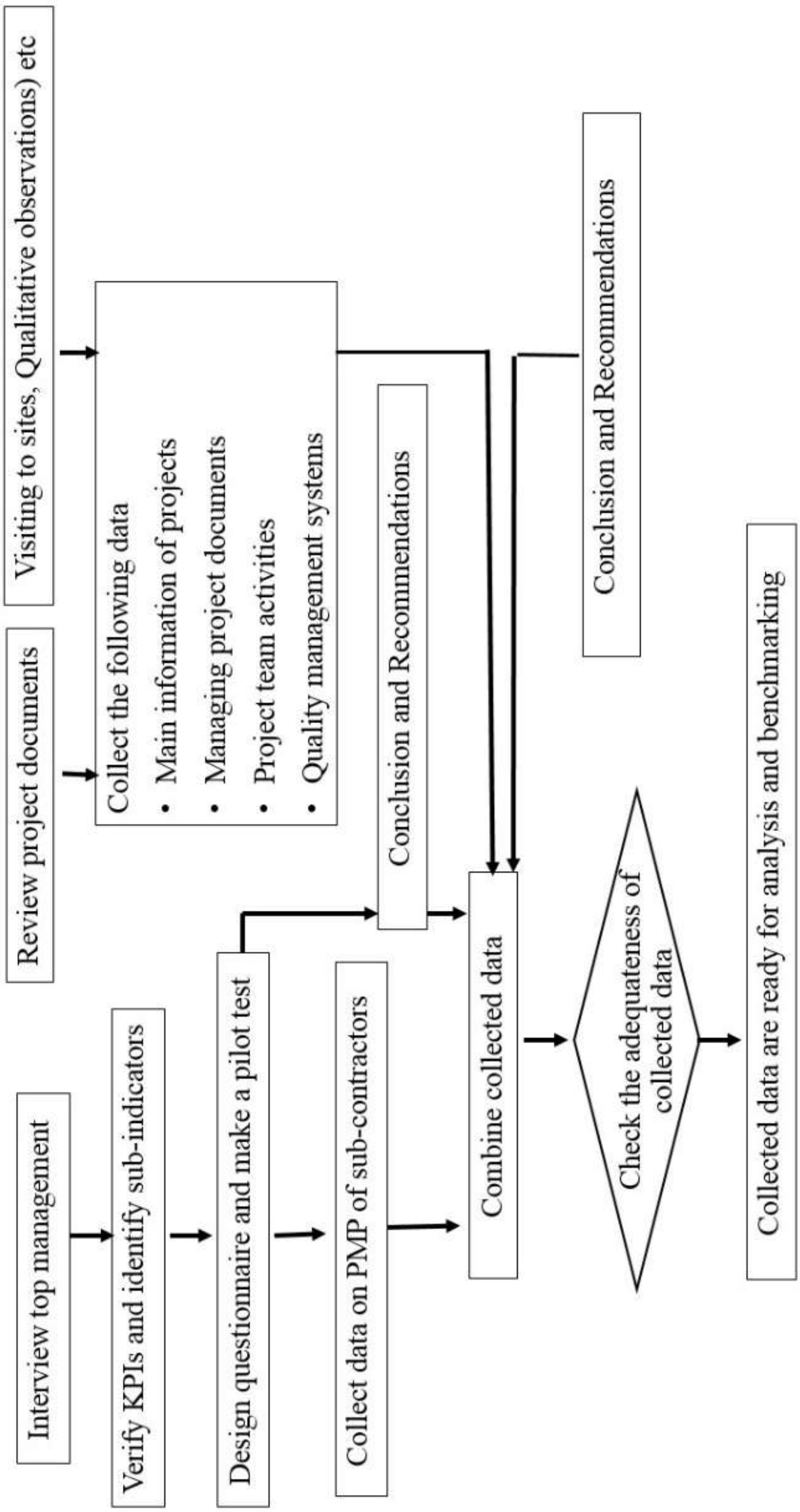


Figure 2.6: Data collection for benchmarking [37]

c. **Step 03: Data Analysis for Benchmarking**

A detailed analysis is needed for collected data under every KPI and indicators. Comparison and analysis of how the performance varied relevant to site conditions and situation are essential before going to set up benchmark performance.

d. **Step 04: Conclusion and Recommendations**

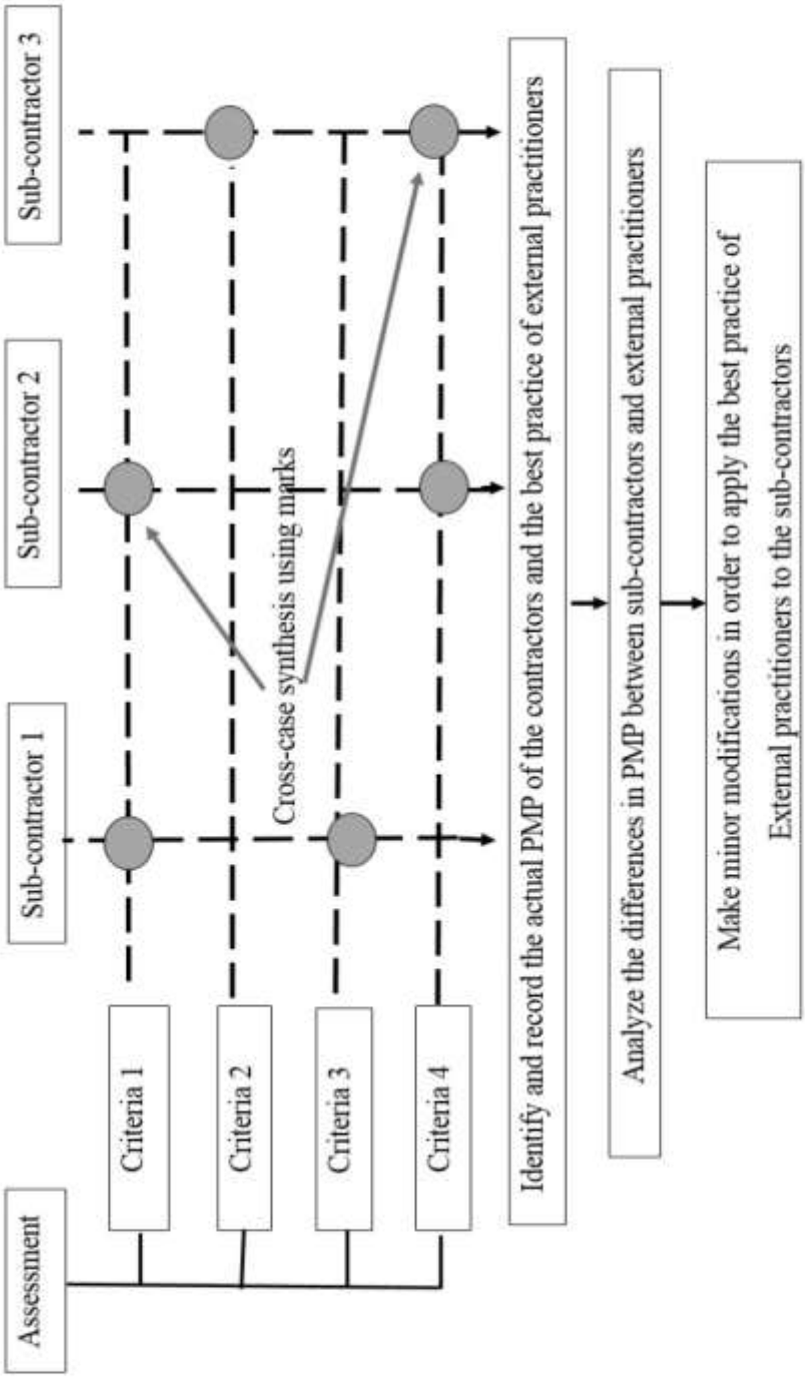


Figure 2.7: Data analysis for benchmarking [37]

3. RESEARCH METHODOLOGY

3.1 Selected Sites for Data Collection

In the study finishing works in building construction were thoroughly studied, while structural trades are studied into that much of depth.

Finishing trades

1. Block work
2. MEP works (Mechanical, Electrical, Plumbing)
3. Plastering
4. Tiling
5. Painting

Structural Trades

1. Form work
2. Reinforcement

Throughout the data collection period in the study researcher was stayed at a large high rise building construction site. Researcher was served for collecting data, identify the productivity pitfalls, and study on the worker time distribution throughout the period. The project was two thirty story buildings proposed and started construction. From April 2018 to February 2019 stayed at the site fulltime. Also, contract price of the project is: Rs. 5,811,873,767.45. Also relevant data was collected from two other building construction sites.

When the study proceeds, the findings were implemented into some extent in a similar kind of project to data collection project. That project is also having two high rise buildings and it was under a different management section.

Table 3.1: Summary of research methodology

Initial Assessment	Factors affecting workers' productivity	1. Literature review 2. Pilot survey 3. Site visits 4. Final questionnaire survey
D et ail	Activity Analysis	1. Site based study

	Sub-contractor assessment framework	2. Literature review 3. Questionnaire survey
	Errors and rework reduction framework	1. Error survey – Site inspection 2. Develop the data base

3.2 Initial Assessment Methodology

Initial assessment framework was developed according to accepted research methods factor list which affects the workers' productivity were identified through literature review then clustered using a pilot study. Final ranking and weighting were done using a questionnaire survey. Measurable criteria's and criteria were identified and weighted through another expert survey opinion. Benchmarking performance and target levels were derived throughout the data collection period with the aid of Activity Analysis, site observations and literature.

Initial assessment is a questionnaire based assessment and it can identify the reason for productivity lags. Initial assessment is capable of assessing the contribution of different disciplines and external factors towards workers' productivity (Management, Plant and equipment, Site facilities, Material supply and stores and project characteristics)

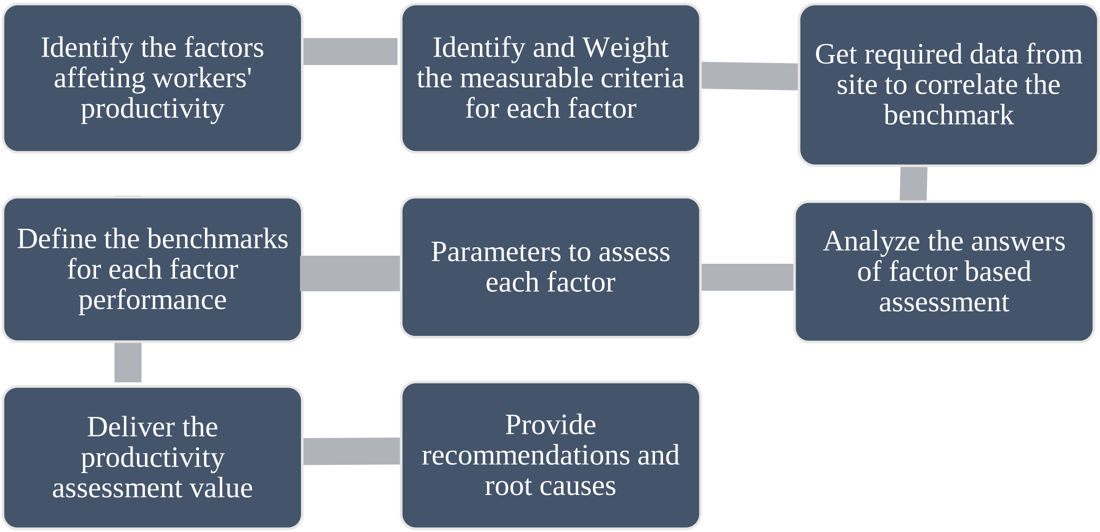


Figure 3.1: Process of the initial assessment framework

Initial assessment part is an extension of a factor based assessment method. It was a work, which was carried out by the author. To achieve good construction productivity, the industry has figured out factors which could affect labour productivity directly. Thereby construction managers will always have a look at them, and they will be acting towards it to minimize the effect on them to productivity. Initial assessment take less time that is why is named as initial assessment.

3.2.1 Identified Critical Factors

Firstly 107 factors were identified through literature, to evaluate construction worker productivity, 62 factors were identified and ranked, which affect construction labour productivity from questionnaire survey [38]. In that research, those factors affecting labour productivity has been categorized into eight categories as follows,

A. Plant and equipment, B. Material, C. Management, D. Manpower, E. Motivational, F. Technical, G. Project and H. Others

Figure 3.2: Worker productivity affecting factor categories [38]

Previously identified 62 factors were ranked according to the relative importance of each factor. Relative importance was derived by performing a questionnaire survey. Considering the relative importance, a weight mark was given to each factor. That marks were used to evaluate the productivity level of a site with the level of the score given by the user for each factor [38].

Top fifteen crucial factors affecting construction worker productivity were indicated in the table which was an outcome of a survey of 208 responses [38].

Table 3.2: Top 15 factors according to RII [38]

Rank	Factor
1	Skill of labour
2	Suitability or quality of plant, equipment, and tools
3	Labour experience
4	Unavailability of material/ Late deliveries of material/material supply
5	Technical ability and construction knowledge of engineer and staff
6	The technology employed and new project techniques
7	Breakdown and damages to the plant and equipment(machinery)
8	Shortage/Inefficiency of tools and equipment
9	Construction method used
10	Communication between site management and labours
11	Amount of wages/unfair wages of construction workers
12	Leadership qualities of the engineer and staff
13	Motivation of labour
14	Quality or suitability of the material
15	Construction manager's ability to manage people and Project planning ability

In the data analysis top ranked factors were listed out for category wise also. Top three ranked factors in each productivity affecting category is listed down in the table 3.3 [38]. After finalizing the factor rankings, the finalized list of crucial factors affecting worker productivity then incorporated to the "Enhancer" web tool initial version.

Table 3.3: Category wise ranking [38]

Category	**Factor**	**Overall Rank**
A. Plant and equipment	Suitability or quality of plant, equipment, and tools	2
	Breakdown and damages to the plant and equipment	7
	Shortage/Inefficiency of tools and equipment	8
B. Material	Unavailability of material/Late deliveries of material	4
	Quality or suitability of the material	14
	Unavailability/Unsuitability of storage location	45
C. Management	Communication between site management and labours	10
	Leadership qualities of the engineer and staff	11
	Construction manager's ability to manage people and project planning ability	15
	Skill of labour	1

D. Manpower	Labour experience	3
	Motivation for labour	13
E. Worker Motivation	Amount of wages/Unfair wages of construction workers	11
	Accommodation	16
	Love and belongingness, Labour recognition and respect	20
F. Technical Competency	Technical ability and construction knowledge of engineer and staff	5
	The technology employed and new project techniques	6
	Construction method used	9
G. Characteristics of Project	Quality control/Standard and specifications	19
	Working environment/Insufficient lighting	37
	Project complexity and design complexity	49
H. Other	Inclement weather/Rain	39
	On-site accidents, Stop works due to accidents	40
	High temperature	41

3.3 Detailed Assessment

Detailed assessment is a combination of interconnected frameworks. Mainly Activity Analysis based worker time distribution assessment, sub-contractor gang assessment and errors and rework reduction framework. Used research methods and the purpose of each framework is summarized in the table 3.4.

Table 3.4: Summary of detailed assessment process

Activity	Research method	Purpose
Activity Analysis	• Site visit	• Identify the possible productivity improvement areas • Evaluates the workers' productivity on trade-wise • Benchmark performance for construction activities
Sub-contractor assessment framework	• Literature review • Questionnaire survey	• Assess crew wise performance and productivity • Identify top performing teams • Improve workers and guide them to build their carrier

Errors and rework reduction framework	• Error survey (Site visit) • Develop the data base- Literature review, Expert opinion	• Enhance project productivity and performance • Reduce waste • Improve work quality and practices

3.3.1 Activity Analysis Based Assessment

In the study, a detailed work force assessment method is derived using the Activity Analysis techniques. Through the study trade wise benchmarks, issues and root causes, the responsible party for non-productive causes, possible improvements were identified. This study was done considering the building construction sector in Sri Lanka.

Introduction to Activity Analysis

In the present situation, the construction workers are highly paid, and the rates are high for the skilled workers. There is a scarcity of the skilled workers in the construction workers.

The workers are not interested in construction activities when the rates are low. A mechanism is needed to get them high wages by improving their performance level.

In this part, the objective is to cover the detailed assessment part. Mainly the study is done according to the Guide to the activity analysis by Construction Industry Institute (CII) [15]. The construction industry has had marginal growth when considering the worker productivity compared to the other industries [39].

Activity Analysis

The workers' productivity is much affected by many external factors. According to reference [38], two main categories that contribute to the worker performance are management and manpower related factors.

In the management related factors includes continuous supervision, adequacy of instructions, coordination of design details, communication and relationship between workers and the management, ability of managers in project planning and human capital management, leadership qualities of the management level, technical knowledge of the engineers and supervisors, size of the crew and distribution of labour, proper management with sub-contractors [38].

Manpower related factors include skill of labour, working for longer periods without holidays and shifts, experience of labourer, motivation of labourer, absenteeism of labourers, working overtime, personal problems of labourers, amount of wages and unfair wages, trainings provided, medical and health and safety provided, late payment of salaries, job security, social activities, accommodation, love and belongings, labour recognition and respect, transport facilities to labourer [38].

Management and manpower related factors puts a big concern for the workers' productivity. To improve the productivity improvements can be implemented in Macro level and Micro level. It was stated that measurement data is needed for two purposes: as a driver for internal improvement and for targeting and benchmarking projects and organizations. Revealing root causes behind productivity and workers' performance and it aims the required change that needs to productivity increase takes place in the micro level [40].

Through the Activity Analysis, a detailed assessment of workers' performance and an assessment for worker productivity can be done as well.

Guide to Activity Analysis categorizes all the activities by the workers into main three categories [15].

Direct Work

Supportive Work = Preparatory Work + Tools and Equipment + Material Handling

Delay Work = Waiting + Travel + Personal

With an increase in productivity means that construction companies can increase wages because companies are getting a high amount of work done within the same time [41].

The duration of the performance has a direct connection on the profitability of the contractors. Claim the delays are difficult to solve in the construction industry [42]. Currently, the competition between construction companies is high. Foreign companies are doing 40% of Sri Lankan projects, and the trend will continue in the next couple of years.

At present most of the construction companies sub-contracted their works. The allocated rates for the sub-contracted works by the companies are significantly low. The contractors have to do more direct works to cover up their daily wages and get a profit.

Since activity sampling is a technique since 1917's recently modified automated analysis techniques were developed [38]. It has built up a job site activity tracking system using video processing. In the process collect a large sample of video data and process.

Construction Industry Institute has developed a guide to doing work study. Based on that guide the definitions were modified compared to the Sri Lankan context.

A brief introduction to each category according to activity analysis definitions are as follows

Direct Work

Direct work includes all the physical productive works relevant to each trade which includes the work that pays off by the company for the contractors and workers. Likewise "All the skilled works in each trade. Making the measurements. Necessary supervision and instructing the crew members by the crew leader/skilled worker".

Preparatory Work

Al the works are necessary for prepare for the direct work. Necessary work area cleaning, tool and equipment cleaning, getting and traveling the equipment to the work place, searching for materials/tools, removing the disturbances (damaged items)

Safety talks and arranging safety protections in the working area. Planning works (receiving, giving instruction)

Getting prepare for the works, putting gloves, arranging the power supply to the equipment. Arrange the supportive scaffoldings, supports

Material Handling

Mixing and preparing the materials according to the manuals. Getting the material/or part to the work place from outside and ineffective material handling activities.

Tools and Equipment

Operating/handling the necessary tools for each trade in the relevant stage of the work. Cutting, drilling mixing, grinding works, levelling, etc. using the relevant equipment. This category includes handling supportive tools for the activity.

Waiting

This category mainly includes the waiting of unskilled worker while the skilled worker is doing the direct works. Miscellaneous delay, equipment delay, material delay, supervisor delay are also included in the category

Waiting for the supervisor to get instructions, materials, get necessary signs. Delays due to unexpected reasons (power supply loss, rain, external disturbances)

Walking / Traveling

Traveling in the working area with empty handed, Traveling early for the lunch and tea breaks and come back after the authorized time, Travelling between tasks with the necessary equipment are included in the travelling/walking category.

Personal

This category excludes normal and authorized breaks and lunch periods. Apart from that time for rest, drinking water, smoking is included in this personal category. Major reason for this is smart phone usage during the working hours,

New Methods in Activity Analysis

The activity analysis method is a continuous process of measuring and improving the amount of time that workers spend on actual construction works [15].

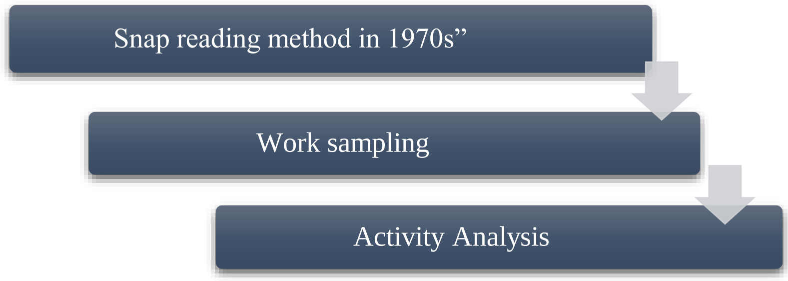


Figure 3.3: Activity Analysis development

In the present snap shot activity sampling method carries hundreds of human hours. Crowdsourcing activity analysis framework 2014 is a framework that collects the data through job site video streams [43].

In the past few years, new trends and solutions developed in the activity analysis. Sensor-based workforce assessment methods leverage Ultra-Wide Band (UWB), Radio Frequency Identification (RFID) tags, or Global Positioning Systems (GPS) as data acquisition device to collect construction worker location information as reference to minimize workforce assessment results [43].

Bag-of-Posed-Histogram mechanism was presented to analyse workers activity types, such as fire caulking, hammering, and idle, in interior condition from RGBD (RGB + Depth) cameras [44].

A typical construction worker day can be classified into few sections. Productive time of a typical construction worker was found out as a small portion. Furthermore is can be elaborates as in the figure 3.4 [45].

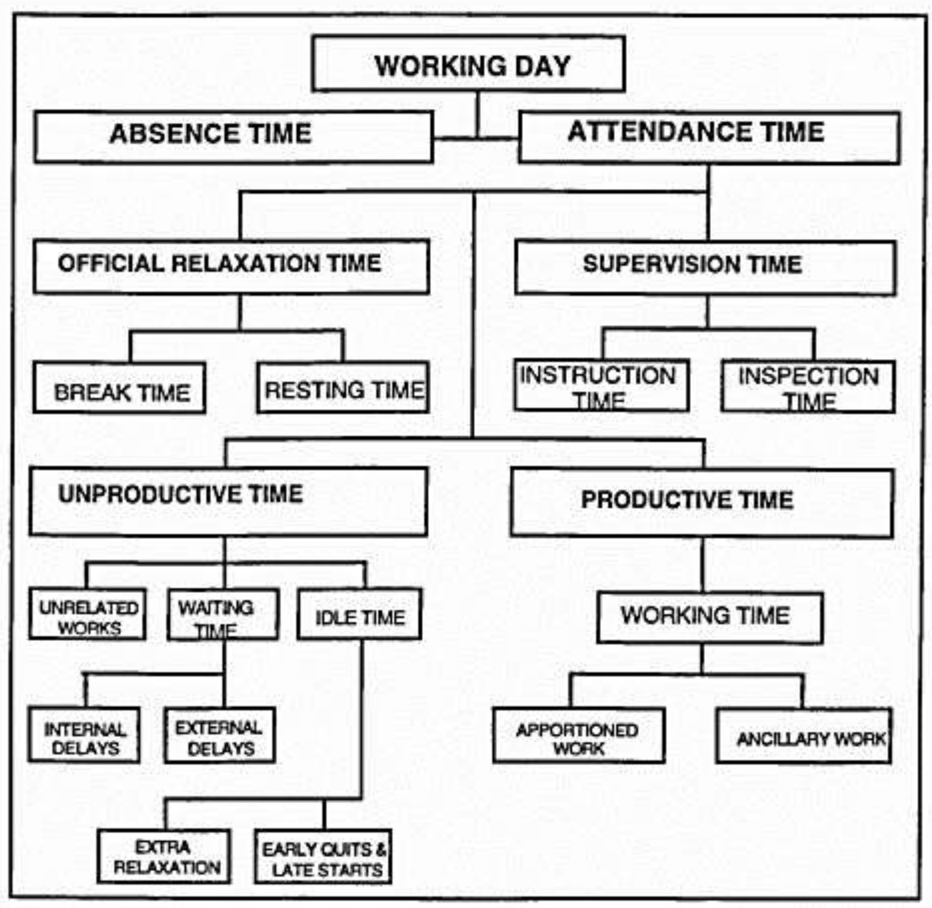


Figure 3.4: Classification of construction working day [45]

3.3.2 Methodology in Activity Analysis Based Assessment

In the building construction, key trades were selected for the study. Activity Analysis results were analysed for the following trades. Tiling, Painting, Plastering, Block work, MEP work, Reinforcement, Formwork

The Activity Analysis was done to assess the time distribution on each category of sub-contractors. All the following results were related to the sub-contractors in each trade.

The data collection sheet was made using the Construction Industry Institute guide. The data collection chart was used to record the percentages in each category for every minute. Consider a worker crew, for every minute took a snapshot and decide the number of workers in each category by their position

Time		Trade		Sub-cont.:		Observer	
Block		Floor		Crew size		Supervisor	

			Observations (1 reading per minute)														
	No	Category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	Direct work															
	2	Preparatory work															
	3	Tools/Equipment															
Session	4	Material handling															
	5	Waiting															
	6	Travel/walking															
	7	Personal															
	8	Rework															
	9	Out of site															
	10																

Figure 3.5: Data collection sheet

It is very much essential to cover up sufficient sample size before analysing the data set. Data sample was collected as per the according to the Guide to Activity Analysis which elaborates in table 3.5 [15].

Table 3.5: Minimum sample sizes per hour

Number of Craft Workers	Minimum Sample Size per Hour
0 - 50	46
51 - 100	84
101 - 150	116

Determining an adequate sample size per hour is critical to the accuracy of the Activity Analysis results. Since the activity analysis was done in trade wise, 50-100 numbers of workers on each trade was recorded for each hour.

Following observation, techniques were followed while collecting the data.

a. Strategic observation techniques – The workers should not be awarded that they are monitored

b. Walk through the working area and make a note of the observations after leaving the area

c. Random routes – To minimize the impact of the situation of being observed, it is also important to ensure that workers are unable to anticipate the exact time of observation.

3.3.3 Sub-Contractor Assessment

In the construction industry labour is one of the crucial requirement. According to the current trend the cost of labour is increasing significantly. To provide a solution to the scarcity of the work force and a higher rate for workers workforce assessment and close monitoring is developed.

Management variables and management practices are main factors which influence contractor performance. Monitoring and controlling of cost, time, quality and safety problem solving, team development skill, management knowledge are identified as the key management variables [46].

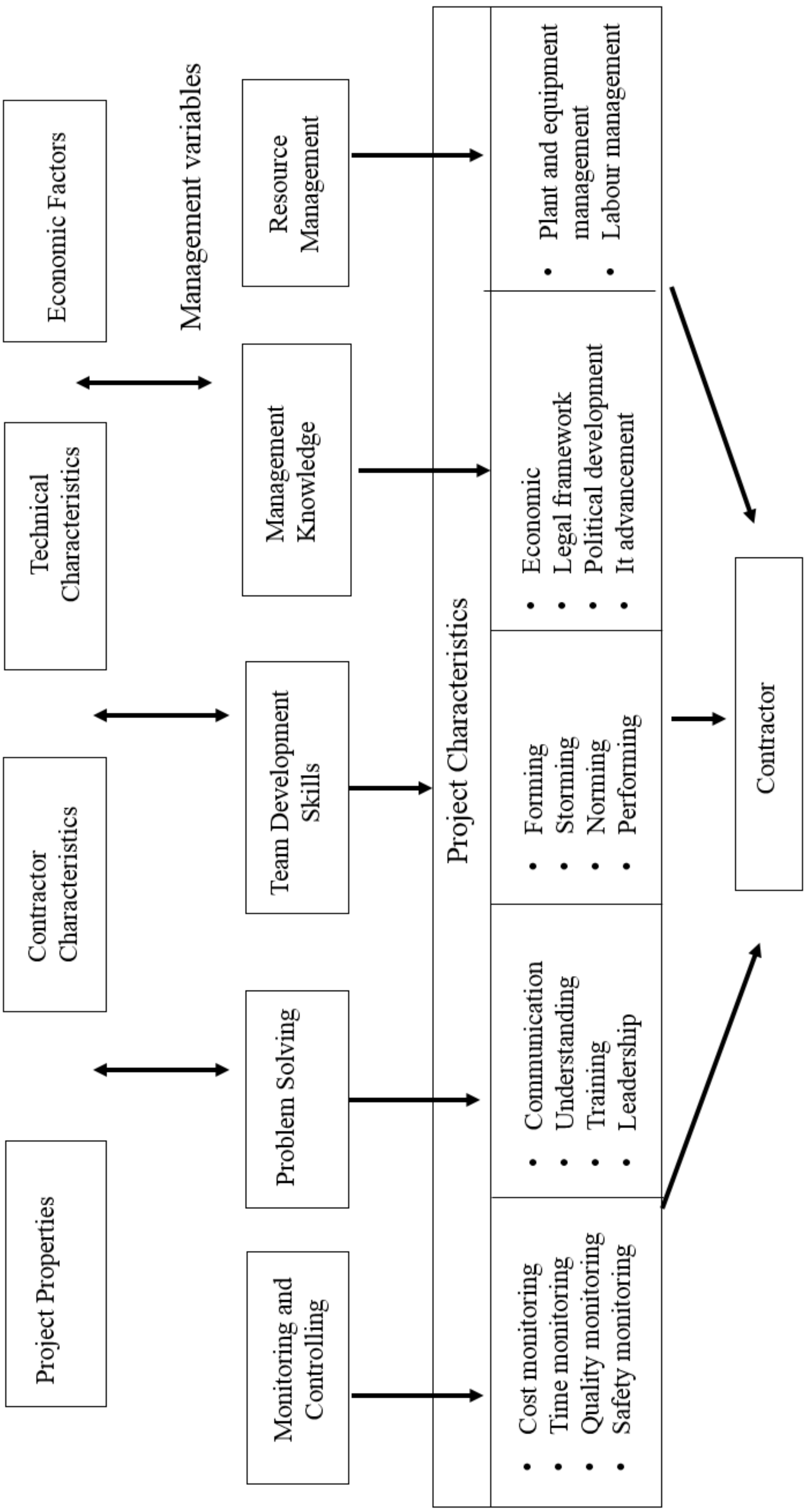


Figure 3.6: Network structure model of the contractor performance [46]

Comprehensive worker performance measurement evaluation the Construction worker performance index is a crew assessment framework. The assessment is based on technical skill, management skills and motivation level. In the CWPI assessment supervisor's assessment play a impor6tant role for the overall assessment [47]. Relevant staff member who is responsible for the sub-contractor crew is need to give his expertise feedback and comments for the final evaluation on sub-contractor crew.

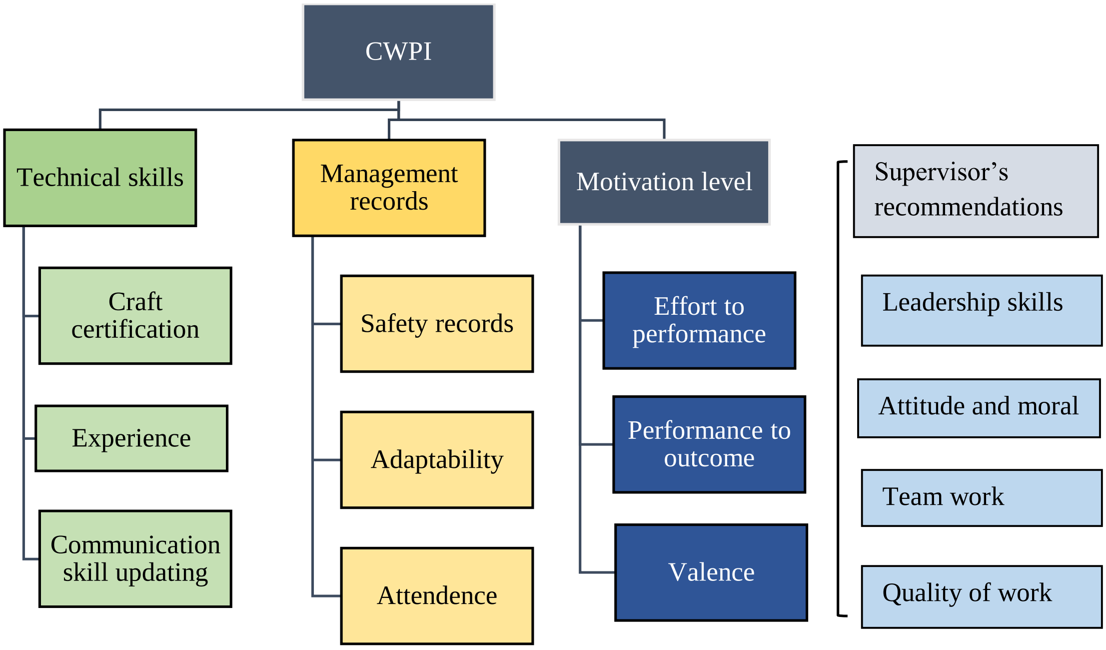


Figure 3.7: Construction worker performance index [47]

It is needed to match construction worker crew characteristics with supervisors' leadership styles. Different supervisors have different supervisory styles. Assigning appropriate supervisors to crews is an essential step in streamlining the construction process [48].

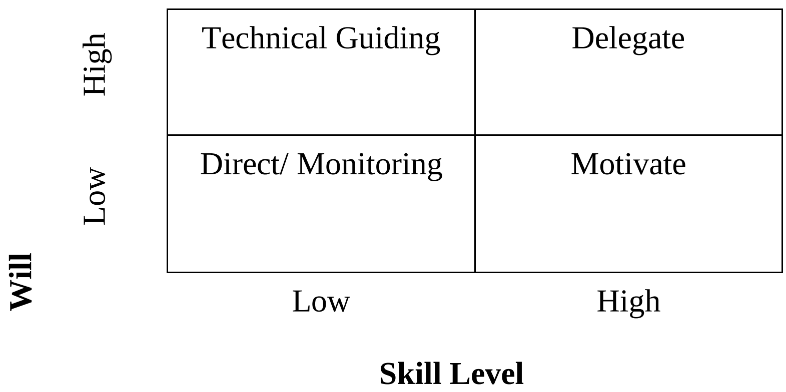


Figure 3.8: Skill will matrix

All the sub-contractor crew in the construction site can be classified into four categories according to the skill will matrix. Technical guiding is needed for a crew less skill and with a high motivation. Close mentoring is needed for a group with less skill and less motivation. Supervisor need to motivate the worker crew with less will and high skill and then a worker crew with high skill and high motivation can be delegated [48].

When shaping crew performance it is not all about their contribution but also management and staff has to play a big part of it as well. Management and staff is responsible for setting up good working condition and effective relationship with workers crews [48].

3.3.4 Errors & Rework Reduction Framework

Previously many researchers suggested frameworks to boost the safety and quality performance of construction projects. They reported on the importance of making a safety culture on achieving higher quality performance [49]. Some measures and recommendation through the study are: Reduce the material waste. Minimize damage to tool and equipment and effective maintenance, Enhance quality working, introduce additional economical layout and work ways. Errors and reworks in a construction project costs a reasonable percentage from total project cost. Errors and reworks cost around 5% [50]. When it consider all kind of construction projects together. In the residential building project value is 3.15% [51].

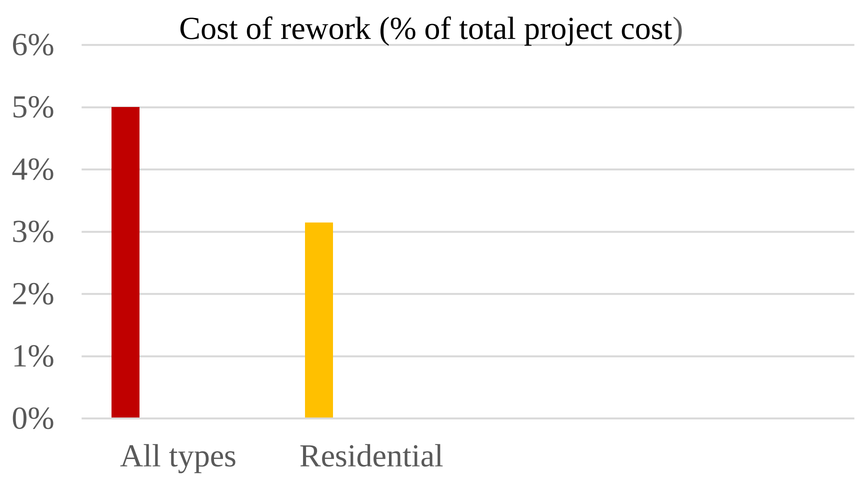
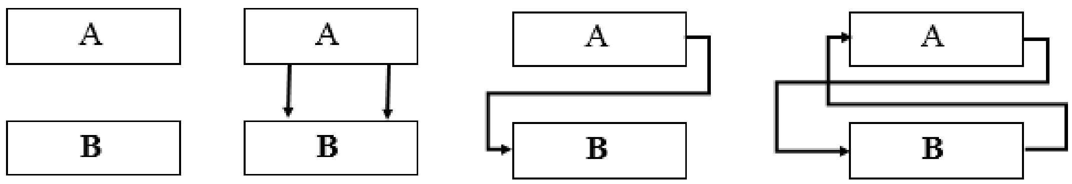


Figure 3.9: Cost impacts of rework reported in various studies [50] [51]

In the construction, it is very difficult to control and deliver the output in ideal conditions. Errors and reworks are identified as a major reason for excessive time and cost in construction [52].

It is quite difficult to make it zero. Though summarizing and real-time analysis with the past data and record can contribute to minimizing the reworks. Within construction, errors have a negative influence on the standard and safety performance of comes [53], [54]. (For instance, a scarcity of quality skill typically follows a deviation from a customary or protocol. Consequently, this needs further work (i.e. rework) to make sure it conforms to given standards.

Also, errors and reworks cause due to the interdependency of the construction activities [55]. Most of the construction works in building sites are semi-dependent or dependent.



Independent Semi – Independent Dependent Inter Dependent

Figure 3.10: Interdependency of construction activities [55]

Errors and reworks represent the spare effort of redoing a method or activity that's incorrectly enforced the primary time. Inept structure and management practices have contributed to stonewalling, share prices, exaggerated errors and misunderstandings, that have invariably resulted in retread occurring incomes [56]. Furthermore root causes for errors and reworks are identified as iteration happens in the site situation, elaborates in figure 3.11 [57].

It was identified errors and reworks are caused due to project characteristics, organizational management practices and project management practices. Caused errors and reworks leads to productivity and project performance loss at the end [57].

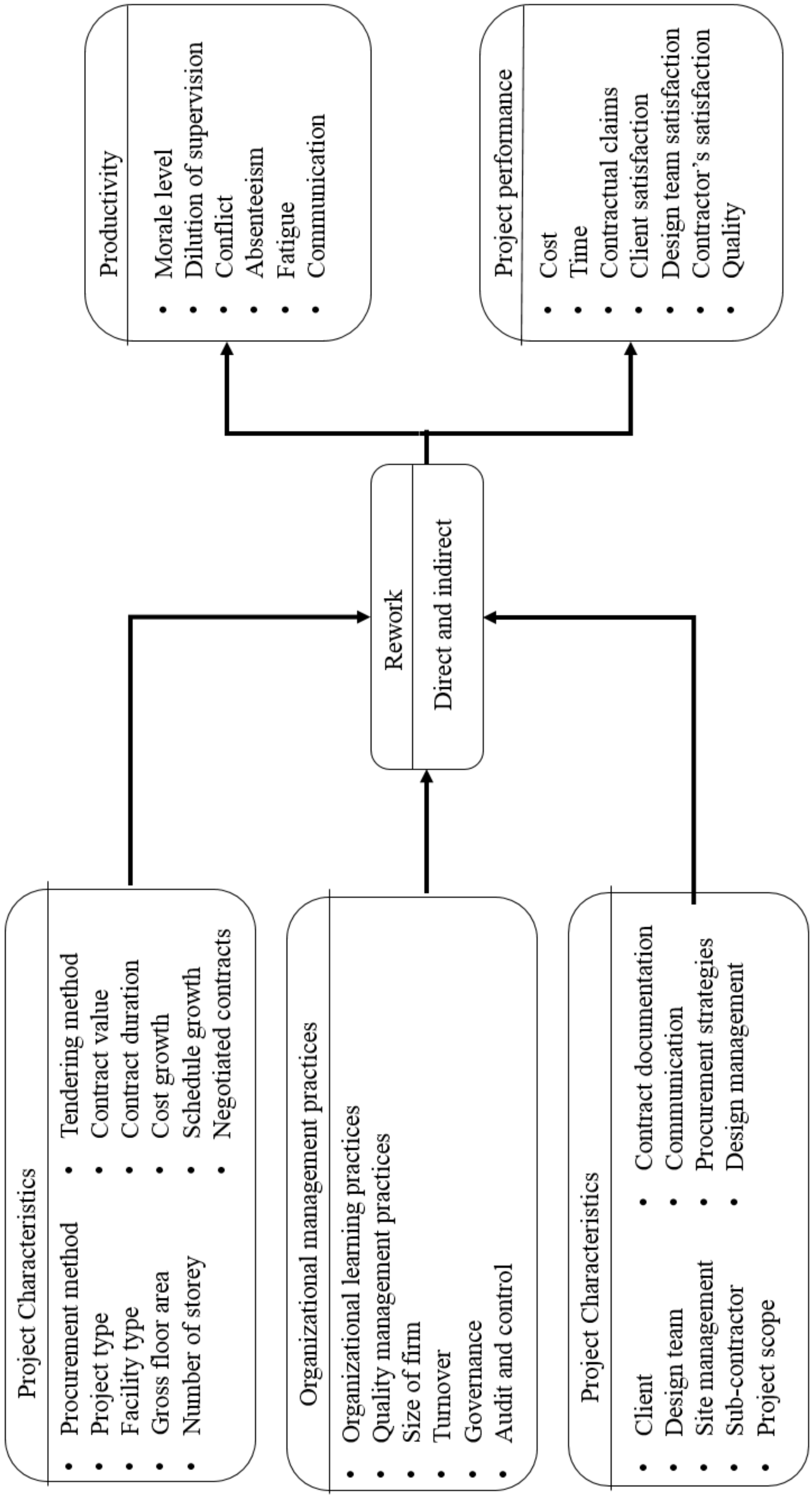


Figure 3.11: Conceptual model of rework determinants [57]

In the case of subcontractors, specific strategies were found out that can be used to minimize the error and rework amount [58], [59], [60] [61].

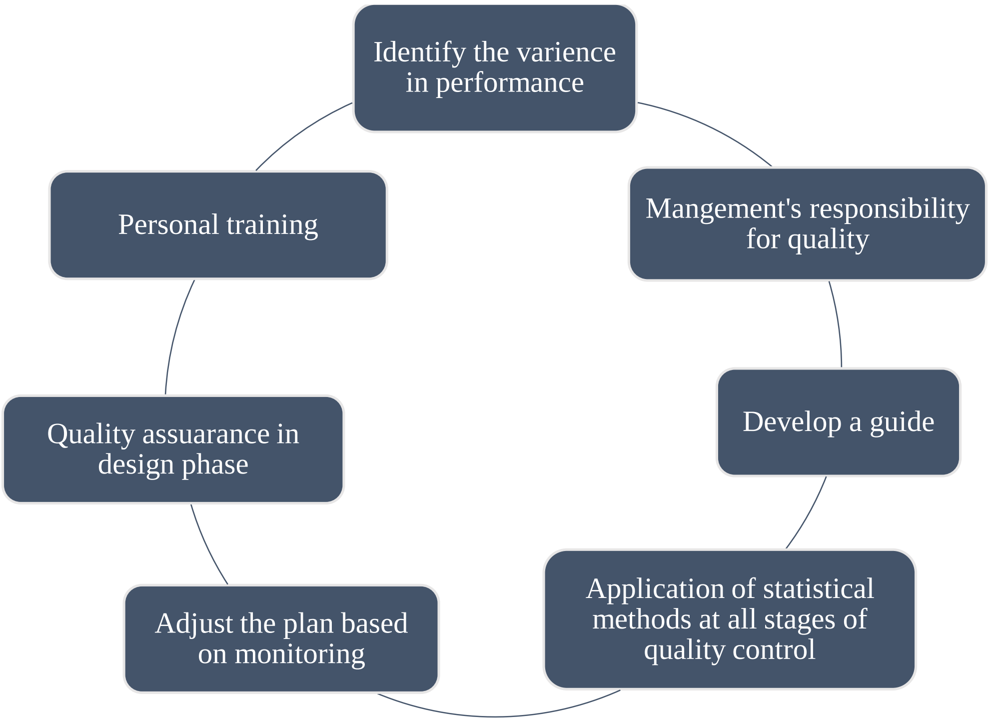


Figure 3.12: Quality control measures

In the construction situation occurrence of errors and reworks have an adverse impact to the project productivity and performance. It has been identified very effective error management and mitigation strategies time to time [62]. To demonstrate how these error management and mitigation strategies work construction movement team has the responsibility.

Table 3.6: Common practices of error management [62]

Practice	Example of quote
Communication	Using lessons learned process during construction projects helped everyone to reduce and mitigate errors and reworks occurred.
Sharing Knowledge	"I was performing on a project in X and finishing a high rise building. I {used to be} lecture X regarding my project as he was similar and period sooner than us. He mentioned regarding a number of the problems that they had baby-faced (i.e.

	rework). That showed a way to avoid creating identical mistakes.
Analyzing	“We spent a lot of time going to site ensuring people knew how to do something before work commenced to make sure they were aware of the potential for mistakes to be made. What I observed was that when rework had to be done, incidents tended to occur.
Error Assistance	“When during commissioning, a valve failed. We worked with the subcontractor (Sub/c) to solve the issue. We do not have to help them, but it was a win-win to help solve the problem. Sub/c does not purposefully try to produce defective work. We also worked hard with the sub/c to ensure they planned their work, so injuries do not occur.
Coordinating and Handling	“Variations were a major contributor to rework and during rectification contributed to injuries. We tried to reduce the impact of variations; this was a goal of ours. When a variation was issued, this often required changes in the sub/c planning.
Culture	No one organization dominated; we are partners. A homogenous culture was developed; no-blame was fundamental. A huge drive to perform work together, share and learn together. When a mistake was made people were encouraged to let everyone know. It was hard at first, but we got there in the end; learning is part of the alliance's fabric

In the start of the construction identify the possible errors and possible reworks need to be identified. Further criticality and frequency of each error and rework will guide the construction team to minimize the amount. As the project proceeds criticality and frequency need to be fine-tuned.

For the analysis construction phases were divided into three stages and the following trades were identified. Structural stage, masonry stage and finishing stage are the identified stages.

During the data collection typical 50 house units which in masonry stage were observed. Those house units were selected from both the towers. Summarised errors and reworks reduction strategy is mentioned in the figure 3.13.

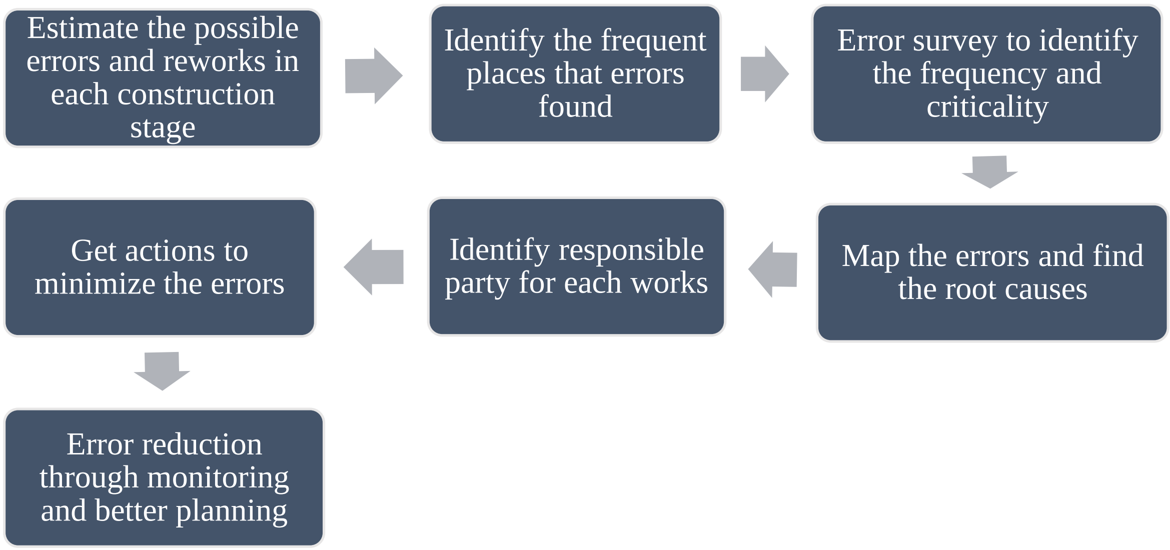


Figure 3.13: Errors and reworks reduction plan

Error identification and estimation was firstly done using the previous inspection sheets. In the general practice QA/QC team does not quantify the error amount. Mainly error survey was used to identify the criticality and frequency of each error in the masonry stage.

4. BACKGROUND STUDY

The delay causes and the problems were identified which are expected to make a cause in productivity and performance. In the process of developing an overall productivity improvement framework, it is essential and important to have a thorough background study. In that process literature review and industry survey supported and contributed to achieve a thorough back ground study.

4.1 Identified Delay Causes through Literature

Seven categories were identified in the literature review. Management, labour, client, material, consultant, project and external are the key categories which causes to construction and performance delay

Figure 4.1: Identified delay cause categories

Under the above delay categories 80 different delay causes were identified and detailed in the table 4.1.

Table 4.1: Identified delays in each category through literature

Category	Factor	References
Client	Finance and payments of completed works/ Late payment by the client to the contractor during construction	[62] ,[63], [64]
	Owner interference	[64]
	Slow decision making by owners	[64], [65], [66]
	Unrealistic imposed contract duration	[64]
	Unrealistic contract durations imposed by the client	[67]
	Delay to furnish and deliver the site to the contractor by the owner	[66]
	Change orders by client during construction period	[66],[68], [65],

	Delay in approving design documents, shop drawings and sample materials/ Delay in work approval	[66], [65],
	Poor communication and coordination among client and other parties	[66]
	Unavailability of incentive programs for target completion and better performance	[64]
	Bid problems	[65]
	Incomplete drawings and specifications	[65]
Contractor	Sub-contractors/ Delays in sub-contractors work	[64], [66]
	Problems due to improper planning and scheduling	[64], [65]
	Mistakes reworks and errors during construction	[64], [66]
	Inadequate contractor experience (planning, scheduling)	[64], [67]
	Poor site management and supervision by the contractor	[66]
	Poor communication and coordination by the contractor with other parties	[66]
	Ineffective construction methods and practices by sub0contractors	[66], [64]
	Inadequate contractors work / Poor performance of work	[66] , [65]
	Change in sub-contractors time to time due to their lower performance	[66]
	Poor qualification of the contractor's technical staff	[66]
	Delay in site mobilization	[66]
	Late payment by contractor to workers during construction	[65]
Management	Poor site management and supervision	[67], [64]
	Improper control over site resource allocation	[67]
	Low speed of decision making within each project team and involving the team	[67]
	Low skills of project planning and scheduling by construction team	[41]
	Inadequate information exchanged between parties and lack of communication among relevant parties	[69], [67]
	Lack of structured methods to identify and categorize the finished components	[69]
Con	Preparation and approval of drawings	[64]

	Quality assurance /control	[64]
	Waiting time for approval of tests and inspections	[64], [65]
	Delay occurs in approving changes and excessive time is taken for carrying out inspection	[66]
	Lack of flexibility while decision making and coordinating	[66]
	Insufficient experience of consultant	[66]
Material and Equipment	Low-quality material	[65], [70]
	Shortage of material	[64]
	Poor procurement programming of materials	[67]
	Shortage of construction materials in the market	[66]
	Changes in material types and specifications during construction	[66]
	Delay occurred in material deliver	[66], [68], [65]
	Late procurement of materials	[66]
	Breakdown in tool and equipment and shortage	[66]
	Low productivity and efficiency of tools	[66]
	Penalty of development materials suppliers	[65],
	Supplier and late delivery of equipment	[65],
	Failure of equipment	[65],
Labour	Labour supply	[64]
	Labour productivity	[64], [69]
	Equipment availability and failure	[64]
	Shortage of skilled and unskilled labour	[67], [66]
	Low labour productivity	[67]
	Delays in subcontractors' work	[67]
	Nationality of labors	[66]
	The low productivity level of labors	[66]
	Personal conflicts among labors	[66]
External / General Factors	Weather situation and effect, Rain effect on construction activities	[64], [68], [65]
	Regulatory changes and building code	[64]
	Problems with neighbors	[64]
	Unforeseen ground conditions	[64], [65]

	Unavailability of utilities in site (such as, water, electricity, telephone, etc.)	[66]
	Effect of social and cultural factors	[66]
	Differing site (ground) conditions	[66]
	Changes in government regulations and laws	[66]
	Inclement weather conditions	[69]
	Traffic congestion between factory and site	[41]
	Environmental problems	[65],
Project / Design	Unforeseen ground conditions	[66]
	Project construction complexity	[66], [68]
	Inadequate definition of substantial completion	[66]
	Ineffective delay penalties	[66]
	Delays in producing design documents	[66]
	Un-use of advanced engineering design software	[66]
	Quality relation	[68]
	Change orders	[64]
	Mistakes and discrepancies in contract documents	[64]

4.2 Industry survey

When trying to develop a practical productivity framework it is important to have a thorough study on existing gaps and drawback in the construction industry, as well as root causes.

In the first stage of the study, an industry survey was conducted. The ultimate goal is to study the existing productivity concepts and methods before developing an overall framework. Gaps and drawbacks in the current construction industry among construction companies were identified and listed out through the survey. The responses were collected to represent seven leading construction companies in Sri Lanka while collecting responses from two Chinese companies as well.

Responses and industry experts' opinion were collected representing seven leading construction companies in Sri Lanka. In the questionnaire several questions were asked from the industry experts to get the opinion on those points.

a. Difficulties and drawbacks with current situations

- lack of skill labours
- The attitude of staff and labours
- Less effort in improving the productivity among the supervisors
- Use only bar charts to monitor the construction works and planning
- Delay in decision making
- Management will not get direct decision to improve good quality
- Non-periodic meeting at sites
- Resistance to system changes of unsuitable peoples
- Issues in communication between construction stakeholders
- Lack of training sessions and workshops to construction workers
- Ineffectiveness in material delivery, construction site layout

b. Sri Lankan workers and foreign workers comparison

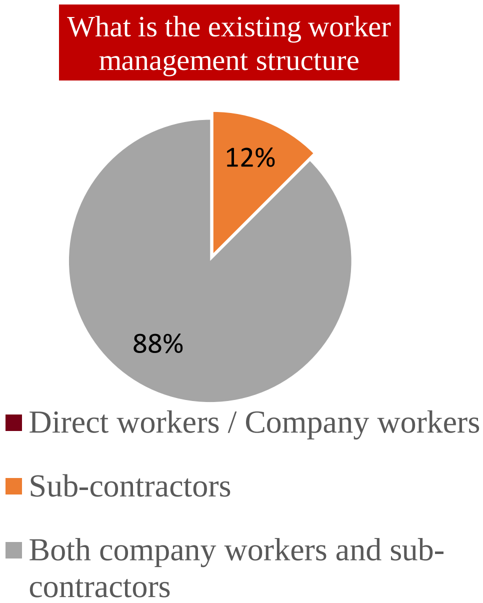
Then a comparison as in the table 4.2 were carried out from the responses. The table elaborates positives and negatives of foreign workers with compared to Sri Lanka workers.

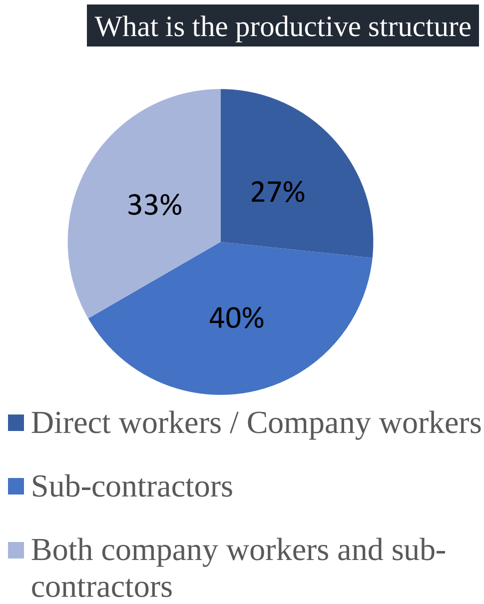
Table 4.2: Performance comparison

Positives	Negatives
• Work 14 - 16 hours • Working hard • Working quickly • Punctuality is better • Consistency of attendance • Skilled workers • Good attitude, Lesser distractions • Higher physical strength	• They're trying to give a service which worth their salary. If we give sufficient facilities like foods and overtime charges they'll give more service than local workers. • Difficult to communicate • Bad attitude towards local supervisors • Need more foods - Specially Bangladeshi labors • Take 2-hour break from 12 to 2

c. Worker management structure

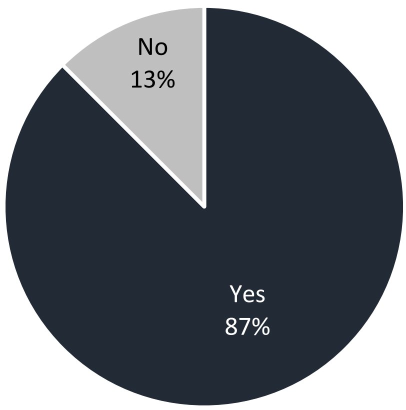
Currently there are three main worker management structures which are only sub-contractors, only company workers and combination of direct workers and sub-contractors. The combination of sub-contractors with combination of direct workers was the main opinion that was analyzed according to the responses. Further 40% of experts were opinioned combination of direct worker and sub-contractor mentioned above point.





d. Measure / Monitor the workers' productivity?

During the study it was found out 87% of the companies are measuring and monitoring the productivity.



Suggested actions

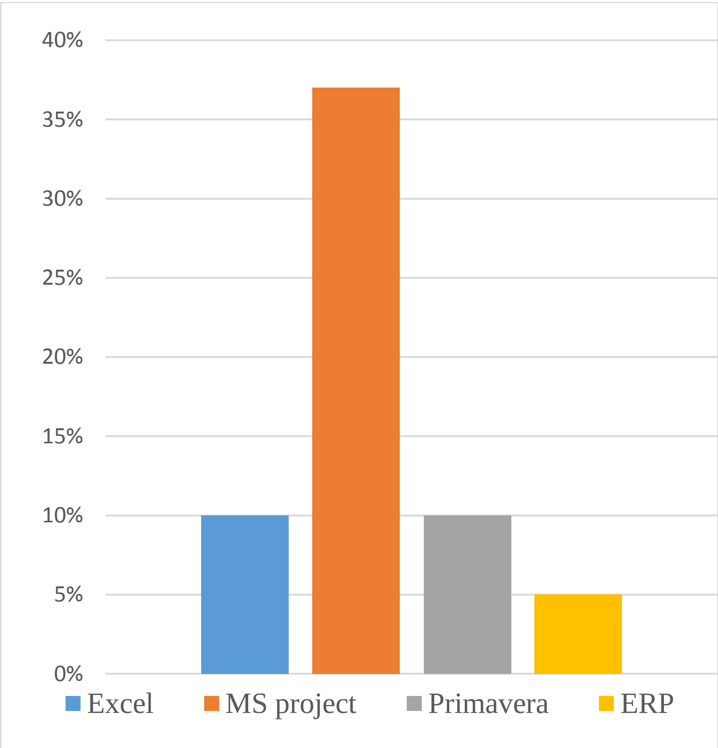
- Monitor daily progress, measure the quantity of work done and how much time expend to it. There is an officer for measure the work is done with cost

- Company need to instruct the supervisors of worker's to continuously monitor the worker's productivity and check their work done at least covers their daily wages
- Given targets should be covered in a given period for the crews
- Weekly basis evaluate the work is done and the expenditures to all items
- Supervisors should submit on work is done records in daily

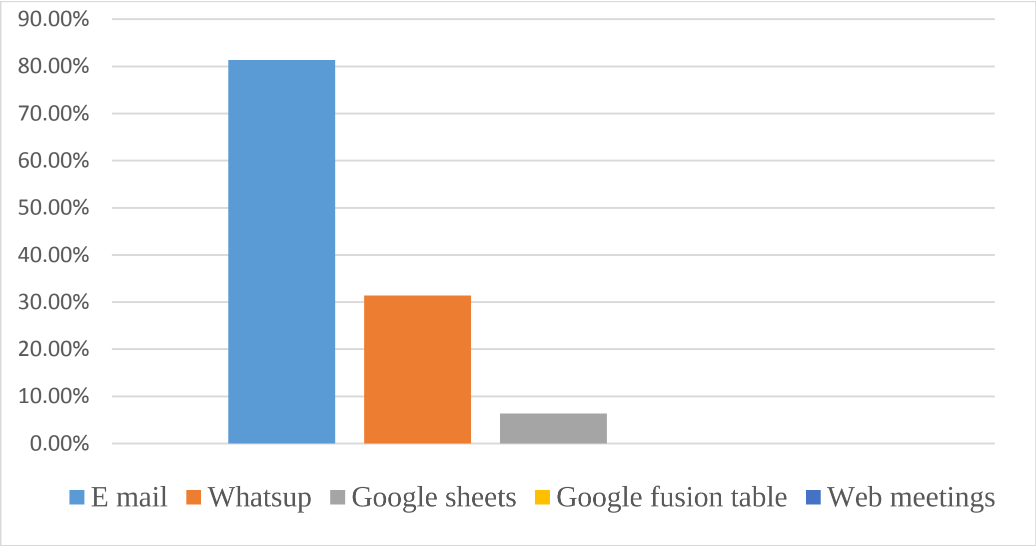
e. Use of IT and technology

Under the use of IT and technology, it was investigated current practices and trends in Sri Lankan construction industry. Following percentages were found out in usability of scheduling software, project managing software and communication techniques. MS project were found out the key scheduling software while some companies practicing both MS project and Primavera.

Advanced Project Managing Software



Communication Techniques



f. Quality assurance actions

- Compare the performance - Have different teams for different locations in the construction site
- Arrange training/awareness programs
- Every weeks arrange the QA meeting / Site meeting Advise in the site
- Efficient technical staff and document keeping / Daily reports of manpower and tools
- All jobs are done under the supervision of a consultant. quality assurance officer did the surveys and submit a report of the quality of the job in monthly
- QA/QC inspections before all work, Separate QA/QC division, Selection of Quality material, Continuous carrier development programs.

g. Errors and reworks reduction actions

- Money reduction / Add penalty for rework amounts
- Continues supervision (by qualified technical officers)
- Monitoring -surveys check every level coordinates under the supervision of engineers and consultants before do concrete or pipe laying in the site
- Assign skilled workers as much as possible
- Inspections from both the Contractor side and Consultant side - according to consultant recommendations.

- Need planning and evaluation before the work. Prepare drawings and reviewing among each other in site meeting.

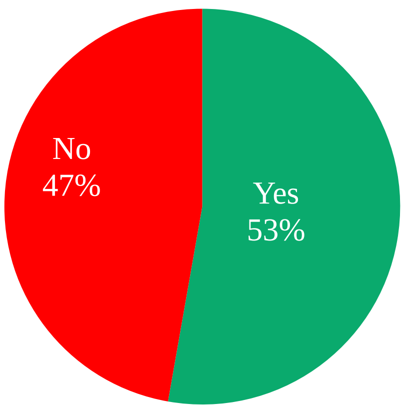
h. Minimizing material wastage

- Continues and proper supervision
- Better pre planning to avoid material reconciliation time to time. Material need to be stored in a proper pre identified place through site layout planning.
- Reuse and recycling of material used in the site
- Preparation of work approval for tasks and issuing the approved material quantities for the relevant work.
- Bar bending is done in a separate yard and they use software to minimize the wastage. Formworks are done in a separate carpenter shop.
- Proper Planning. Accurate drawings

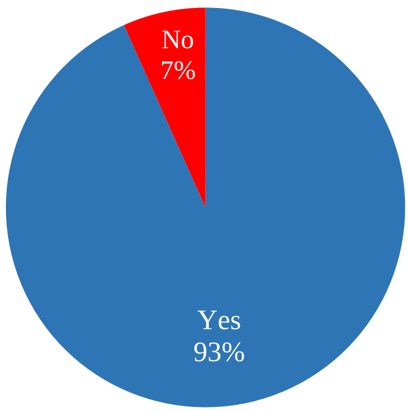
i. Evaluation and appreciation process of workers

53% of the companies were found to be having an incentive program for worker performance. Majority of the respondent experts were believed and stated their opinion, there should be a performance based incentive performance for better productivity performance.

Is there an incentive program



Does incentive based performance is needed



j. Identified possible improvements

- Performance-based incentives
    - Giving targets for workers

- Effective communication between parties. Communication among sites - There should be a network among the projects to acknowledge day to day site issue/challenges, etc faced within individual sites.
- Better supervision is needed for lower management by the top management
- Due to the higher hierarchical structure a long time to get an approval for work orders. Decentralize the power of deciding middle management
- Assigning suitable works for suitable officers and workers
- Need proper, close monitoring progress
    - Cost analysis of the labors for their daily work done. And give feedback to labours and reduce their workmanship categories.
- Total job should be planned with the site weather condition
- Continuous carrier development programs for site staff.
- Mainly divided into section and every section run under the supervision of separate managers.
- Pay additional O/T, Refreshment, Day offs for full night shifts
- Improve the use of new techniques

  Improved procurement handling and use ERP

  Arrange progress meetings continuously

  Training programs about new methods

  New formwork systems

5. INITIAL ASSESSMENT

Initial assessment is an extension of enhancer.lk. Through the study it was find a solution to issues and drawbacks, found out in the previous questionnaire based assessment.

5.1 Limitations in the First Version of the Enhancer Tool (enhancer.lk)

When considering the assessment of tool following limitations could be identified.

- A five-point Likert scale will be given to the user to rate the factor. Therefore, the score for the factor can be subjective according to the user.

- Use of the five-point Likert scale makes the relative measurement of productivity rather qualitative than quantitative.

- The tool will highlight only the issues regarding the factor and will not highlight the root causes of the issues at the site.

If further elaborated, categories of factors affecting labour productivity are different and scattered. Therefore, identifying solutions for a poorly scoring category only will not be successful since the related other issues could not be identified since root causes for the problems were not identified.

For example, if there is an issue with material delivery to a single crew and it has led to workers being waiting. But this waiting for material has led to laborers to have more personal works like using the phone, talking, etc. Mean time the supervisors also have put a lack of supervision on them. When considering the overall site conditions material delivery could be at an acceptable state while workers seem not performing. But the real issue was with material delivery to that crew.

Initial Assessment is developed to identify the relative measurement for productivity by minimizing the limitations of the previous tool. In the previous research the assessing of labour productivity was done by giving a relative productivity assessment value considering the relative importance of the 62 factors identified. In this framework method of attaining to the score of a factor will be changed while the other steps of arriving at the relative productivity measurements remain.

5.2 Deriving a Quantitative Mark

To arrive at the score for factor following process is identified. Since the score to be required is a quantifiable one each factor will be identified with Measurable criteria for it. Though the measurable criteria for factor were identified, they can be having different relativity to the factor. Therefore, each criterion will need a comparative score within a factor. Along with the comparative score of criteria, if a measurement is given to the criteria, the combined figure can bring a score to the factor.

But to give a measurement to the measurable criteria, each criterion will be identified with measurable indicator. Therefore, this indicator will be able to identify the mark for each criterion. With the marks for criteria along with comparative scores for criteria, score for a factor will be received and by putting the scores for the factors to the tool more quantitative relative productivity assessment figure will be received.

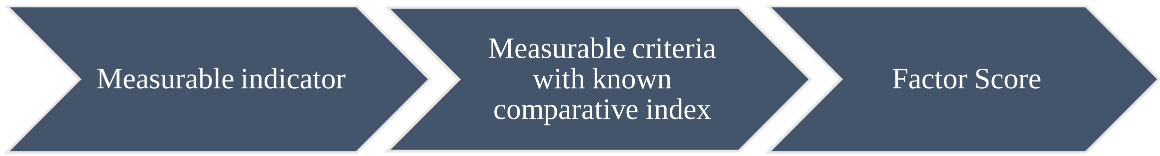


Figure 5.1: Process of deriving of quantitative mark

$$\text{Factor Score} = \sum \left(\begin{array}{l}\text{Mark from} \\ \text{measurable} \\ \text{indicator}\end{array} \times \begin{array}{l}\text{Comparative Score of} \\ \text{Criterion}\end{array} \right)$$

5.3 Identification of Measurable Criteria and Measurable Indicators

When considering the method of marks getting for each factor, the score will be carried by the measurable criteria for each factor. Therefore, by going on literature, construction site visits and results of Activity Analysis different criteria that could measure each factor was identified. Finally, altogether 204 measurable criteria were identified such that each factor will have more than a criterion to give a score to the factor. Though the measurable criteria are available a measurable score for each criterion will be given by the Measurable Indicator. Therefore, every measurable criterion has its measurable indicator. Measurable indicators are also identified by referring to literature, site observations done and Activity Analysis process.

5.4 Validation of Measurable Criteria and Indicators by Performing a Questionnaire Survey

Since each factor has been identified with several measurable criteria, a questionnaire survey was done to validate those criteria and to identify the importance of them to a single factor. An online Questionnaire survey was distributed among Top management personals, Project managers, Site Engineers, Engineer Assistants and Technical officers in the construction industry. Altogether 45 responses were collected for the survey, and comparative score for selected measurable criteria for a factor was identified using the responses received.

5.5 Related and Probable Cases for each Factor

The selected Measurable Indicators have been benchmarked as follows so that each indicator gives maximum to minimum mark range according to the maximum and minimum marked assigned for the factor from the previous tool. The sources for the required data also have been identified to modify the sources and make it easy for users to identify the data required. The source general will be the overall data collected on-site at the commencement of the project and will change some data at the milestones of the project.

For the Initial Assessment, the first thing which was done is the identification of Measurable criteria and Measurable indicators. The following Table 9 will show the identified Measurable criteria for each factor and its Measurable indicator. Numbering for the factor will be given with the Capital letter assigned for each category as per the previous research, and each criterion is numbered as sub division of the factor. Measurable criteria are ranked among factor according to the responses received for the Questionnaire survey distributed among Industry Practitioners. Following Pie Chart shows the variation of responses according to personals involved in it.

Accordingly, the Measurable criteria were numbered according to the rank received among factor while the factors were ordered according to the rank received by each factor in the previous research.

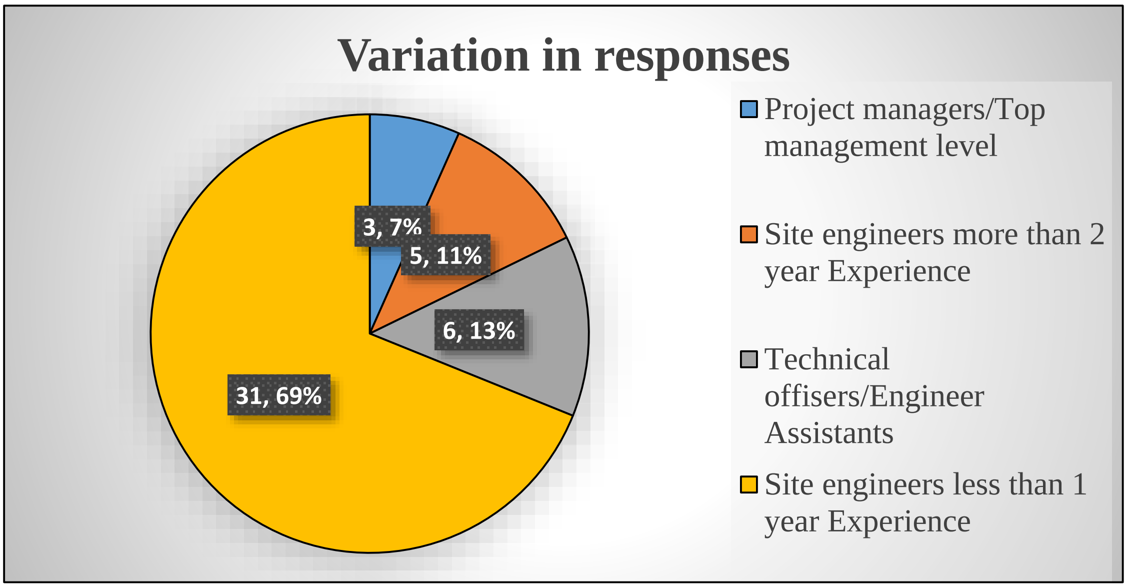


Figure 5.2: Variation of responses

*45 responses from industry people were collected

Table 5.1 presents the detailed measurable indicators, identified through experts opinion and literature review. Comparative score was calculated according to the survey responses.

Table 5.1: Indicators for each main factor

Factor and Measurable Criteria	Measurable Indicator	Comparative Score	Rank Among Factor
A) Plant and equipment related factors			
A 1) Suitability or quality of plant, equipment and tools			
A 1.1) Maintenance records	Availability	0.27	1
A 1.2) Working hours per day	Equipment usage per day	0.21	2
A 1.3) Quantity	Available quantity	0.19	3
A 1.4) Working Capacity	Acceptable working capacity	0.18	4
A 1.5) Available types	Sizes, Functions	0.16	5

A 2) Breakdown and damages to the equipment(machinery) and plant			
A 2.1) Equipment maintenance records	Availability/Not	0.40	1
A 2.2) Break down hours per week or per month	Break down hours from daily reports	0.35	2
A 2.3) Breakdown frequency	Number of Breakdowns per week	0.26	3
A 3) Shortage/Inefficiency of tools and equipment			
A 3.1) Quantity (Available/Required)	Percentage available over requirement	0.25	1
A 3.2) Daily record on tool and equipment usage	Availability and details	0.19	2
A 3.3) Resources in the company	Grading of the company	0.18	3
A 3.4) Activity duration	Activity duration from labor records	0.16	4
A 3.5) Categorization under activities (Resources)	Categorized / Not	0.12	5
A 3.6) Equipment ownership (Owned, Hired)	Percentage of equipment ownership	0.10	6
A 4) Effective Monitoring of plant and equipment utilization			
A 4.1) Equipment maintenance records	Maintenance record availability	0.29	1
A 4.2) Break down hours	Break Down hours' availability	0.26	2
A 4.3) Break down the frequency	Break down frequency availability	0.26	2
A 4.4) Waiting time for equipment	Delay of work records in the daily report	0.19	4
B) Material related factors			
B 1) Unavailability of material/ Late deliveries of material/material supply			
B 1.1) Stores records	Number of unavailable items recorded	0.18	1
B 1.2) Delay in material supply	Delays in supply as per stores records	0.14	2
B 1.3) Work delays due to material	Delay of work per week	0.13	3
B 1.4) Material wastage	Percentage of wastage	0.13	3
B 1.5) Requests for material per day	Number of times materials issued or requests	0.13	3
B 1.6) Material stock in working site	Adequacy of material at the site	0.12	6
B 1.7) Extra amount of material storage	Availability of inventory and number of days availability	0.12	6

B 1.8) Trade wise material usage in the site per day	Trade wise material issuing records availability	0.05	7
B 2) Quality or suitability of the material			
B 2.1) Material quality reports	Quality adequacy by quality assurance	0.46	1
B 2.2) Reworks and errors due to material quality	Reworks recorded in daily reports	0.32	2
B 2.3) Material wastage	Wastage percentage	0.23	3
B 3) Suitability of storage location			
B 3.1) Distance to each material supply path	Distance	0.26	1
B 3.2) Work delays due to material supply	Delay of work records in the daily report	0.23	2
B 3.3) Amount of materials issued per day	Issue quantity per day	0.22	3
B 3.4) Material and tool issuing procedure	Number of documents per issue	0.16	4
B 3.5) Number of labor arrivals daily to the stores	Number of Daily issuing	0.13	5
C) Management related factors			
C 1) Communication between site management and labors			
C 1.1) No: of Site meetings	Number of meetings per month	0.30	1
C 1.2) Language proficiency of the staff	Number of proficient languages	0.28	2
C 1.3) Instruction procedure	Number of hierarchies in upward level at the site	0.21	3
C 1.4) Reworks and errors due to communication	Number of reworks due to poor instruction	0.21	3
C 2) Leadership qualities of the engineer and staff			
C 2.1) Planning, decision making, and scheduling	People-oriented or task oriented	0.14	1
C 2.2) Good Attitudes	Level of attitudes	0.13	2
C 2.3) Negotiation while decision making	Worse/ Acceptable	0.13	2
C 2.4) Work crew handling	Friendly / Normal / Strict	0.12	4
C 2.5) Correct decision making	Number of reworks due to poor instruction	0.12	4
C 2.6) Inter personal skills	Grading for interpersonal skills	0.11	6
C 2.7) Education background	Educational qualification	0.10	7
C 2.8) Extra-curricular activities	Number of activities	0.07	8

C 2.9) Past records on performance (Progress/ Profit/ Losses)	Past profit percentage, Variance percentage	0.07	9
C 3) Construction manager's ability to manage people and Project planning ability			
C 3.1) Planning, decision making, and scheduling	SPI, Number of reworks	0.18	1
C 3.2) Profit margins of completed projects	Profit margins of completed projects	0.16	2
C 3.3) Decision making	Number of reworks due to poor instruction	0.16	2
C 3.4) Completed projects detail	Level of Availability	0.15	4
C 3.5) Progress achieving the ability	Project lagging time, CPI and SPI	0.14	5
C 3.6) Inter personal skills	Level of interpersonal skills	0.14	5
C 3.7) Extra-curricular activities	Number of activities	0.06	6
C 4) Supervisory incompetence/ Instructions delay			
C 4.1) Technical skill levels	Professional qualification level	0.26	1
C 4.2) Inspection approving attempts	Number of attempts	0.24	2
C 4.3) Progress achieving	Earned value ratio	0.22	3
C 4.4) Reworks due to errors	Nature of reworks	0.17	4
C 4.5) RFI frequency	RFI frequency per week	0.11	5
C 5) Crew size and composition /Distribution of labor			
C 5.1) Worker composition (Skilled/ Unskilled)	Percentage of skilled and unskilled workers	0.32	1
C 5.2) Work for per unit or floor	Labor requirement vs actual	0.23	2
C 5.3) Worker attendance	Labor attendance	0.20	3
C 5.4) Trade wise worker amount in the site	Trade wise worker percentage	0.16	4
C 5.5) Crew size in trade wise	Number in crew	0.10	5
C 6) Reworks/Reworks due to construction errors			
C 6.1) Progress delay	Earned value	0.29	1
C 6.2) Reworks type/amount	Amount due to rework	0.24	2
C 6.3) Inspection approving attempts	Number of attempts	0.23	3
C 6.4) Frequency of reworks per week/month	Frequency	0.23	3
C 7) Sequencing problem in the schedule work			
C 7.1) Progress delay	Earned value ratio	0.27	1

C 7.2) Inspection failure	Number of failures	0.21	2
C 7.3) Reworks due to scheduling	Delay due to reworks	0.21	2
C 7.4) Delays in critical activities	Delay time in critical activities	0.19	4
C 7.5) Trade wise (Painting, plastering) Work delay	Delay time in activities	0.13	5
C 8) Unrealistic scheduling and expectations of labor performance			
C 8.1) Overtime hours	Number of overtime hours allowed	0.37	1
C 8.2) Incomplete targets	Earned value ratio	0.24	2
C 8.3) Base targets in each activity	Percentage of direct work than the base level in detail assessment	0.20	3
C 8.4) Work was done in activity wise at the end of the day	Average Work completion percentage than schedule	0.19	4
C 9) Lack of periodic meeting with labor			
C 9.1) Communication procedure	Number of hierarchies in upward level	0.30	1
C 9.2) Number of site meetings	Number of meetings	0.29	2
C 9.3) Attendance to the meetings (Supervisor/worker)	Attendance percentage for meetings	0.26	3
C 9.4) Language proficiency of staff	Number of proficient languages	0.15	4
C 10) Inspection delay by authorities (Engineer/site manager)			
C 10.1) Inspection delay between work completion and request	Delay time between completion and request	0.51	1
C 10.2) Inspection time plan	Availability	0.49	2
C 11) Relationship between management and workers			
C 11.1) Method to contact the managers to workers	Number of hierarchies upwards	0.37	1
C 11.2) Number of meetings per month	Number of meetings	0.26	2
C 11.3) Access to the mobile/calling	Accessibility by calls	0.19	3
C 11.4) Contact detail of management availability on the site	Availability of details	0.17	4
C 12) Coordination among design disciplines /site management coordination ability			
C 12.1) Progress meetings frequency	Frequency per month	0.32	1

C 12.2) No: of technical meetings	Number of meetings	0.28	2
C 12.3) Hierarchy of the company	Number of subordinates and levels	0.27	3
C 12.4) Delay in RFI	Delay time	0.12	4
C 13) Proportion of work subcontracted and unreliable subcontractors			
C 13.1) Work percentages by sub-contractors	Percentage	0.27	1
C 13.2) Sub-contractor's capacity	Grading	0.22	2
C 13.3) Possible works that can be delivered to the sub-contractors	Value of work, Percentage of work	0.20	3
C 13.4) Trade wise worker force	Number of workers in trade wise by labor records	0.20	3
C 13.5) No: of sub-contractor gangs	Number of gangs	0.11	5
C 14) Stringent inspection by the engineer			
C 14.1) Engineers' involvement	Number of documents need a signature	0.29	1
C 14.2) Meetings with officers and workers	Number of meetings present	0.27	2
C 14.3) No: of site visits	Number of site visits per day	0.25	3
C 14.4) Instruction sessions per week by the engineer	Number of sessions	0.19	4
D) Manpower related factors			
D 1) Skill of labor			
D 1.1) Skill level (Ability to read drawings, skilled tools)	Professional qualifications	0.38	1
D 1.2) Number of skilled labors	Number of skilled labor	0.34	2
D 1.3) Labor composition	Ratio to skilled and unskilled	0.28	3
D 2) Labor experience			
D 2.1) Experience of the labor	Number of years	0.56 9231	1
D 2.2) Project experience/work done records	Number of projects worked	0.43 0769	2
D 3) Motivation of labor			
D 3.1) Labor satisfaction	Level of satisfaction	0.27	1
D 3.2) Earnings per activity	level	0.27	1
D 3.3) Accommodation facilities	Level of accommodation	0.26	3
D 3.4) Site facilities	Number of facilities	0.19	4
D 4) Working overtime (provision of extra money after normal work			
D 4.1) Over time rates	Overtime premium	0.51	1
D 4.2) Overtime hours	Number of hours allowed per day	0.49	2

D 5) Working for long periods without holiday/shift work			
D 5.1) Shutdowns in the site	Frequency	0.29	1
D 5.2) Holiday schedule in the site	Level of schedule	0.28	2
D 5.3) Number of holidays for a labor	Number of holidays	0.24	3
D 5.4) Average working days for a labor	Number of average working days	0.20	4
D 6) Labor personal problems			
D 6.1) Economic background	Number employed in family	0.37	1
D 6.2) No: of family members	Number of members	0.25	2
D 6.3) Family background	Type of family (Extended, Nuclear)	0.24	3
D 6.4) Home town (Distance)	Distance to home	0.14	4
D 7) Workforce absenteeism			
D 7.1) Attendance	Attendance level	0.56	1
D 7.2) Number of holidays	Number of leaves per month	0.44	2
D 8) Walkouts or strikes			
D 8.1) Number of walkouts and strikes	Number of walkouts and strikes	0.41	1
D 8.2) Reassignments	Number of Reassignments	0.34	2
D 8.3) Attendance (For walkouts)	Attendance level	0.26	3
E) Motivational related factors			
E 1) Amount of wages/unfair wages of construction workers			
E 1.1) Rates for labor categories	Rates different to categories	0.43	1
E 1.2) Amount of wages	Amount compared to industry	0.29	2
E 1.3) Working hours per day	Number of hours working	0.29	2
E 2) Accommodation			
E 2.1) Accommodation capacity	Provided capacity	0.52	1
E 2.2) Facilities	Level of facilities provided	0.48	2
E 3) Love and belongingness, labors recognition and respect			
E 3.1) Complains from labors	Number of complains	0.39	1
E 3.2) Labor background detail	Availability and amount of details	0.36	2
E 3.3) Feedback on love and belongingness by labors	Level of feedbacks	0.25	3
E 4) Incentive payments/bonus at the end of project or year			
E 4.1) Salary increments	Salary increment frequency	0.51	1
E 4.2) Bonus amount for the labors	Bonus premium or percentage	0.49	2
E 5) Opportunity to undertake challenging tasks/targets, giving responsibility			

E 5.1) No: of work crew leaders	Number of leaders	0.52	1
E 5.2) Base targets in each activity	Direct work percentage from detail assessment	0.48	2
E 6) Late payment of salaries and wages			
E 6.1) Dates for salary	Salary date announcement	0.36	1
E 6.2) Advances for the salary	Salary advances offered	0.34	2
E 6.3) Number of delaying dates	Number of delay days	0.30	3
E 7) Lack of training sessions, recognition to the job			
E 7.1) Number of training per year	Number of trainings per year	0.60	1
E 7.2) Job description	Availability of job description, assigned tasks, and level of details	0.40	2
E 8) Medical care/health and safety provision			
E 8.1) Medical facilities in the site	Level of a medical facility	0.54	1
E 8.2) Health insurances for the workers	Amount of insurance	0.46	2
E 9) Lack of places eating and relaxation			
E 9.1) Relaxation facilities and capacity	Capacity provided	0.43	1
E 9.2) Number of labors in the site	Space received per labour	0.30	2
E 9.3) Wash room capacity	Adequacy of capacity provided	0.27	3
E 10) Job security (permanent job, job all the time, payment)			
E 10.1) Number of permanent workers	The proportion of permanent workers	0.44	1
E 10.2) Working years requirement for permanent	Number of years required to be permanent	0.35	2
E 10.3) Company policies	Stability of company policies for job security	0.20	3
E 11) Transport facilities for the workers			
E 11.1) Distance to the accommodations	Distance	0.35	1
E 11.2) Transporting vehicles capacity	Capacity provided with transport	0.33	2
E 11.3) Transport allowance	The amount for the allowance	0.32	3
E 12) Competition with colleagues and project team			
E 12.1) Intensive payments for high performance	Amount of incentives	0.55	1
E 12.2) Bill payments	Amount payable	0.45	2

E 13)Social activity opportunities (sports and entertainment)/welfare condition			
E 13.1) Social activities	Number of activities per year	0.38	1
E 13.2) Number of Trips	Number of trips per year	0.32	2
E 13.3) Day outs/ Get together	Number of day outs / Get together per year	0.30	3
F) Technical related factors			
F 1) Technical ability and construction knowledge of engineer and staff			
F 1.1) Professional qualification	Level of qualification	0.34	1
F 1.2) Educational qualifications of the staff	Level of education for uppermost level	0.28	2
F 1.3) Problem solving and issue identifying	Minimized additional costs per month after progress	0.27	3
F 1.4) Reworks and errors quantity	Number of reworks due to errors per week	0.12	4
F 2) Technology employed and new project techniques			
F 2.1) Technical manuals used in the site	Number of manuals, Version of manual	0.53	1
F 2.2) Quality control methods	Level of the quality control procedure	0.47	2
F 3) Construction method used			
F 3.1) Method statements availability	Availability	0.58	1
F 3.2) Changes in construction methods	Number of reworks due to changes	0.42	2
F 4) Incomplete drawings, missing details in drawings			
F 4.1) Design changes	Number of design changes	0.53	1
F 4.2) Number of RFI s per month	Number of RFI per month	0.47	2
F 5) Delay in responding to request for information (RFI)			
F 5.1) Work delay due to delay in RFI	Delay time	0.60	1
F 5.2) Number of dates	Number of dates for response	0.40	2
F 6) Poor site layout and organization			
F 6.1) Material delivery	Time is taken to deliver material with in site at the request	0.31	1
F 6.2) Access to the site	Width of the access road	0.30	2
F 6.3) Location of the concrete plant	Distance to plant	0.23	3

F 6.4) Company policies on material request	Number of documents gone for requesting	0.16	4
F 7) Changes order by client/change order causing additional work/Alterations of schedule			
F 7.1) Amount of additional works	Amount	0.56	1
F 7.2) Number of changes in design and the scale	Number of design changes	0.44	2
F 8) Alteration of design during project execution			
F 8.2) Number of changes in design and the scale	Number of changes	0.58	1
F 8.1) Amount of additional works	Amount or proportion	0.42	2
G) Project Characteristics			
G 1) Quality control/standard and specifications			
G 1.1) QA/QC practices during the construction	Level of practicing of QA/QC	0.29	1
G 1.2) Quality certificates achieved by the company	Number of certificates obtain	0.28	2
G 1.3) Number of quality control officers and staff	Number of staffs assigned	0.27	3
G 1.4) Errors and reworks in construction	Number of reworks after inspection	0.16	4
G 2) Working environment/insufficient lightning			
G 2.1) Lighting condition	Light condition	0.38	1
G 2.2) Working environment	Working space adequacy	0.36	2
G 2.3) Availability of extra resources (Hand lights)	Availability of extra resources	0.26	3
G 3) Project complexity and design complexity/compatibility among documents			
G 3.1) Advanced construction methods	Advance method availability	0.28	1
G 3.2) Scale of the project	Project value	0.26	2
G 3.3) Project value	Project value	0.25	3
G 3.4) Project duration	Project duration	0.21	4
G 4) Site condition, access, subsoil, topography			
G 4.1) Sub soil condition	Sub soil condition	0.36	1
G 4.2) Access	Accessibility	0.33	2
G 4.3) Topography of the site location	Terrain conditions	0.30	3
G 5) Site congestion/overcrowding			

G 5.1) Number of workers	Number of workers	0.37	1
G 5.2) Number of Hoists and lifts	Number of hoists and lifts	0.32	2
G 5.3) Material supply system	Level of Material supply system	0.31	3
G 6) Site layout			
G 6.1) Location of the site	Distance from entrance	0.57	1
G 6.2) Storage, Administration office	Distance to stores and office	0.43	2
H) Other factors			
H 1) Inclement weather/rain			
H 1.1) Raining period	Maximum raining period for the season	0.31	1
H 1.2) Current construction stage of the site	Suitability of weather to current construction stage	0.25	2
H 1.3) Amount of rain	Rainfall level	0.23	3
H 1.4) Type of works in the site	Number of works affected by weather	0.22	4
H 2) On-site accidents, stop work due to accidents			
H 2.1) Number of accidents	Number of accidents per month	0.53	1
H 2.2) Delays in the works due to accidents	Delay time due to accidents	0.47	2
H 3) High temperature			
H 3.1) Facilities provided to sustain against temperature	Level of facilities provided	0.43	1
H 3.2) Temperature value	Temperature	0.31	2
H 3.3) Drinking water availability in the site	Availability of water	0.26	3
H 4) Safety laws and their execution			
H 4.1) Safety standards followed	Level of following safety precautions	0.46	1
H 4.2) Number of accidents per month	Number of accidents	0.28	2
H 4.3) Safety awards achieved	Number of awards achieved	0.26	3
H 5) Inflation/fluctuation of material prices, interest rate/cost of capital			
H 5.1) Inflation	Rate of inflation	0.56	1
H 5.2) Variation in material price	Range of variation	0.44	2
H 6) Claim situation/high wind			
H 6.1) Amount of works in exposed areas	The proportion of exposed work	0.61	1
H 6.2) Wind speed	Speed of wind	0.39	2

5.6 Contribution from Other Disciplinary Towards Worker Productivity- Fish Bone Diagram

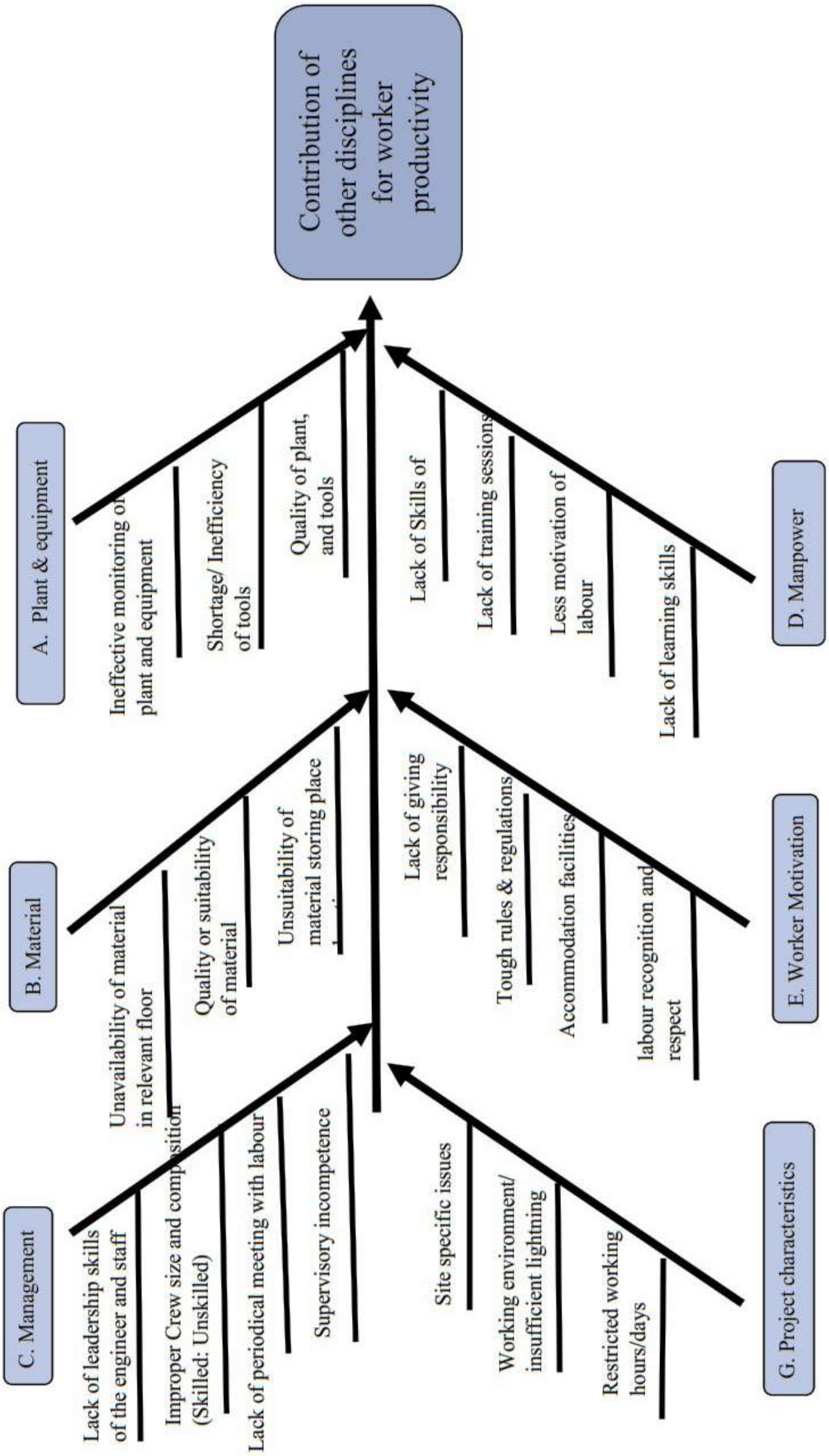


Figure 5.3: Contribution from other disciplinary towards productivity

6. DETAILED ASSESSMENT

6.1 Data Analysis of Activity Analysis

Following colour codes were used to identify different activity categories, and it is carried out throughout the study

Table 6.1: Number of workers observed per hour

Hour	Tiling	Painting	Plaster	Block Work	MEP	Formwork	Reinforceme nt	Total
7:00-8:00	32	20	44	8	2	0	0	106
8:00-9:00	63	61	80	55	12	13	38	322
9:00-10:00	73	59	48	48	45	41	75	389
10:00-11:00	60	21	17	6	26	18	39	187
11:00-12:00	72	77	62	0	42	50	87	390
Lunch								
1:00-2:00	55	36	44	8	28	26	51	248
2:00-3:00	73	53	19	21	62	13	37	278
3:00-4:00	38	21	22	12	19	0	17	129
4:00-5:00	19	18	4	0	16	12	12	81
Total	485	366	340	158	252	173	356	1601

6.1.1 Activity Analysis Calculations

$$\text{Activity Percentage} = \frac{\text{Day 1 Activity total} + \text{Day 2 activity total} + \text{Day 3 activity toatal} + \cdots.}{\text{Total Number of observations}}$$

Total Activity Percentage

Table 6.2: Activity categories and colour code

Category	Colour code		
Direct work		Direct work	

Preparatory work		Preparatory work	
Tools / Equipment			
Material handling			
Waiting		Delay work	
Travel / Walking			
Personal			
Rework			
Out of sight			

Table 6.3: Trade wise Activity Analysis percentages

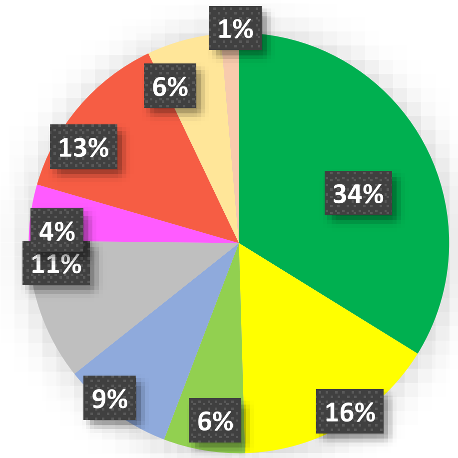
	Tiling	Painting	Plaster	Block Work	MEP	Formwork	Reinforcement
Direct work	34%	52%	37%	46%	49%	29%	52%
Preparatory	16%	15%	14%	13%	17%	21%	7%
Tool & equipment	6%	1%	1%	0%	3%	0%	0%
Material handle	9%	6%	16%	12%	1%	7%	6%
Waiting	11%	5%	13%	8%	9%	37%	24%
Travel/Walking	4%	5%	4%	2%	5%	1%	1%
Personal	13%	15%	12%	18%	13%	1%	5%
Rework	6%	1%	2%	0%	2%	0%	0%
Out of sight	1%	0%	1%	1%	1%	4%	5%

Table 6.4: Activity percentages under main categories

	Tiling	Painting	Plaster	Block Work	MEP	Formwork	Reinforce
Direct work (%)	34	52	37	46	49	29	52
Preparatory (%)	31	22	31	25	21	28	13
Delay work (%)	35	26	32	29	30	43	35

Tiling

Total activity percentages - Tiling



Category	Percentage	Total
Direct work	34%	34%
preparatory work	16%	
Tools/Equipment	6%	
Material handling	9%	31%
Waiting	11%	
Travel/ Walking	4%	
Personal	13%	
Rework	6%	
Out of sight	1%	35%

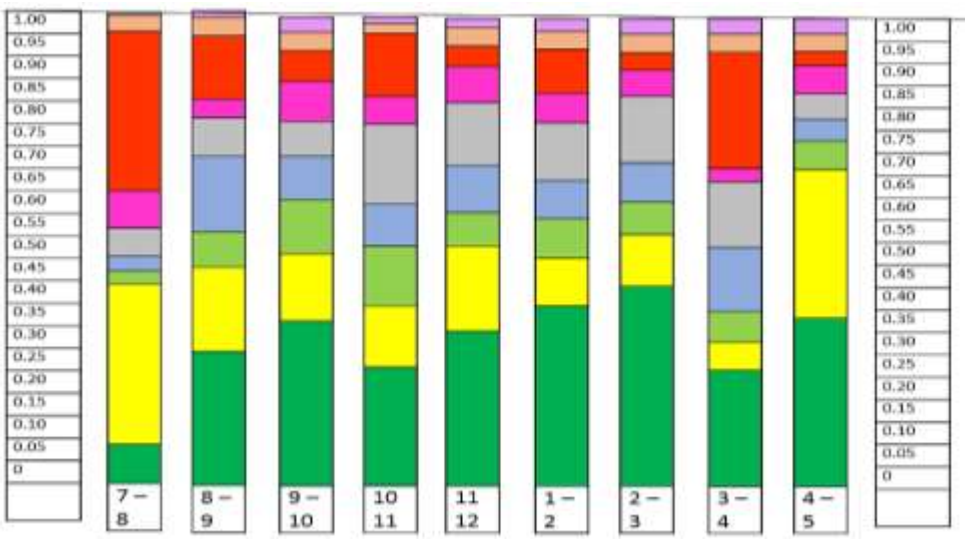


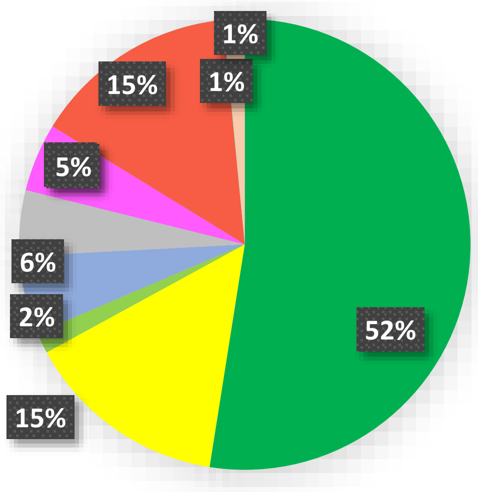
Figure 6.1: Tiling hourly activity percentage

Tiling is a special skilled work. Among the selected trades, it has the lowest direct work percentage.

- Workers tend to get breakfast at the start of the day therefore personal time is high around that time
- Preparatory time is also high at the start of the day. This is due to
    - unavailability of material
    - Waiting for the supervisor
- In the evening 3:00 pm - 4:00 pm the personal time is high due to
    - excessive time in tea breaks
    - Early quits and a late start in the tea.

Painting

Total activity percentages - Painting



Category	Percentage	Total
Direct work	52%	52%
preparatory work	15%	
Tools/Equipment	2%	
Material handling	6%	23%
Waiting	4%	
Travel/ Walking	5%	
Personal	15%	
Rework	1%	
Out of sight	1%	26%

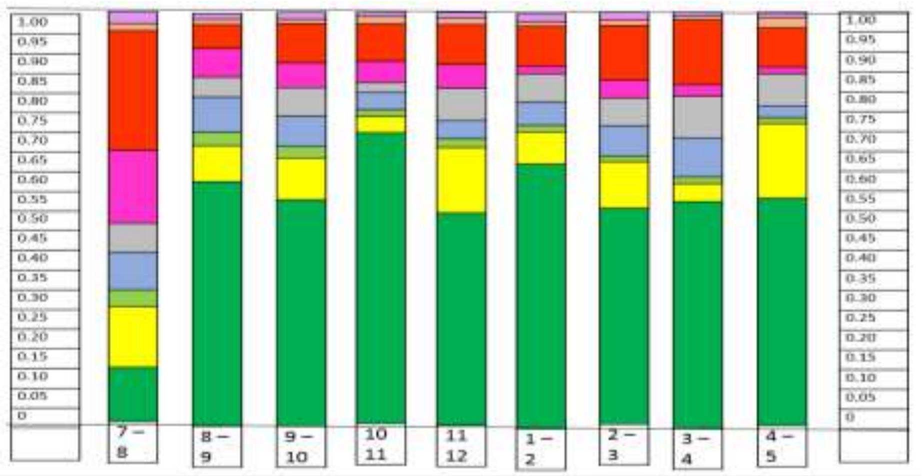
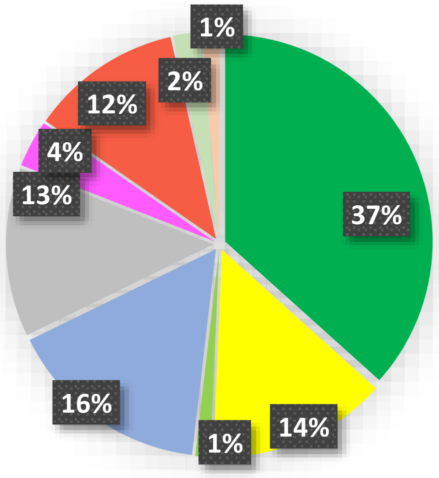


Figure 6.2: Painting hourly activity percentage

1. Direct work percentage is high because almost all the painters are skilled workers. The skilled workers prepare the materials for them and work isolate even when they are in a crew.
2. Delay time is high at the beginning of the day.

Plastering

Total activity percentages - Plastering



Category	Percentage	Total
Direct work	37%	37%
preparatory work	14%	
Tools/Equipment	1%	
Material handling	16%	31%
Waiting	13%	
Travel/ Walking	4%	
Personal	12%	
Rework	2%	
Out of sight	1%	32%

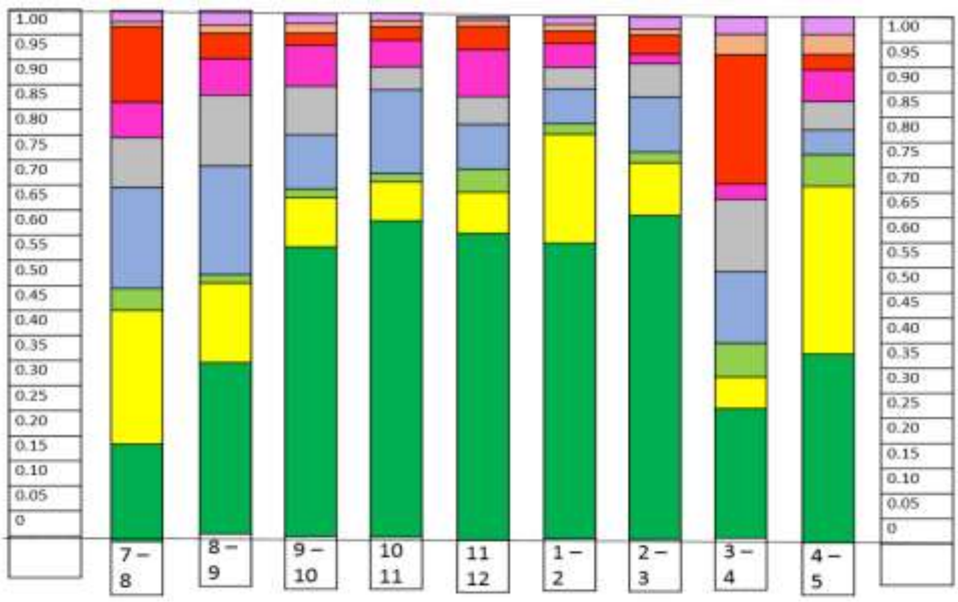
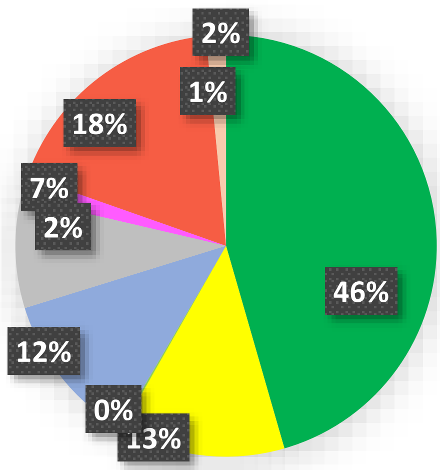


Figure 6.3: Plastering hourly activity percentage

1. In the plastering trade to reduce the excessive material handling time material supply has to improve and provide sufficient scale of material preparing equipment
2. The productive work time is high from 9:00 am to 12:00 noon. Preparatory time is high due to early quits of the works

Block Work

Total activity percentages – Block work



Category	Percentage	Total
Direct work	46%	46%
preparatory work	13%	
Tools/Equipment	0%	
Material handling	12%	25%
Waiting	2%	
Travel/ Walking	7%	
Personal	18%	
Rework	1%	
Out of sight	2%	29%

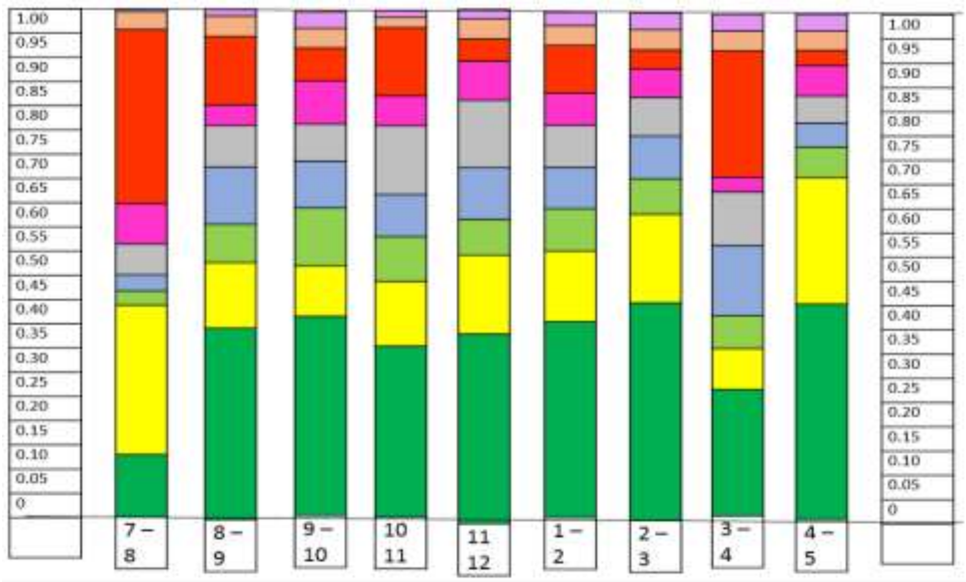
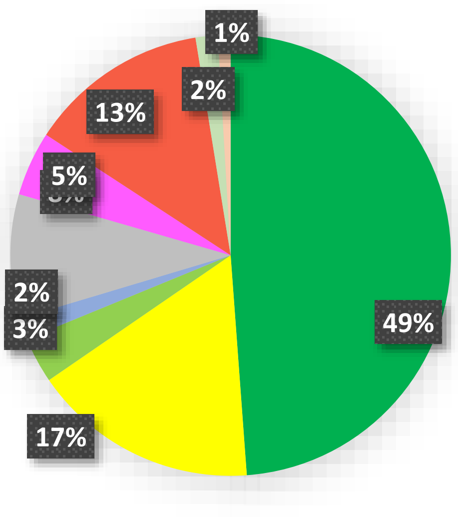


Figure 6.4: Block work hourly activity percentage

1. Workers tend to get breakfast at the start of the day therefore personal time is high around that time
2. Providing a sufficient amount of blocks, cement, and sand to the site is very much important to reduce the non-productive time

MEP Work

Total activity percentages – MEP Work



Category	Percentage	Total
Direct work	49%	49%
preparatory work	17%	
Tools/Equipment	3%	
Material handling	2%	22%
Rework	8%	
Travel/ Walking	5%	
Personal	13%	
	2%	
Out of sight	1%	29%

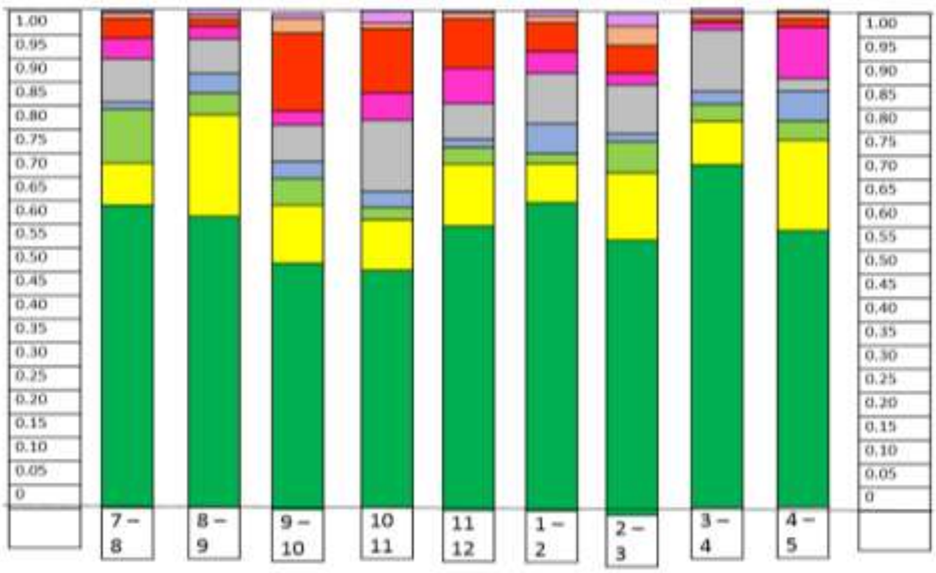
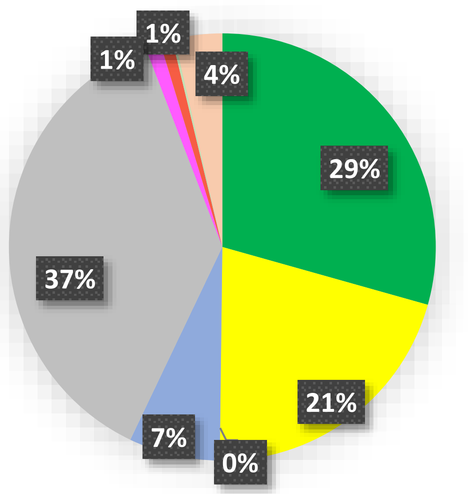


Figure 6.5: MEP hourly activity percentage

1. Direct work percentage is high because the MEP works are sub-contracted to the separate companies, where the supervision is high.
2. The non-productive time is much low at the start of the day when compared to the other trades because the supervisors have arranged the required thing before the start of the works.

Form Work

Total activity percentages – Form work



Category	Percentage	Total
Direct work	29%	29%
preparatory work	21%	
Tools/Equipment	0%	
Material handling	7%	28%
Waiting	37%	
Travel/ Walking	1%	
Personal	1%	
Rework	4%	
Out of sight	0%	43%

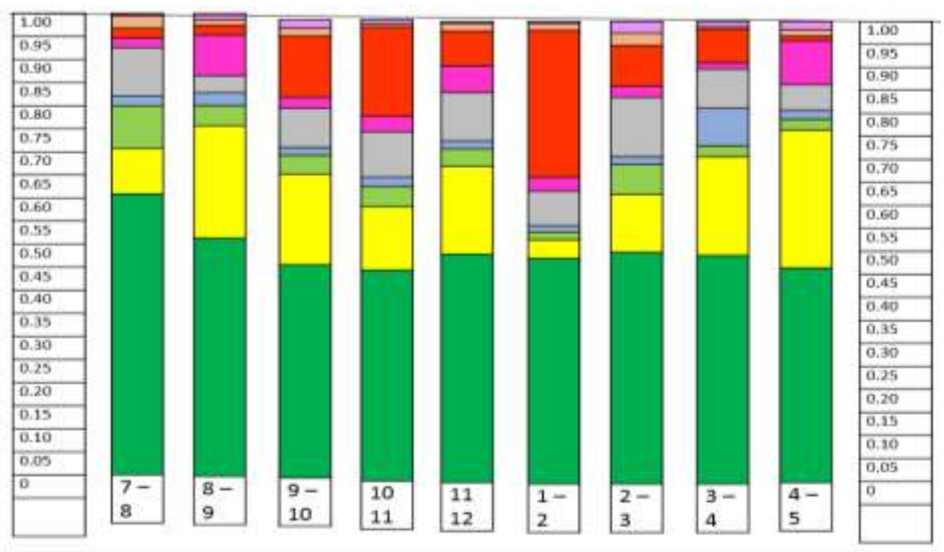
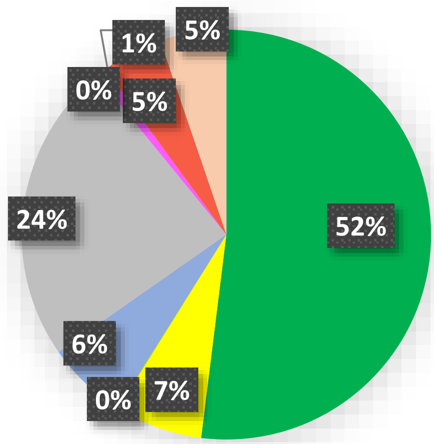


Figure 6.6: Form work hourly activity percentage

1. At the start of the day, direct work percentage is high. Because formwork is a continuous work for floor to floor hence no much preparation from day to day other than preparation start of the work.
2. After lunch workers get excessive time for relaxation, this may be because they work in the hot weather conditions during that time making it difficult to work.
3. Overall direct work percentage is high with compared to the other trades

Reinforcement

Total activity percentages – Reinforcement



Category	Percentage	Total
Direct work	52%	52%
preparatory work	7%	
Tools/Equipment	0%	
Material handling	6%	13%
Waiting	24%	
Travel/ Walking	0%	
Personal	5%	
Rework	5%	
Out of sight	1%	35%

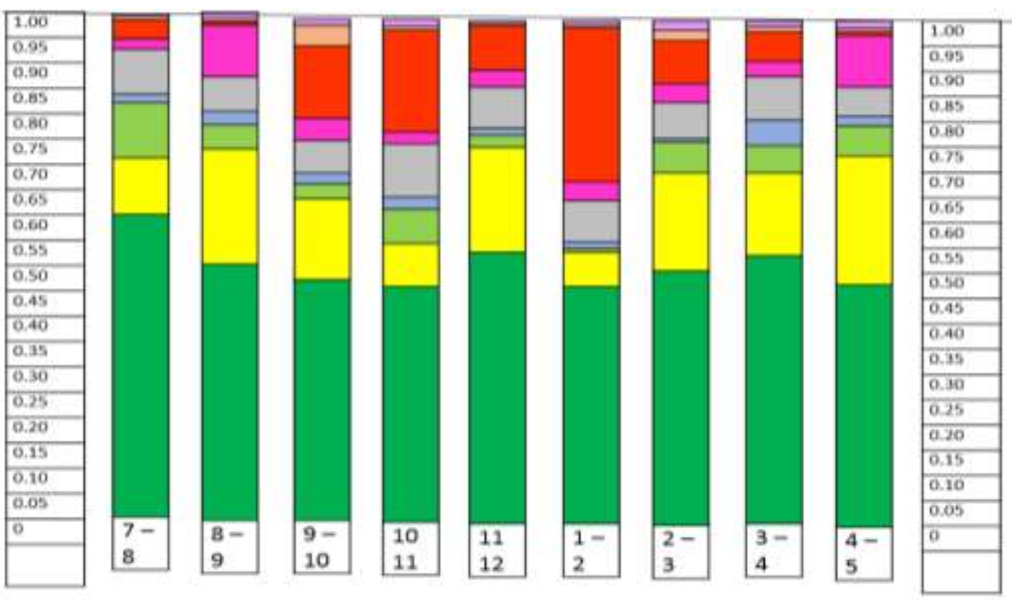


Figure 6.7: Reinforcement hourly activity percentage

At the start of the day, direct work percentage is high. Because formwork is a continuous work for a floor to floor hence no much preparation from day to day other than preparation start of the work. This may be because they work in the hot weather conditions during that time making it is a bit difficult to work.

Average Non-Productive Time in Each Trade

Table 6.5: Average non-productive time in each trade

Trade	Delay Work Percentage	Daily Average Non-productive Time
Tiling	35%	8 * 0.35 = 2.88 hours
Painting	26%	8 * 0.26 = 2.08 hours
Plaster	32%	8 * 0.32 = 2.56 hours
Block Work	29%	8 * 0.29 = 2.32 hours
MEP Works	29%	8 * 0.29 = 2.32 hours

*Assumed average working hours is 8 hours for a labourer excluding lunch time and tea times.

Best Worker Crew Combinations

Crew combination is defined as ration between skilled workers and unskilled workers within the crew. Based on the collected data following crew combination results were found. It cannot express that two skilled to one unskilled combination is optimum for all other site conditions, but the results imply it is suitable for this project structure.

Crew combination is very important to optimize the productive time. The crew has to cover the daily wage and need to optimize the profit. The finding can be used to avoid excessive or fewer people within the crew.

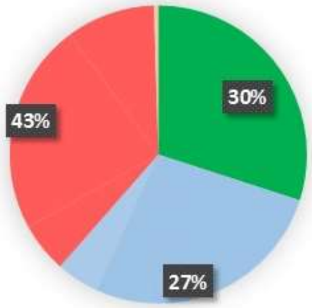
In tiling, plastering and block work trade it was found out, two skilled to one unskilled crew combination optimize the direct work percentage of the worker crews. Generally sub-contractor crew does not include unskilled workers due to less amount of preparatory works.

Table 6.6: Tiling worker crew combination

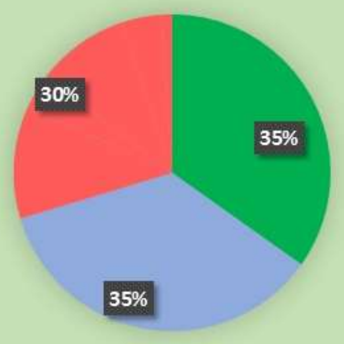
Tiling

Category	All	1	2	3	4
Direct	34%	30%	36%	35%	31%
Preparatory	31%	27%	25%	35%	24%
Delay	35%	43%	39%	30%	45%

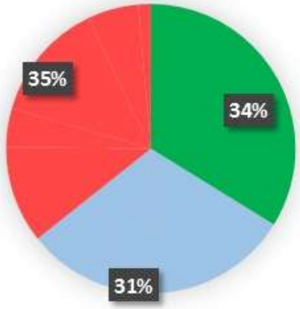
1 member (Skilled)



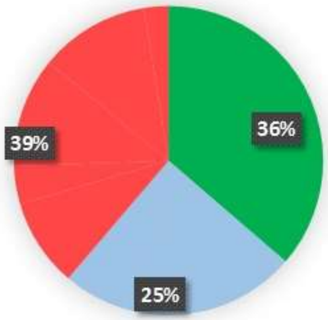
3 members (2 Skilled & 1 Unskilled)



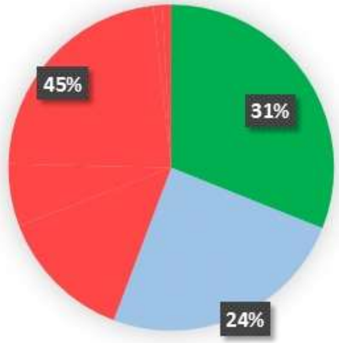
Overall



2 members (1 Skilled & 1 Unskilled)



4 members (2 Skilled & 2 Unskilled)



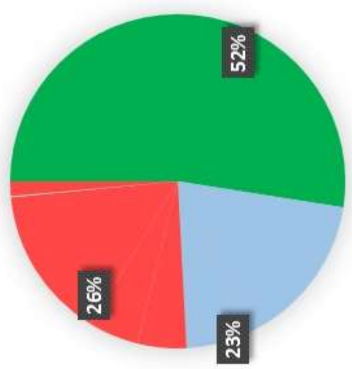
19

Table 6.7: Painting worker crew combination

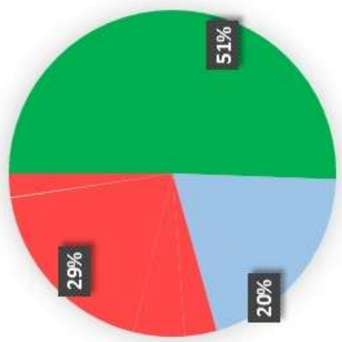
Painting

Category	All	1&2	3&4
Direct	52%	51%	54%
Preparatory	23%	20%	22%
Delay	26%	29%	24%

Overall



1 & 2 members (Skilled)



3 & 4 members (Skilled)

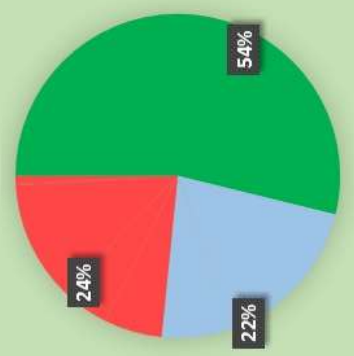
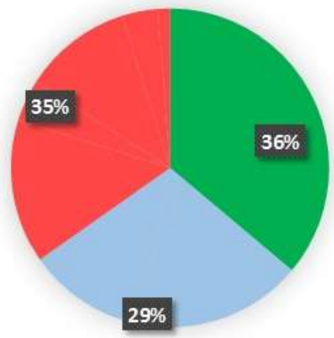


Table 6.8: Plastering worker crew combination

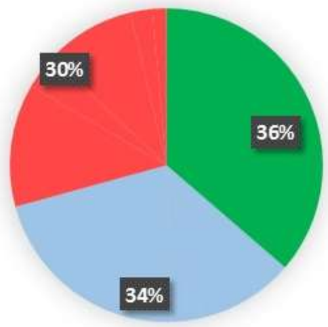
Plastering

Category	All	2	3	4	5
Direct	37%	36%	43%	36%	34%
Preparatory	31%	29%	26%	34%	35%
Delay	32%	35%	31%	30%	31%

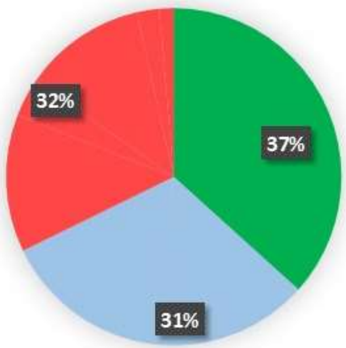
2 members (1 Skilled & 1 Unskilled)



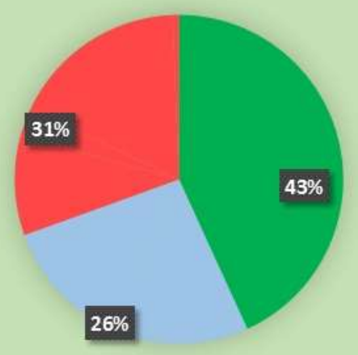
4 members (2 Skilled & 1 Unskilled)



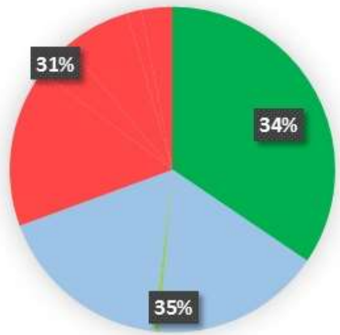
Overall



3 members (2 Skilled & 1 Unskilled)



5 & more (2 Skilled & 2 Unskilled)



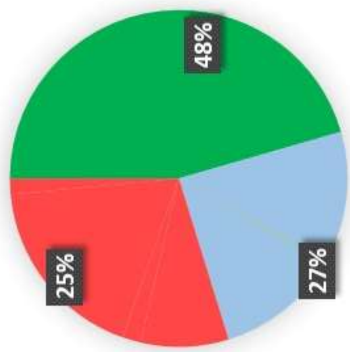
21

Table 6.9: Block Work worker crew combination

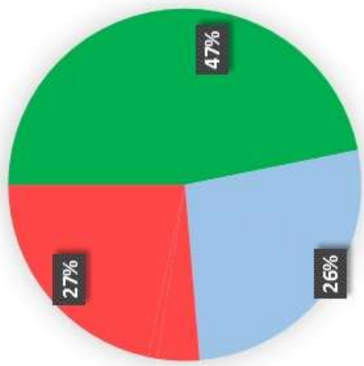
Block Work

Category	All	2	More than 2
Direct	48%	47%	48%
Preparatory	27%	26%	29%
Delay	25%	27%	23%

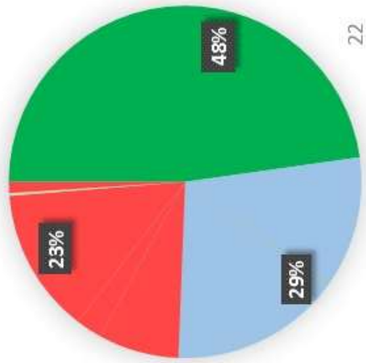
Overall



1& 2 members Skilled &Unskilled



More than 2 members (Skilled & Unskilled)



6.1.2 Root Causes and Improvement Areas

These are identified reasons for excessive work percentages in each category in the general scenario. The reasons were identified, and the responsible party for each root cause was identified in trade wise.

Preparatory work has a connection to the productive works. Nevertheless excessive preparatory works should be avoided. Higher direct work percentage drives a high amount of work done at the end of the day.

Activity analysis results can guide the low performing worker gangs to improve the performance. The bill payments will depend on the direct work percentage. Improve the direct work percentage. Reduce delay work percentage

These are some identified reasons for excessive work percentages in each category in the general scenario. The reasons were identified, and the responsible party for each root cause was identified in trade wise.

Following table 6.10 and table 6.11 show the responsible party for each excessive reason in trade wise. According to the results, it could be easily understood that a big part of responsibilities accounts to the workers and crew. Management and staff have a responsibility for the preparation time, Material Handling.

Identify the Responsible Party for Root Causes

Following tables show the responsible party for each excessive reason in trade wise. According to the results, it can easily understand a big part of responsibilities accounts to the workers and crew. Management and staff have a responsibility for the preparation time, Material Handling.

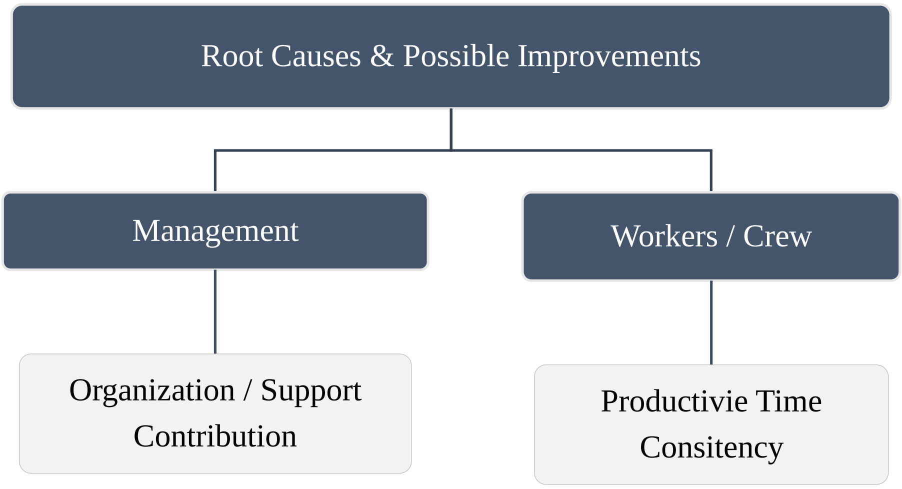


Figure 6.8: Responsibility breakdown

Root Causes and Reasons

Table 6.10: Identified root causes and responsibility breakdown of management party

Management / Staff
Excessive preparatory work • Lack of information (Drawings, dimension markings, Issues in setting out, to place height gauges) • Quality of completed works in stages (cleaning, defects Lack of cleanliness in bedding surface • Storing material in improper places (Covers the working places, have to remove due to disturbance) • Lack of instructions/information • Insufficient amount of material on the working floor • Lack of cleanliness in the working area • Previous work stop situation • Quality of completed works in stages (cleaning, defects) • Difficulty in reaching instructions
Tools and Equipment • Bad practices in tool usage (Not using relevant personal protective equipment – goggles, gloves) • Lack of organization in tool handling • Low quality/ capacity of the equipment

Material Handling • Insufficient amount of material on work place (on the floor level) • Low capacity of material preparing places
Waiting • Waiting for the tools • Unavailability of materials in the working floors • Wait for the supervisor to get instructions(morning, working time) • Insufficient tools in the site
Personal Time • Lack of supervision • Bad work practices (Due to the dust – improper protection to the dust)
Rework • Previous stage incomplete works – During the work finishing MEP works are damaged • Damages to the completed works from other activities

Table 6.11: Identified root causes and responsibility breakdown of workers

Workers / Crew
Excessive preparatory work • Lack of cleanliness in bedding surface • Storing material in improper places (Covers the working places, have to remove due to disturbance) • Cleaning the tools and material preparing equipment and places (Mixer and buckets) • Arranging the scaffoldings • Cleaning the material preparing buckets and tools (Scraper, Mixer) • Lack of work organizing skills of crew leader • Lack of Cleanliness in the working place (Removing the mortar)
Tools and Equipment • Lack of skills in tool usage (Cutting curves, tile cutting Grinder, Drill, Glue gun) • Use the tools frequently (not doing the things at once – lack of organization • Bad practices in tool usage (Not using relevant personal protective equipment – goggles, gloves) • Lack of organization in tool handling • Low quality/ capacity of the equipment

• Poor performance/skill by the worker when using equipment
Material Handling • Lack of organization in material preparation • Storing material in improper places • Insufficient amount of material on work place • Low capacity of material preparing places and equipment
Waiting • Worker crew combination (Skilled / Unskilled)- Most of the time unskilled workers are waiting • Lack of coordination between crew members • Wait for the supervisor to get instructions (morning, working time) • Lack of skills of unskilled workers (Unskilled labour have to get relevant skills to reduce waiting time) • Able to use the tile cutter • Mark the dimensions correctly • Able to use the grinder and cut curves on tiles • Able to place the mortar in the wall • Fill the mortar for the hollows in another side of the wall • Lack of organization between works (Place the mortar, Finish the surface after drying, does not come to the working place at once) • Unavailability of materials in the working floors
Traveling /Walking • Travel for the breaks before the allowed time • Personal walks (Walking here and there) • Communication issues (Get the bill payments, Mark the work is done records) • To meet supervisor, QS division, stores, Canteen, Labour camp • Improper material/tool in the site • Improper site layout • Communication issues
Personal Time • Smart phone usage and unnecessary personal chats • After breakfast, they are relaxing • While sanding the applied paint laborers tend to relax frequently (Due to the dust – improper protection to the dust) • Drug addiction of the workers (Labors use some drugs during working hours) • Unnecessary chats (Personal) with crew members

• Smoking • Workers' attitudes/culture • Extra time in tea and lunch breaks • Lack of supervision • Lack of instructions • Workers' attitudes / culture
Rework • Due to lack of skill in tiling tillers get two to three times to place one tile into the required level • Not achieve the required quality • Horizontal and vertical alignment of the wall • 90* degree in the edges and corners

Preparatory work has a connection to the productive works. But excessive preparatory works should be avoided. Higher direct work percentage drives a high amount of work done at the end of the day. Activity analysis results can guide the low performing worker gangs to improve the performance. The bill payments will depend on the direct work percentage. Improve the direct work percentage. Reduce delay work percentage. When the direct work percentage is low, it gets much time to complete a job that causes a delay in project completion.

Activity analysis results can guide the low performing worker gangs to improve the performance. We can compare the wise gang performance with ideal situations as an example If the gang A complaining the profit margin is low, can prove the reason for that – Low direct work percentage

Tiling Gang A
Direct work – 50%
Waiting – 15%
Personal – 20%

Tiling Gang B
Direct work – 70%
Waiting - 8%
Personal – 10%

Reason for the low profit –
Low direct work percentage

Fish Bone Diagram for Excessive Non-Productive Time

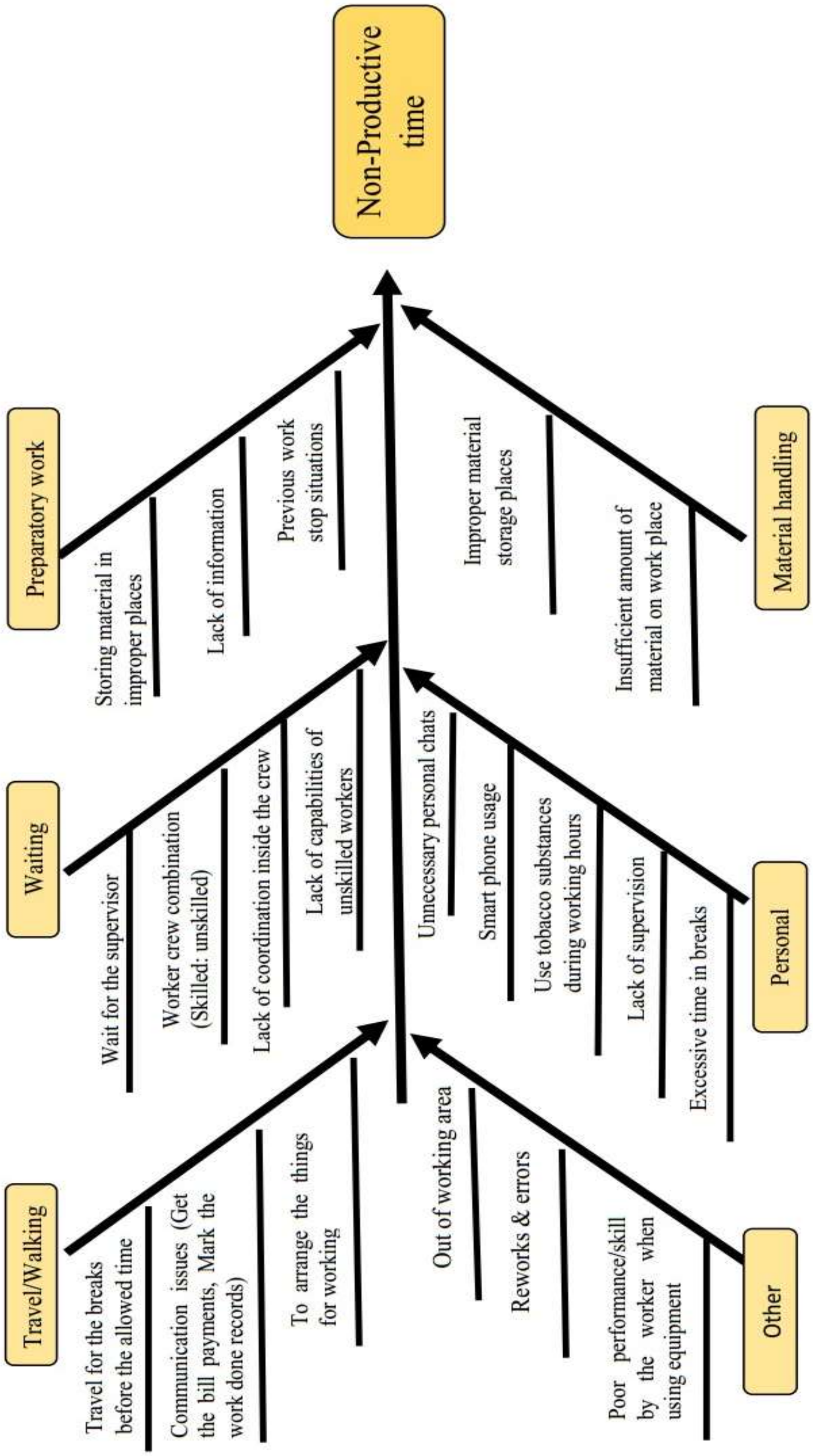


Figure 6.9: Root causes for excessive non-productive time

6.2 Sub-Contractor Assessment Framework

Developed sub-contractor assessment is mainly a factor based assessment. It is reinforced with onsite data to cross check the performance and assessment value. Activity analysis results, crew wise errors and rework amount, attendance records and other available management records in different divisions in the site are connected to the sub-contractor assessment process in the productivity improvement tool.

Sub-contractor evaluation framework

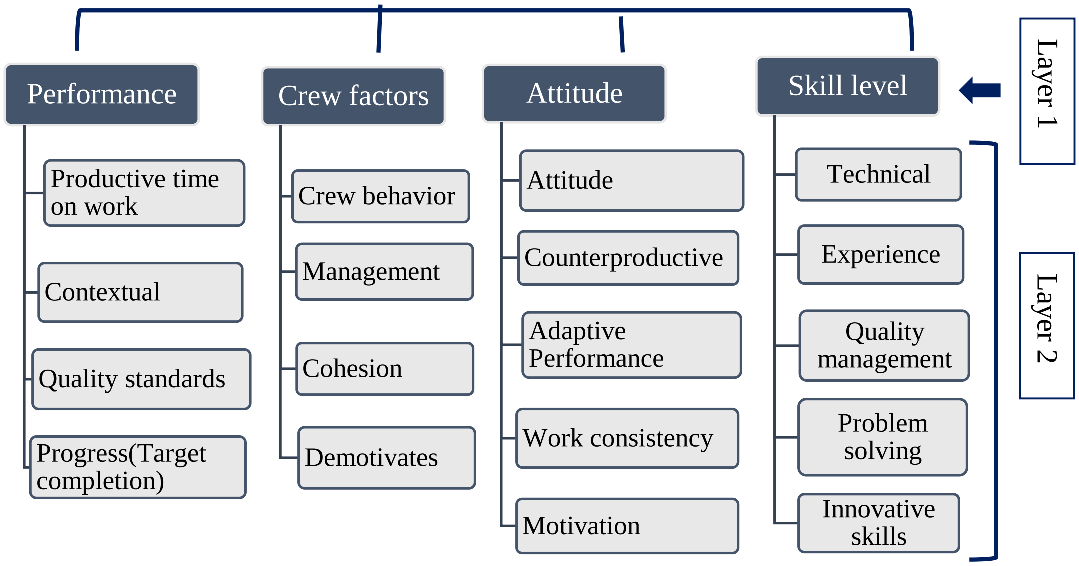


Figure 6.10: Developed sub-contractor assessment framework

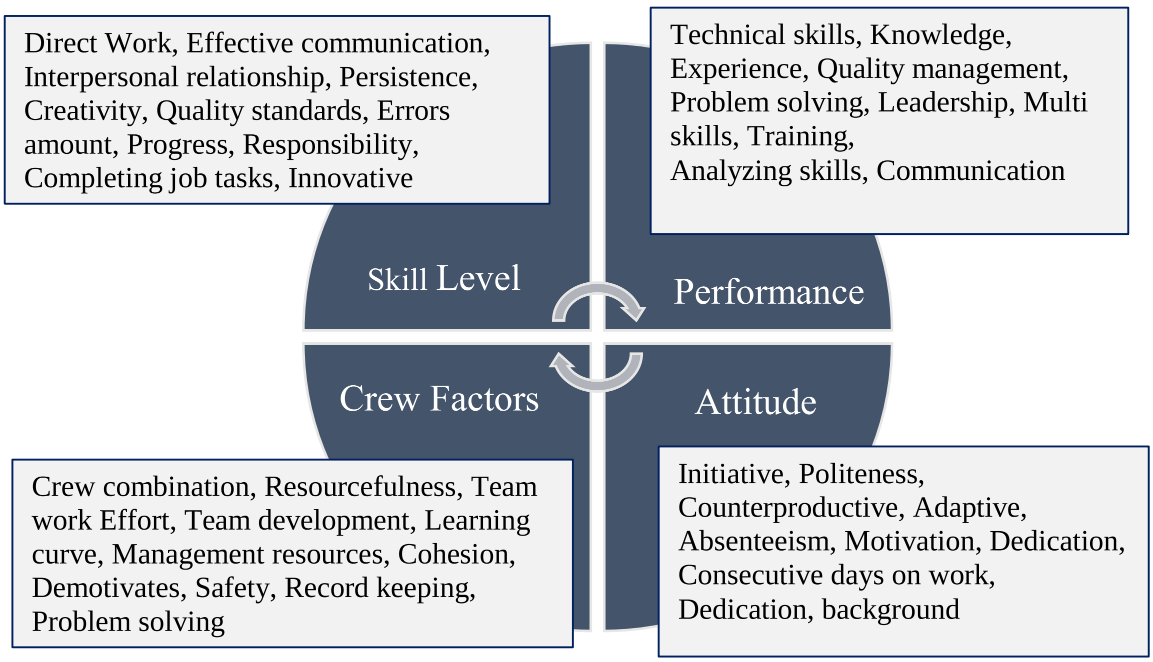


Figure 6.11: Comprehensive view of selected factors

Suggested sub-contractor assessment mainly divided into four areas performance, skill level, crew factors, and attitude. It further elaborates in the table 6.12.Performance which includes crew productive time, work quality, work amount and progress are key suitable indicators in sub-contractor performance evaluation framework which is connected to the detailed assessment. Crew factors, attitude, skill level are the main areas in the framework. Under each main areas other suitable evaluation criteria are listed down as in the table 6.12.

Table 6.12: Selected factors form literature

Performance		
Time distribution	Direct work, Preparatory work, Delay work	[15], [73], [43], [74], [75], [76]
Contextual	Communication • Effectiveness • Interpersonal relation • Communication style Persistence / Dedication	[71], [72], [76], [82], [83], [84], [85], [86], [87]
Quality standards	Completing job tasks (All the works), Working accurately and neatly Errors amount - Check according to the reworks records	[71], [15], [47], [88]
Progress	Target completion records Taking responsibility	[71], [77], [80], [88], [89], [90], [91], ,[92], [93]
Crew Factors		
Crew combination –(Sk: Usk)	Ability to provide extra people and machines, Teamwork and contribution, Age of team members, Leading peoples in the crew, Leadership,	[71], [79], [77], [48], [94], [95], [96], [97]
Team development skill	Communication within the group, Plan the workers time distribution, Team spirit / Teamwork / Communication style, Team learning curve	[71], [77], [78], [48], [91], [70], [93], [85], [98] [99]
Management Knowledge/ Resources management	Material and tools usage, Pay wages to the worker on time, Co-operation with management Obey the safety rules / Concern on safety	[71], [78], [77], [47], [91], [92], [93],
Cohesion	Attraction to the group - Task Attraction to the group - Task	[47], [81], [103]

Demotivates	Receptiveness in team Personal problems	[100]
Attitude		
Attitude	Initiative / Enthusiasm for the work in a crew, Attention to the work / Direct work, Concern in task delay and provide support, Number of consecutive days before bill and advance, Trust	[71], [77], [47], [85], [95], [102]
Counter productive	Off-task behavior, Tardiness / Dislike Gossiping, Fighting and arguing with crew	[71], [80]
Adaptive performance	Being flexible to other crews and company Understanding the project and its goal	[71], [80], [95], [102]
Attendance	Too many or longer breaks, Attendance and unauthorized holidays, Accommodation place / House	[71], [47], [80]
Motivation	Motivation, Consecutive days on work / Dedication, The effort to performance and outcome	[71], [77]
Skill Level		
Technical	Job skill, Job knowledge, Improving knowledge Multi-skill, Job skill	[71], [47], [77], [87], [101]
Experience	Experience /number of years Correct construction practices	[78], [104], [47], [79], [101]
Quality management	Work quality, accuracy, Knowledge and practicing of quality management, Audit of QMS by crew leaders	[71], [78], [79], [76]
Problem-solving	Face to the problems and overcome, Understand the problem of acting and communicating appropriately, Correct decision making	[71], [78], [47], [87], [91], [92], [102]
Innovative skills	Innovative methods to improve the process and productivity, Adjusting plans to situation	[71], [82], [87]

6.2.1 Sub-Contractor Performance Issues - Fish Bone Diagram

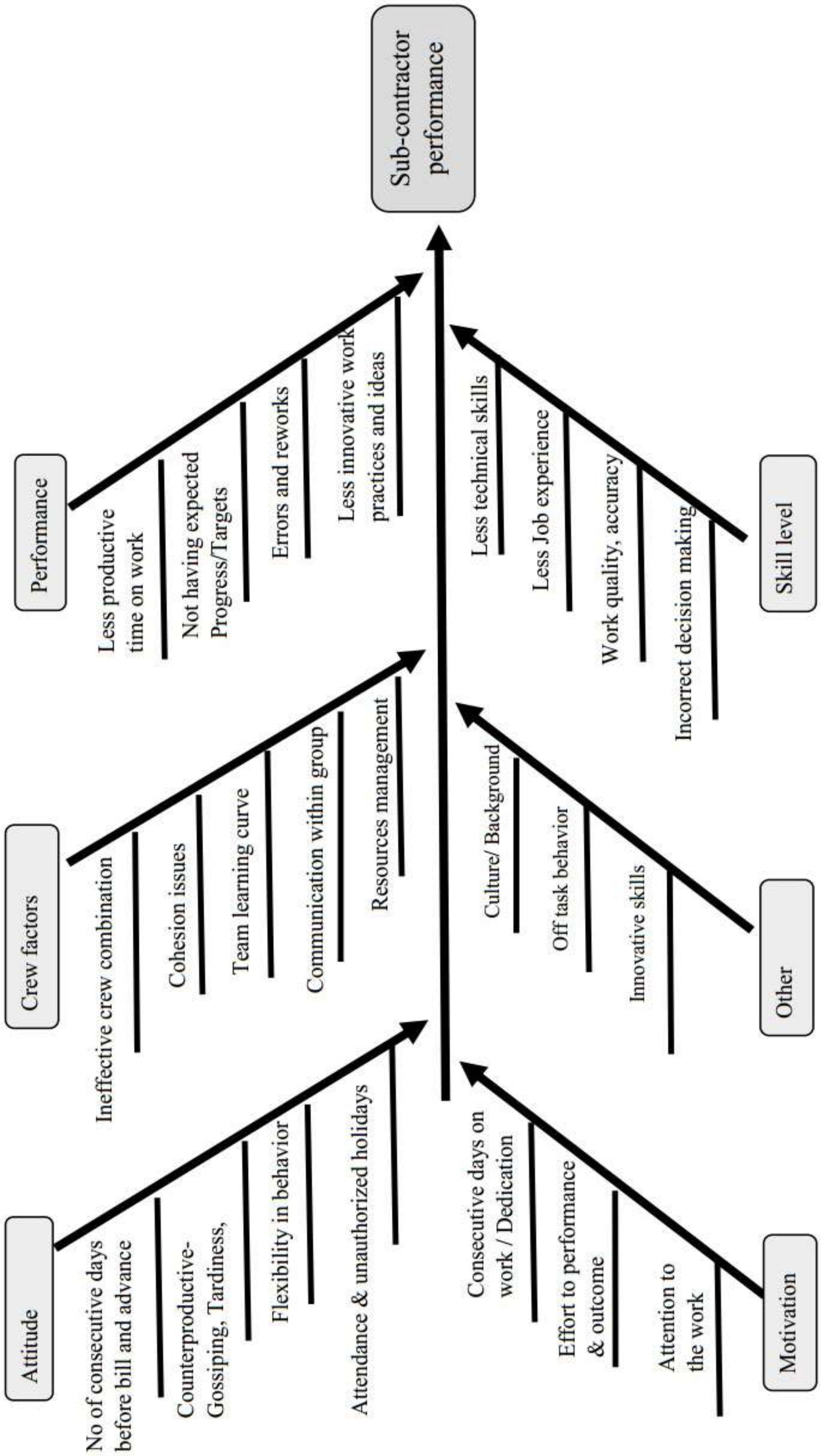


Figure 6.12: Sub-contractor performance issues

6.3 Errors and Reworks Reduction Framework Data Collection

Analyzing the nature, frequent areas, and trends was identified as a key to minimize the repetitive errors. In a large construction site mainly high rise building construction projects most of the towers are having typical floors. In the framework which is a major part in detailed assessment, possible errors and reworks were identified under three main stages structural, masonry and finishing.

Table 6.13: Identified construction stages

Structural stage	Reinforcement
	Formwork
	Concreting
Masonry stage	Block work
	Plastering
Finishing stage	Painting
	Tiling / Rendering
	MEP works

Based on the layout of the data collected site frequent areas of errors were identified. Then staff members were informed about the frequent and critical errors as well and the possible places. It was contributed and helped to minimize the error amount in the project.

Table 6.14: Identified errors in structural stage

Error	Frequent areas and places
Missing / Incorrect positioning of starters	Bathroom Krebs, Stiffness column
Missing groves	Kitchen, Bedroom electrical
Horizontal and vertical alignment of columns/Shear walls	Living area
Missing service ducts (Electrical, Mechanical) / Required sizes	Balcony ducts, Bathroom ducts
Tie plate removing	Living area

Balance in Formwork (Pin walls /Stiffness columns)	Lift wall, Bathroom cupboard
Unraveling of concrete	Balcony, Balcony shade, Living area
Honeycombs of walls and columns / Expose of rebar	Staircase, Stiffness column
Concrete in unnecessary areas	Balcony, BD wall
Sealing cushions on concrete – excessively	Duct openings, Stiffness column
Incorrect SFL of slabs, Beams	Balcony

Table 6.15: Identified errors in finishing stage

		Error	Frequent areas
Finishing stage	Tiling	Hollowness	Bathroom, Kitchen, Living area
		Horizontal and vertical leveling in wall tiling	Bathroom, Kitchen
		Openings and cuts in correct positions	Kitchen, Bathroom
		Straight lines in between tile joints	Bathroom walls, Kitchen
		Damages to the tile edges	Living area floor, Kitchen
		The level difference in lines and joints	Living area, Kitchen floor
	Painting	90* degree in corners and edges	Wall joints, Bends
		Completeness in sunk box edges and ceiling lines	Living area, Bedroom
		Horizontal and vertical smoothness	Living area

Table 6.16: Identified errors in finishing stage

		Error	Frequent areas
Finishing stage	MEP work	Dimensions and correct positioning	Door window, Pantry
		Missing Electrical points (Sun boxes)	Bedrooms, Living area
		Engineering doors fitting	Main door, Bedrooms
		Skirting line horizontality	Living room, Bedroom
		Handrails finishing and protecting	Balcony
		Bathroom fittings spacing, positioning	Bathroom
		Door window placing and alignment	Living area walls, Wall edges, bends

6.3.1 Criticality and Frequency of Masonry Stage Errors

Identified Error Amount in Masonry Stage are highlighted in the table 6.17 highlights the frequent and critical errors in masonry stage. The average error amount per unit is shown as the frequency. Based on the suitability to calculation it was used the units such as square feet, length feet and no of times.

Table 6.17: Frequent and critical errors in masonry stage

Masonry Stage				
	Error	Criticality	Frequency	Frequent places
M1	90* edges and corners		90.85 L Feet	Wall joints and bends
				Door window frame edges
				Fin wall edges
M2	Horizontality and Verticality		172.8 ft2	Soffit in living room
				Wall surfaces
				Around the sunk box plaster
				bedrooms

M3	Hollowness and cracks		6.15ft2	Wall plaster Frequently in beam edges Top of door window reveals
M4	Dimensions		9.3 times	Door window openings Distribution board wall Bathroom door
M5	Skirting line		33.05 L Feet	Living area Bedroom
M6	Alignment/Positioning		0.6 times	Distribution board wall panel board Bedroom window frame
M7	Thickness		Two times	Cupboard wall Door frame
M8	Reveil finishing		10.05 L Feet	Top reveal indoors
M9	Plaster completeness		22.5 ft2	Beam plaster in the bedroom Sunk box edges

6.3.2 Error Mapping

Here the aim is to link the errors to the next construction stage to identify the criticality of that error. This mentioned and developed process is need to slightly modify when apply to another project. Figure 6.13 shows how the impact of the each error in to other construction activities.

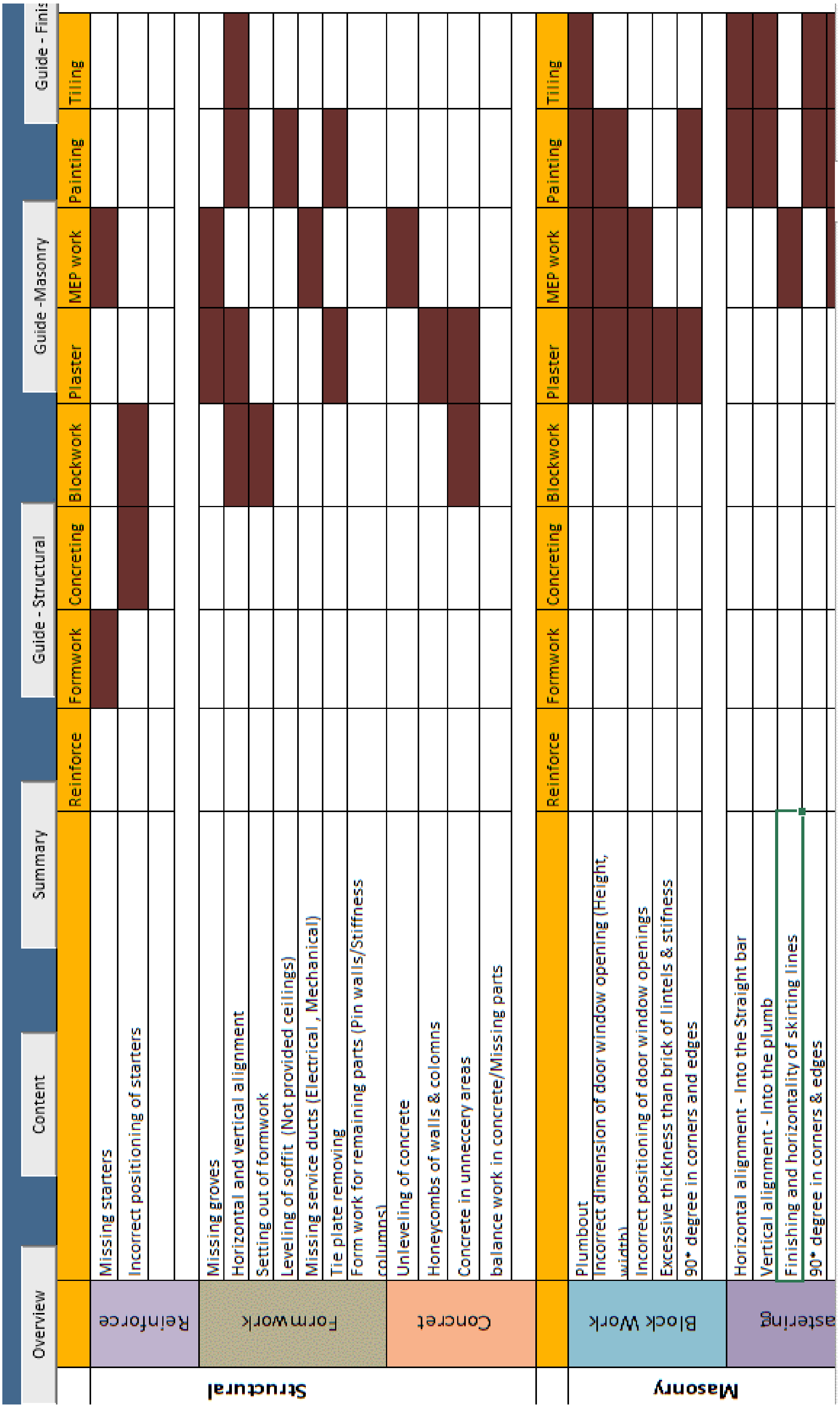


Figure 6.13: Error mapping

7. OVERALL PRODUCTIVITY IMPROVEMENT TOOL

7.1 First Version of the Tool

Overall productivity assessment which was developed under two main section initial assessment and detailed assessment can be used separately and as well as a interconnected framework. Although frameworks are facilitated to use be used with paper works, the developed frameworks are incorporated into a template which can easily be plugged into a web tool. A digital form of the developed tools are capable of delivering many valuable information within less time. The main objective to integrate the tool into a tool is accessibility to large crowd and comfort in use.

An initial version of the web-tool ("Enhancer"- enhancer.lk) was developed. The "Enhancer" tool can analyse the performance using a set of developer productivity tools. Furthermore, developed tool can suggest best practices according to the inserted data and information. It can work as a helping hand for productivity improvement.

The structure of the productivity improvement tool is discussed in this chapter. First the user who are from different administration levels, can log into the tool. Figure 7.1 is the front page of the tool and figure 7.2 is the login page.

7.1.1 Login Page of the Enhancer Tool

Figure 7.1: Tool front page

7.1.2 Authorization Levels in the Login

Figure 7.2: Login page of the tool

7.1.3 Overall Productivity Assessment

When the user comes to the productivity assessment page he can select the sections that need to be assessed or rewiewed. User has the direct access into initial assessment or detailed assessment in the home page.

Figure 7.3: Home page of the tool

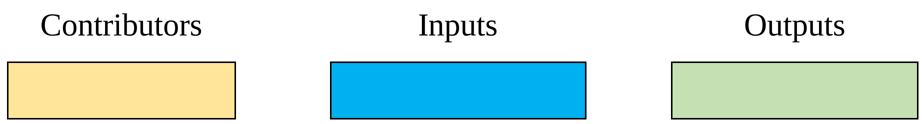
7.1.4 Use Case Structure of the Tool

Different kind of data sets are expected to be collected and need to insert in to the tool. The frequency of collecting data sets are,

- One time for a site
- Daily basis
- Extracted from the existing data sheets through a simple interface

Overall productivity improvement tool, there are many contributors who provide relevant data and information for the overall assessment. Developed productivity improvement tool can deliver valuable output information to make recommendations and decisions to improve the productivity. Figure 7.5 is structured the inputs and outputs of the tool.

Following color code is used to indicate contributors, inputs and outputs



In the developed tool, analyzed information are shared with different management levels based on the pre-defined authentication. Some level get only notifications while other authorized levels get detailed information. Responsible management parties can take suitable decisions and actions based on the information produced by the tool.

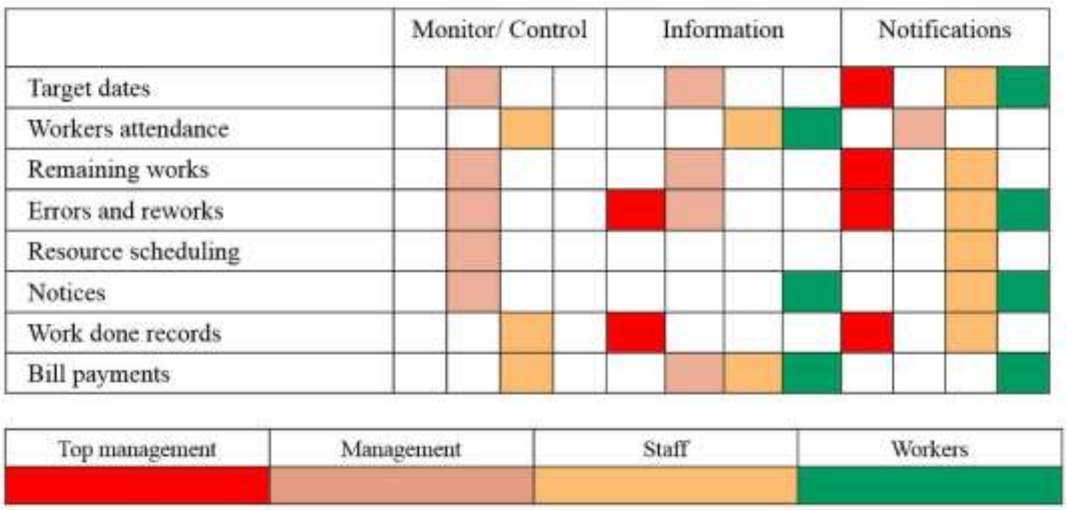


Figure 7.4: Proposed communication concept structure

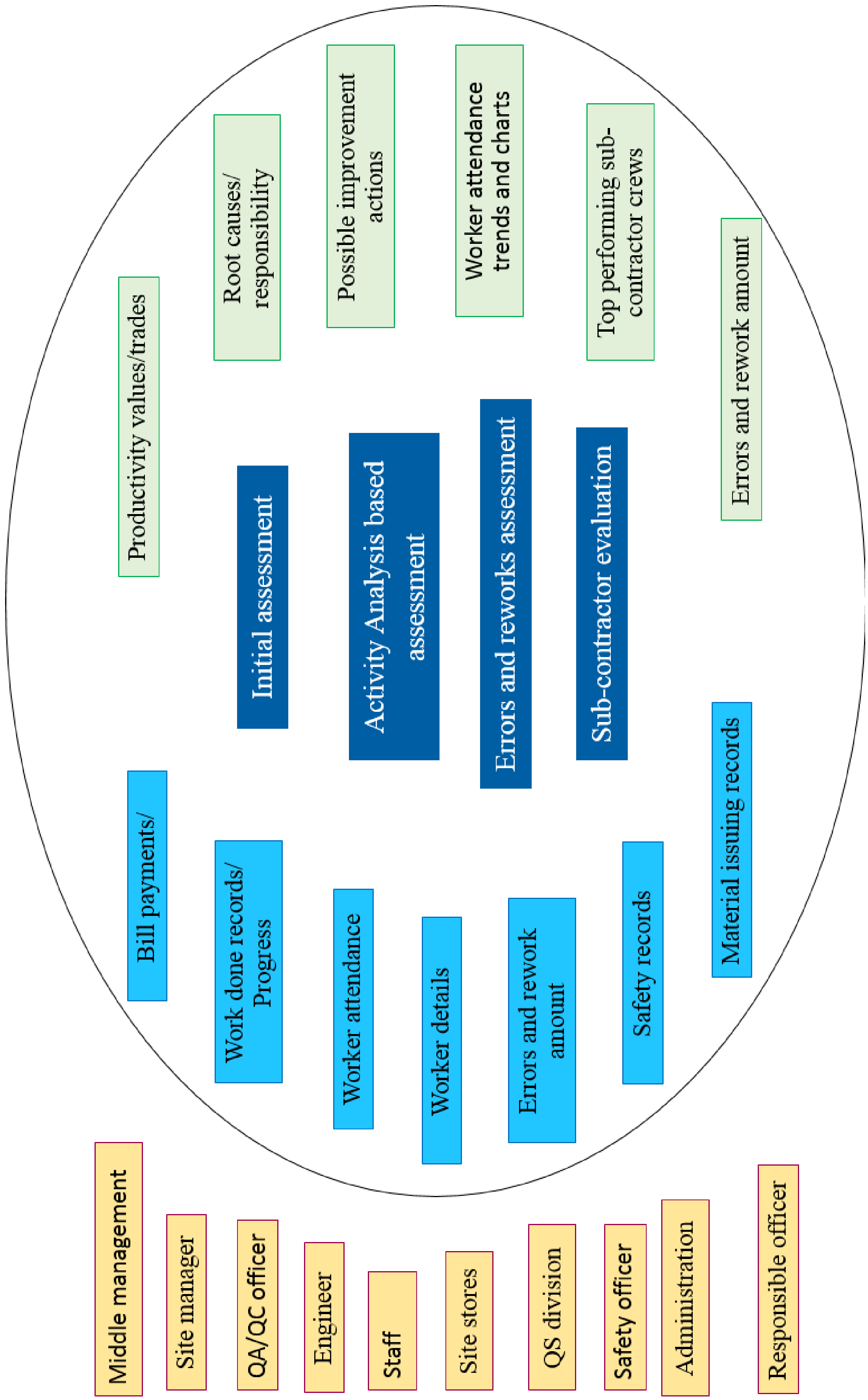


Figure 7.5: Use case structure of the tool

7.2 Initial Assessment Process of the Tool

Initial assessment is a questionnaire based assessment, which take less time for the complete assessment. Initial assessment is capable of,

- Identify the issues and external factors that reduce workers' productivity
- Ensure the support from management for workers' performance
- Identify possible improvements within the site

Since initial assessment is a questionnaire, through a simple interface, relevant data will be extracted to compare and validate the answers given in initial assessment questionnaire. E.g. Attendance in and out, Bill payments, Work progress – Work quality, daily and monthly progress, Errors and rework amount, Material amount used per activity wise, Material supply system. Site location and access, Labour quantity, Construction methods used

7.3 Detailed Assessment of the Tool

All the sections developed under detailed assessment were integrated in to the tool. Different section were provided for Activity Analysis based performance assessment, Sub-contractor assessment and Errors and rework assessment.

7.3.1 Activity Analysis Based Performance Assessment

Data input window- Figure 7.6

> The interface is developed to facilitate the Activity Analysis. Responsible staff members can insert the data into one 15 minute time interval time to time. At the same time Activity data for other sub-contractor crew in all the trades also can be inserted. Automated calculation will be happened after each data input

Activity results in trade wise – Figure 7.7

> Trade wise Activity results and hourly Activity percentages are visualized in a separate window. All management layers can easily access to those results.

Root causes and possible improvement time – Figure 7.8

> Root causes and possible improvements relevant to activity percentages, are suggested by the tool. Responsibility break down elaborated based on trade wise is also discussed in detail.

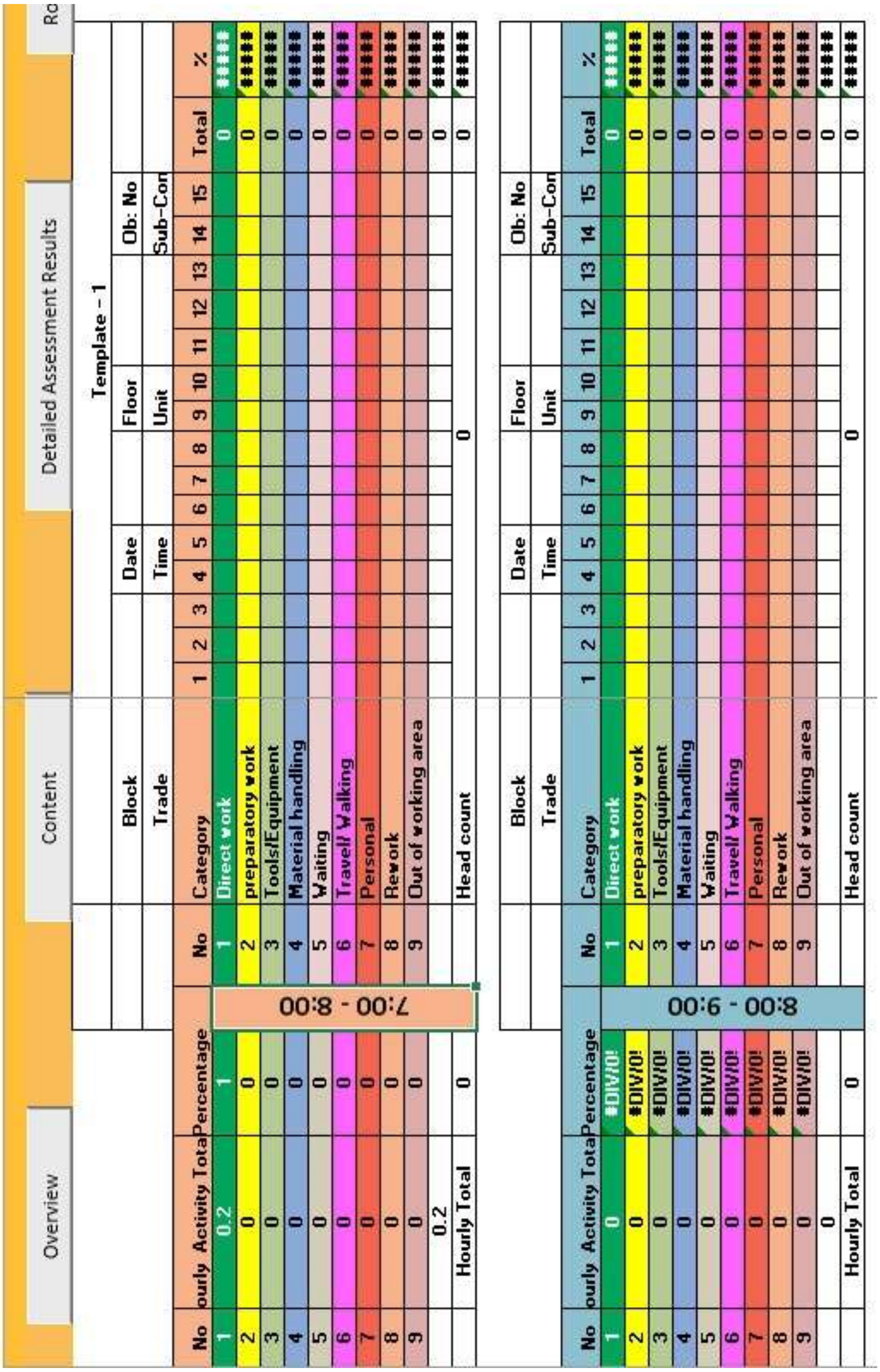


Figure 7.6: Data input page for Activity Analysis

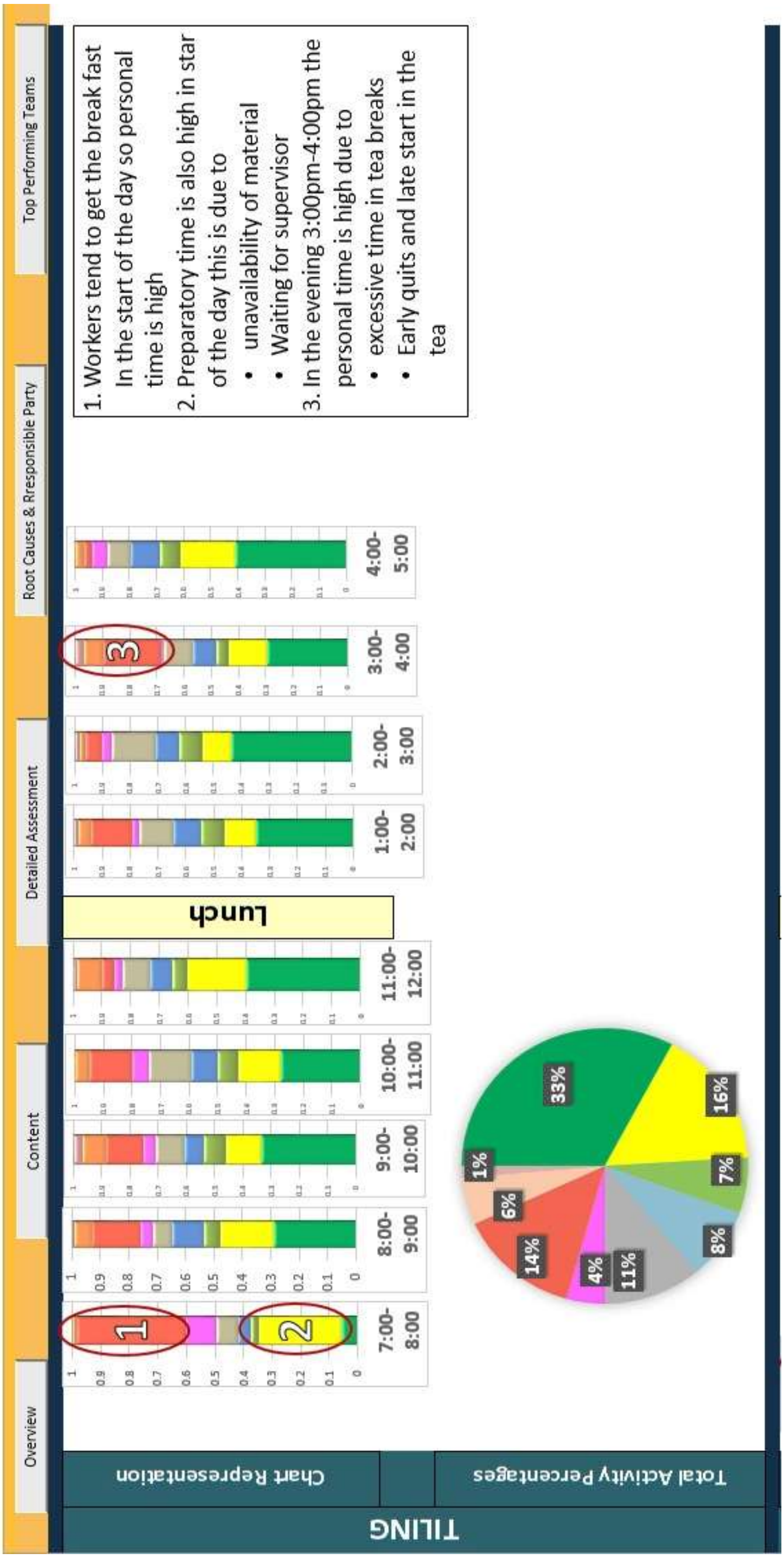


Figure 7.7: Activity results for tiling trade

Overview | Content | Detailed Assessment

Tiling	
Management and Staff	Labour
Excessive preparatory work - 16%	**Excessive preparatory work - 16%**
• Incomplete tile line marking	• Lack of cleanliness in bedding surface
• Lack of cleanliness in bedding surface	• Storing material in improper places (Covers the working places , have to remove due to disturbance)
• Storing material in improper places (Covers the working places , have to remove due to disturbance)	• Lack of instructions
• Lack of instructions	• Cleaning the tools and material preparing equipment (Mixer & buckets)
Material Handling - 9%	• Lack of work organizing skills of crew leader
• Insufficient amount of material on work place (In the floor level)	**Tools and Equipment (Tile cutter Grinder) - 6%**
• Low capacity/ quality of material preparing places and equipment	• Lack of skills in tool usage (Cutting curves, tile cutting)
Waiting – 11%	• Bad practices in tool usage (Not using relevant personal protective equipment – goggles, gloves)
• Unavailability of materials in the working floors	**Material Handling - 9%**
• Wait for the supervisor to get instructions(morning, working time)	• Insufficient amount of material preparing for a session
Travelling - 4%	**Waiting – 11%**
• Communication issues (Get the bill payments, Mark the work	• Worker crew combination (Skilled / Unskilled)- Most of the

Figure 7.8: Root causes for an excessive non-productive time in trade wise

7.3.2 Sub-contractor Assessment

When the user directed in to the sub-contractor assessment window, it can be accessed to sections for summary, criteria, benchmarks and management records. Sub-contractor crew performance can be assessed using the tool. After the assessment tool will identify top performing teams, positive and negatives of other crews. The assessment is mapped to the crew wise management record to reinforce and validate the assessment. Figure 7.9 shows the home page of the sub-contractor assessment home page.

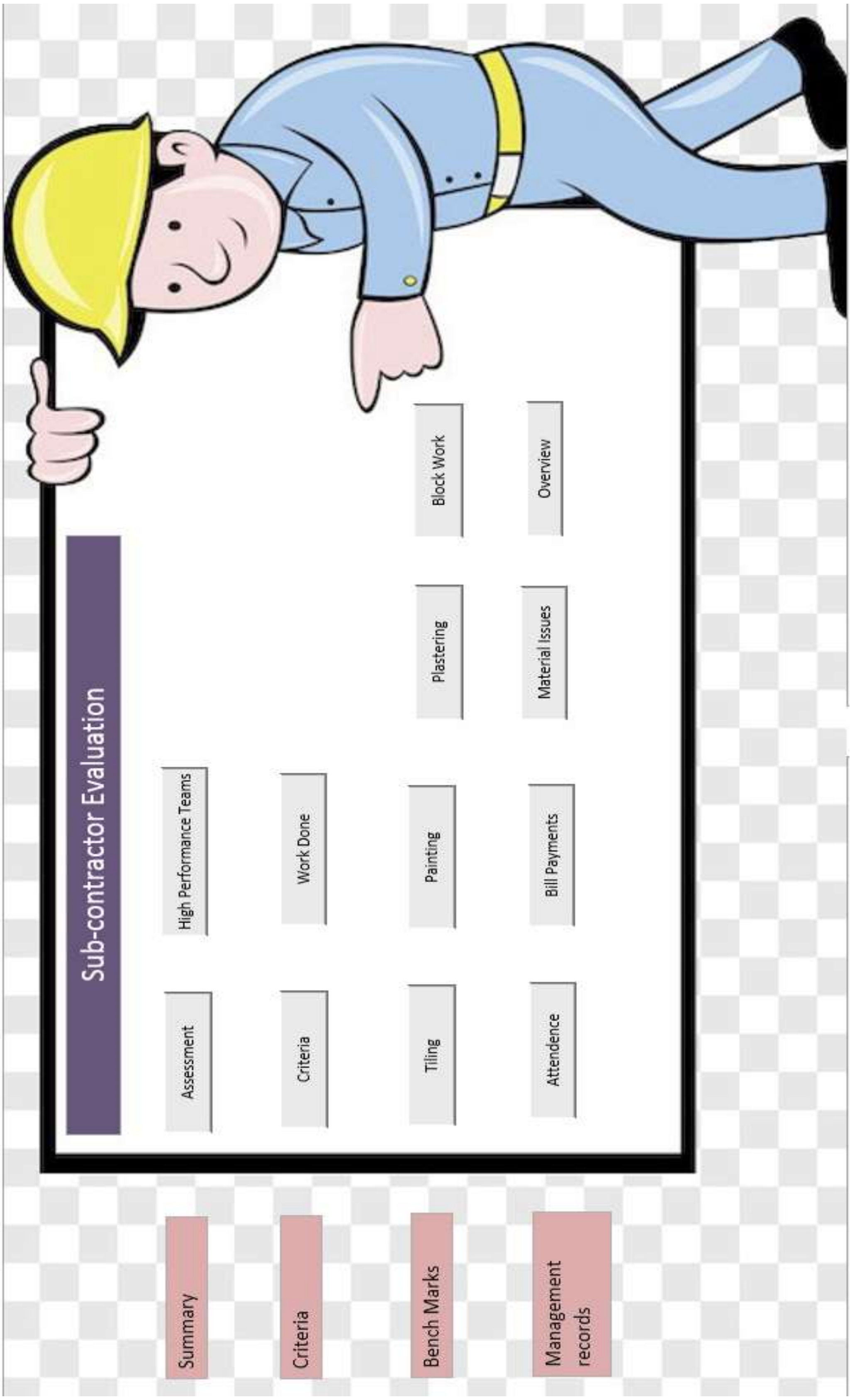


Figure 7.9: Sub-contractor assessment home page

7.3.3 Errors and Reworks Reduction Framework

Errors and rework reduction framework were developed relevant to building construction projects. For the analysis identified three stages were incorporated into the tool structural stage, masonry stage and finishing stage. Similar to other assessments error and rework assessment also facilitated to be operated by authorized parties in the construction team.

Figure 7.10: Home page of errors and rework assessment

In the errors and rework reduction framework, user can access to the summary of the identified errors which is similar to figure 7.11. Using the buttons provide in front of each error title user, he can jump in to the error minimization guide. Then the resources (figure and recommendation) can be used to reduce the error amount.

Figure 7.11: Errors and reworks home page

Overview		Content	
Structural	S1	Missing/incorrect positioning of starters	S1
	S2	Missing groves	S2
	S3	Horizontal and vertical alignment of Beams/columns/Shear walls	S3
	S4	Missing service ducts (Electrical , Mechanical) / Required sizes	S4
	S5	Tie plate removing	S5
	S6	Balance in form work (Pin walls/Stiffness columns)	S6
	S7	Lack of finishing in concrete	S7
	S8	Honeycombs of walls & colomns/Ex[pose of rebar	S8
	S9	Concrete in unneccery areas	S9
	S10	Sealing cushions on concrete-exxcessively	S10
	S11	Incorrect SFL of slabs, beams	S11
Masonry	M1	90* edges and corners	M1
	M2	Horizontality & Verticality	M2
	M3	Hollowness	M3
	M4	Dimensions	M4
	M5	Skierting line	M5
	M6	Alignment/Positioning	M6

Figure 7.12: Summary of the identified errors and reworks

Figure 7.13: Data entry sheet for errors and rework quantification

7.4 Capabilities of Overall Productivity Improvement Tool

Ultimate objective of the tool is to improve the construction workers' productivity. The tool is facilitated to reinforce the ultimate objective with following capacities and deliverables.

- It can convert the data into valuable information through accepted research methods. More accurate information is very valuable for correct and timely decision making process.
- Management can easily access to the results and findings. It can reinforce continuous monitoring mechanism. Have an easy reporting system even for complex data
- Tool can accumulate valuable data, relevant to productivity, wastes and performance. Simply tool can serve as a helping hand to identify productivity issues and their root causes
- Tool can deliver valuable data by interconnecting multiple data sources

7.5 Next Version of the Tool

Productivity Improvement tool can be easily integrate in web based or software based platform.

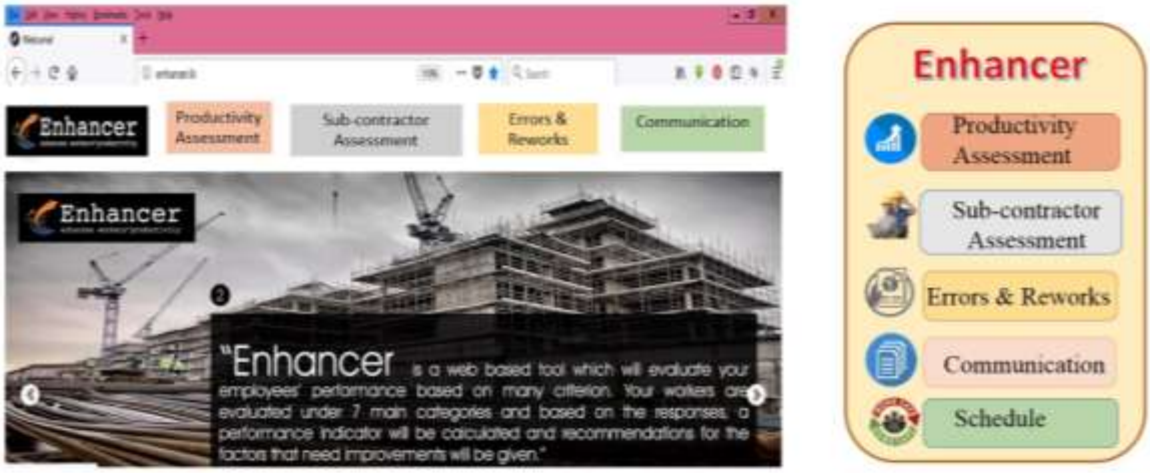


Figure 7.14: Next version of the tool

8. IMPLEMENTATION OF THE TOOL

8.1 Initial Implementation Works Carried Out

During the data collection period research finding were shared with the construction management team (GM, CEO, DGM Quality and Safety and Productivity). Presentation and a discussion were arranged at a two month time interval with above team members. Some initial implementation works were carried out after Activity Analysis are mentioned in the table 8.1.

Table 8.1: Implementation works carried out using Activity Analysis based assessment

11/06/2018	Activity Analysis results were submitted in a report
08/11/2018	Two weeks study on tiling issues in one tower
16/01/2019	Awareness presentation on productivity issues with other project teams
27/01/2019	Designed posters on productivity for other projects

8.2 Pilot Implementation in Tiling Trade

At the end of the study period pilot implementation was done in tiling trade. After one month observation following issues were identified using the developed framework and recommendations were provided. Construction management team has implemented the recommendations within the site.

According to the investigation and data analysis it was found out among the tiling worker crews, one skilled crew and one two skilled and one unskilled worker crews were more productive.

When one skilled tiler is working in a house unit. It was taken 20- 22 days to complete the unit. When two skilled tillers and one unskilled worker are working – 8-10 days were taken

- Assign continuous work and maintain the consistency of work. If they are assigned to unit 5, try best to assign the unit 5 in next time as well
- Improve direct work percentages
    a. Adjustments to the tiling sequence. For example, first bathrooms then living and bedroom floors and finally the kitchen area

   b. Skilled and unskilled worker combinations. One skilled worker gang and two skilled to one unskilled worker gang are the identified productive crew combinations
   c. Assign the work to the tiling workers based on their preference. Use different combinations like tile bedding and tiling or only tiling (Assign masons for tile bedding works based on the opinion and idea of the contractors)

- Reduce the tile wastage
   a. Reduce the number of tile cuts by having an overall preplan about the tile requirement (number of full tiles, half tiles, corners etc.)
   b. Sub-contractors should be educated not to waste tiles and supervisors should be responsible to utilize the tiles
   c. Counting the number of tiles needed for unit wise to get the overall requirement
- Improve the support from staff
   a. Ensure the completeness of pre-construction works – floor levels, chipping. Properly making ready the houses for tiling (Cleaning, Material supply, Finish the other works, Not disturbing to the tile works)
   b. Rectifying the defects - Can assign few masons to fix the errors and defects
   c. Sufficient amount of material delivery

8.3 Proposed Implementation Method

Figure 8.1 shows the proposed continuous productivity improvement process, expected to have using the tool. When it is going to implement the tool in particular site following adjustments and steps need to be followed. As per the figure 8.1 base model is developed. Second step is site sampling. Even tool has a strong data base, it need to be checked the tolerance between the bench marks and other guidelines with the new site conditions.

After setting up the tool into the site conditions other step will guide the construction team for continuous improvement in productivity and performance.

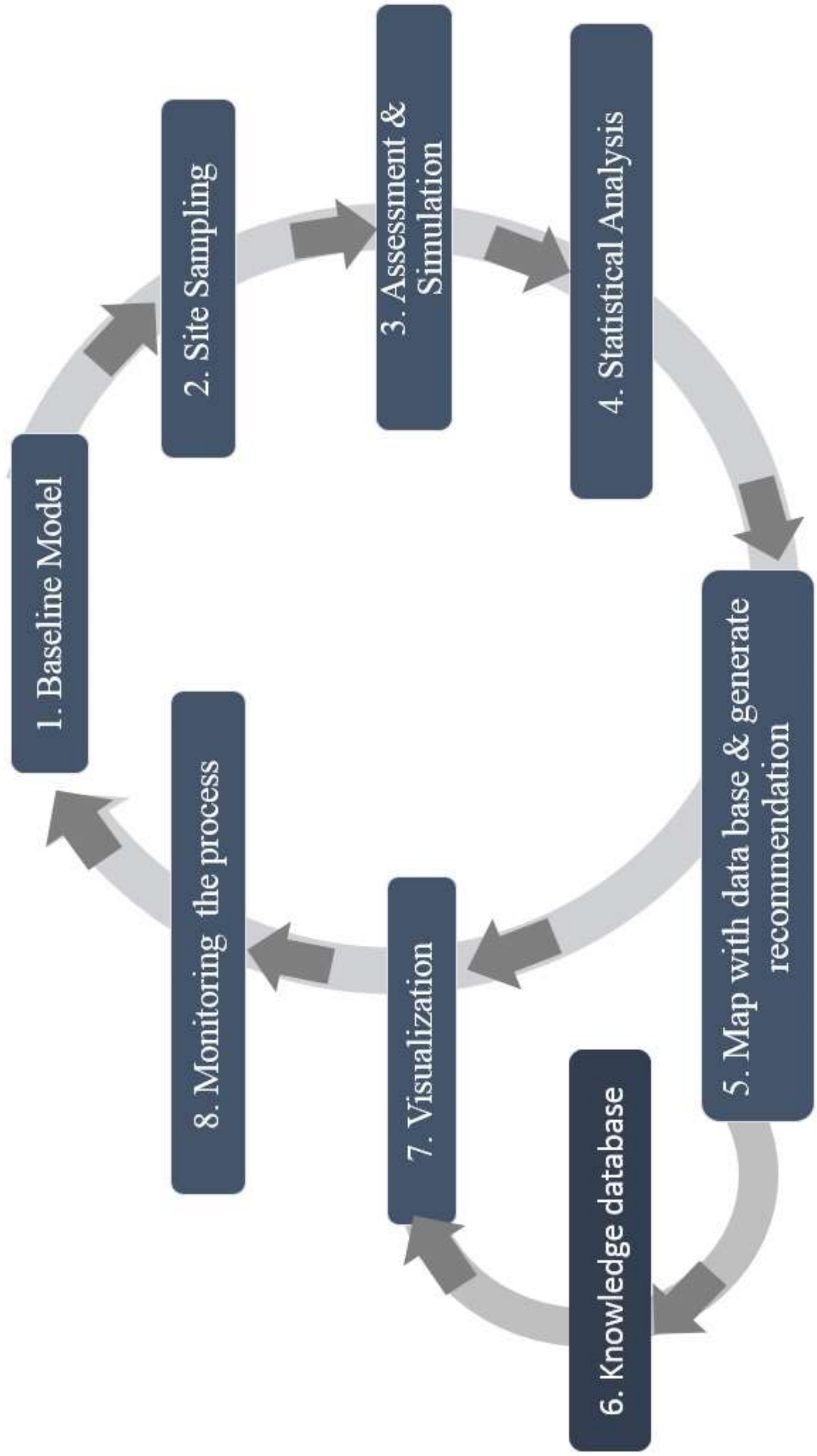


Figure 8.1: Proposed continuous improvement process for productivity improvement tool

8.4 Productivity Improvement Officer

In the implementation process it is recommended to assign a staff member, who will be responsible to reduce the waste, identify root causes and then take necessary actions to improve the productivity. The planned construction productivity improvement officer is certain to assume full responsibility for construction productivity improvement initiatives endlessly throughout the project's life cycle, with an additional purposeful follow-up. The CPIO ought to be unconditional with the required power and management to effectively perform the tasks. The ultimate scope of labor of the CPIO and different workers must be outlined specifically for the individual project.

Productivity improvement officer is need to be involved in the construction activities in the site. Figure 8.2 shows how it is need to be changed when the project proceeds.

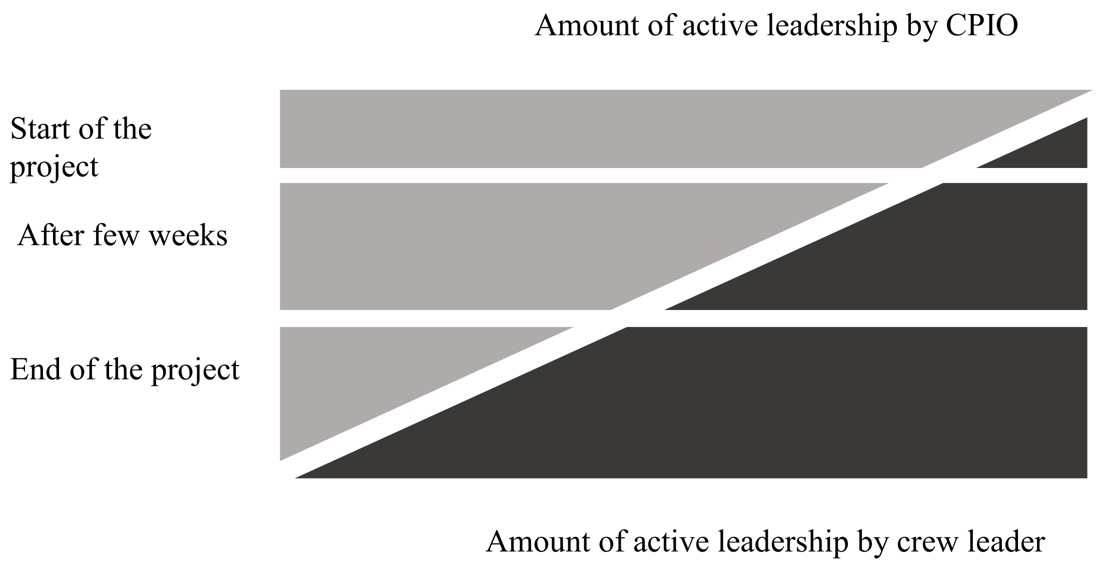


Figure 8.2: Continuum of leadership shared between CPIO and crew leader

9. CONCLUSION AND RECOMMENDATIONS

The main idea of this research is an assessment of labour productivity in Sri Lankan construction sites. The importance of an assessment framework was discussed. Therefore, the current situation in labour market and identification of factors affecting to labour productivity were identified.

So as to develop a framework and identify different requirements productivity improvement tool has been performed. Thereby the present situation in the construction industry with different trades could be identified and the observations and the results of it were helpful to identify the measurable criteria and measurable indicators for the framework.

In the Initial Assessment relative productivity is measured from the measurement which will be given to the measurable indicator. Therefore, the indicator measurement will be the measurement of the criteria for identified factor which is then multiplied with comparative score resulting a measurement to the factor. Then that measurement along with the relative importance will provide the productivity measurement of the construction sites.

In the Initial Assessment it highlights the contribution of other disciplines to workers' productivity. It investigates the issues that cause to reduce the productivity of workers in different areas of construction. This will be helpful to improve the supporting activities of construction.

When considering the measurable indicators for the framework the sources of information is identified and those sources will have to improve such that the information can be obtained with minimal time to the users of the framework.

From the Detailed Assessment productivity improvements directly relevant to labourers and management are highlighted. Also, Detailed Assessment will be helpful in benchmarking the measurable indicators according to site conditions. More focus on trends and patterns of workers time duration on a day is highly helpful to identify root causes for the lag. Through identifying the root causes management can make decision to overcome those. Therefore, this approach can make a higher impact to the continuous improvement of labourers and staff.

More samples will give more reliable base conditions of the trade. Therefore, this can be used to monitor the performance very easily. Thereby Detailed Assessment will be very helpful to guide sub-contractors to have higher profit margins while increasing the direct work percentages and reducing delays. Further Detailed Assessment can lead to competitiveness between trades and also will able to identify optimum crew combination for work.

Finally as a whole developed overall worker productivity improvement model can serve as a helping hand to improve the worker performance. It will further guide to continuous improvement in overall productivity as well.

9.1 Effect of the Management of Tool Time

As discussed in the Activity Analysis section, change in the management is affected for the tool time. The results in Table 9.1 is elaborated and conform it future.

Table 9.1: Time distribution variation based on the management change

	Management A	Management B
Direct Work	40.52%	50.33%
Preparatory Work	15.56%	11.02%
Tools/Equipment	3.52%	0.82%
Material Hand	8.22%	14.16%
Waiting	9.70%	5.82%
Travel/ Walking	4.61%	2.14%
Personal	13.75%	14.67%
Rework	2.79%	0.54%
Out of Site	1.34%	0.50%
Total	100.00%	100.00%

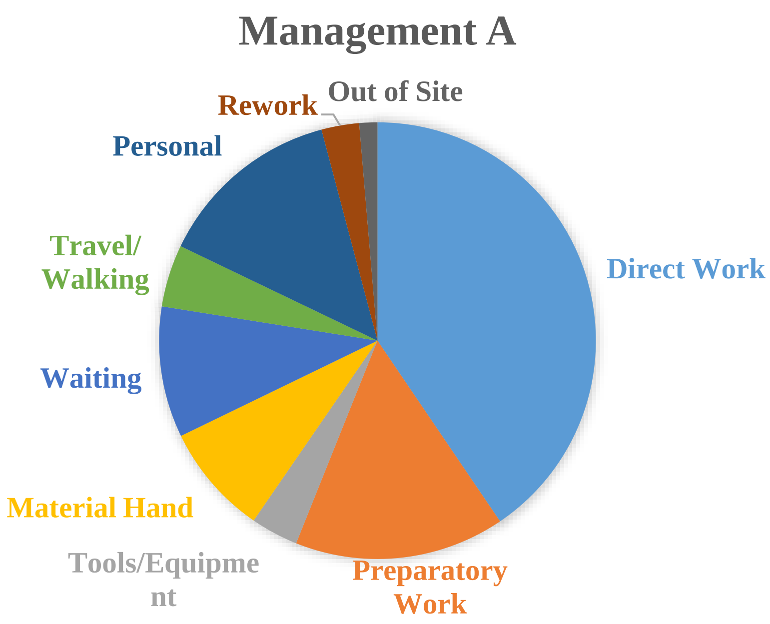


Figure 9.1: Activity Analysis results of site A

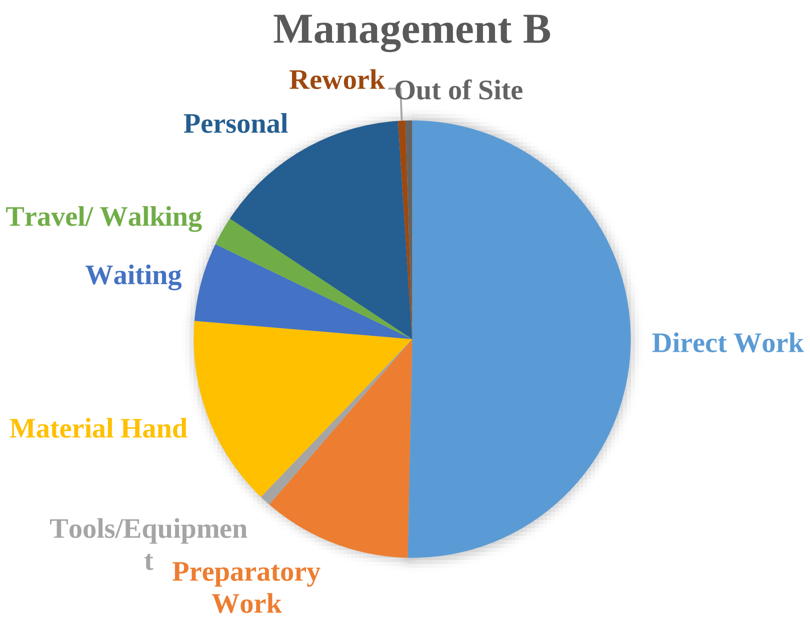


Figure 9.2: Activity Analysis results of site B

As discussed in the results of Activity Analysis, management has the major contribution towards the direct work percentage of sub-contractors. Under Management A, the direct work percentage is 40.52% while it has a 50.33% direct work percentage under Management B. The change in variation in direct work amount is mainly caused due to preparatory amount and management has a higher responsibility to preparatory work.

9.2 Overall Recommendations for Productivity Improvement

After developing all those research tools and frameworks it was implemented in the project. These are the points and facts that were observed in the purpose of improving productivity in the site. The recommendations were listed out and a few introductory sessions were carried out among staff and workers together and respectively.

1. Sub-contractors management

Sub-contractor management was identified as one of the key productivity improvement areas. Following issues were identified.

- Worker crew combination
- Inconsistency in attendance of the workers
- Inconsistency in performance
- Lack of established sub-contractors in the site
- Treating to the new sub-contractors

Recommendations:

In order to be profitable, it is essential to cultivate a culture of consistently high performing, sub-contractors.

- Work allocation – Two or three days look ahead schedule needs to be prepared for sub-contractors. This will help the sub-contractors to organize their work schedules and provide their contribution accordingly
- Worker distribution- supervisor should monitor proper work distribution of skilled and unskilled labourers. This is to ensure covering sufficient amount of daily work targets. Even though this is not a responsibility of the company staff, it will help contractor to perform better
- Records Management - The responsible company staff member (supervisor) needs to monitor and keep records such as attendance, daily work completion etc. about the sub-contractors
- Analyzing the contractor-wise performance by the staff officer
    a. Continuous improvement of the crew combination to obtain the best crew combination with the highest performance levels.
    b. Identification of crew wise errors and reworks quantities periodically

c. Closely monitor the profitability of the sub-contractors – if they are heading towards a loss, it is essential to notify them early as possible to cover up the losses. That will motivate them to perform better.

- Obtaining the optimum work cycle from fresh contractors – Achieving the optimum work cycle early as possible will lead to higher profits. Hence, assigning them the work with clear instructions and making them adjust to the rhythm gradually
  a. Tiling gang, initially might take 30 days for the completion of work. After completing 2 or 3 units, the completion cycle gets optimized to around 20 days. Further, during the initial period incentives can be introduced on top of the agreed rates. This is to minimize their losses until they obtain the optimum work cycle.
  b. Frequent instructions, communication and closely monitoring until they get adjusted to the rhythm
  c. Maintain a consistency when assigning the works, if initially unit 5 assigned, they need to assign the same unit as much as possible
  d. If the sub-contractor has to incur any losses due to the problems or delays which company is responsible (such as material un availability, site is not ready etc.), maintaining a contingency reserve to cover up their daily wages
- Appreciation and rewards
  a. Incentives should be introduced to encourage high performances measured based on finishing work on time, within budget with the desired quality
  b. Developing a transparent scheme (which communicated to all the workers) to select high performing workers (best tiler, best painter etc.) and appreciate them in front of other workers, highlighting how they achieved it. This will be a motivation for others to perform better.

2. Key Findings of the Activity Analysis - Less Trade-Wise Direct Work Amount

During the activity analysis following issues were identified

- Taking extra breaks and taking early breaks – taking breakfast at the site, excessive phone usage, leave for breaks early
- After lunch work scheduled starts around 1:30 pm (excessive time in breaks)

- Loss of sub-contractors' time due to delay in taking actions by the staff
    a. Incomplete MEP works
    b. Delays in material delivery

    Handing over the work to the next task after proper inspection without errors – and assign extra workers to get immediate rectifications

Recommendations

- In order to reduce the travel time and queues at canteens it is recommend to widen the canteen facility in the upper floor to accommodate the workers during the rush hours
- Crew leaders should be responsible to bring the team to the site on time in the mornings and after the breaks
- Taking immediate actions on issues and problems - If the contractors loose working hours, it will reflect in the bill as a loss.
- When a unit is handed over for the sub-contractor, all the supportive works need to be completed
- It is essential to calculate the material quantities properly for each work and it is required to ensure that the adequate quantities available at the site (It was frequently noted that due to the unavailability of materials, requirement was fulfilled from other floors. This impacts the progress of both the floors)

  e.g. - Number of tiles per unit and different tile sizes (2'x2', 2'x1', and 1'x1')

3. Problems in bill payment structure

- The sub-contractor's lack of understanding about the recording procedures of the work done leads to misunderstandings and confusions
- Not having a consistency among all the staff members about work recording procedures

Recommendations

- Some of the supervisors are not fully aware about the standard procedure of bill rates and the calculation procedures when undertaking the remaining work. Therefore, it is essential to keep the supervisors educated about it. So that the supervisors can justify the amount paid in case of a confusion.

- A standard record book and charts to maintain the records of labors – Purpose of this to avoid confusions
- Provide a simple printed bill including below information.
    a. Per head rate calculation
    b. Attendance of relevant month
    c. Transparency in bill payments (printed bill with a specific note for the reduction on money, per head value calculation)

    This can be used to reduce the misunderstandings and misinterpretations among contractors and the company

4. Quality of sub-contractors

It was noted that some contractors with sufficient skills to perform a task

- Inadequate organizing and team management skills
- Inadequate technical skills
- Not meeting quality and time targets

Recommendations

- Introducing a sub-contractor grading scheme (Please refer progress review presentation 3 about the proposed grading scheme for sub-contractors)
- Using the same grading scheme to assess new sub-contractors
    a. Proper assessment of their past performance
    b. Assessment of skill level of the workers - Using the difficult tasks to be completed (e.g.: 90^o edges in plastering, miter edge in tiling)
    c. Proper assessment of crew factors such as management skills, attitudes, innovative skills, team performance when grading them
- Often laborers do not have a proper understanding of key points in quality. This increases the amount of rework. Hence, properly educating them about the concept of quality and achieving quality targets is essential

5. Miscommunication among staff members and the laborers

- Sub-contractors often not communicating about their work schedules and holidays
- Inadequate pre-planning of construction works and lack of communication between workers who are assigned to the task and sub-contractors

Recommendations

- Matching the supervisor to the trade
    a. Identify the suitability of supervisors for the work assigned
    b. Identify the drawbacks and performances of sub-contractors on trade-wise

    It is recommended to assign supervisors who have good social skills, with cost focus to the tiling trade, detail oriented supervisors to the plastering crew and hardworking, quality target oriented supervisors to the structural work (it is essential to avoid any reworks in this stage as it will be costly to rectify them. Eg. Plumb out of the shear walls, missing MEP grooves, missing reinforcement starters etc.

- Flexibility in decision making
    a. Smooth adaptation of the new sub-contractors to the site by educating them about the ICC quality, safety, worker management structures, bill payment procedures and other practices.
    b. Allocating a time for new sub-contractors to adjust to the company culture - This step is important as the sub-contractors who are coming from other sites adjusted to different working cultures and procedures. Therefore, it is essential to give them a time to get adjusted to the site
    c. It is important to welcome the new ideas and work routing proposed by the sub-contractors. Also it is important to accommodate their ideas whenever possible, otherwise it will lead to demotivation of sub-contractors and poor performances. Always better to go for a Win-win solution
    d. Establishment of conflict resolution mechanism – It is important to establish a conflict resolution mechanism and properly communicate them to the workers and sub-contractors

6. Coordination among the staff members

- Lack of clear vision about the complete project which can lead to lack of teamwork
- Not getting sufficient inputs from different disciplines (such as MEP to Structural etc.) when delivering the outcome

- Balance works and reworks caused due to lack of coordination between different disciplines (handing over the work before completing them eg. MEP works)

Recommendations

- It was noted that the solutions recommended by the senior management may not address the issues as expected and the support from the supervisors is essential. Therefore, Getting the ideas from the supervisors when planning and scheduling to minimize the difficulties
- Keeping site engineers and supervisors informed about the progress
- Improving the communication mechanisms of the senior management.
- When discussing site matters and problems, it is required to keep everyone aware that all of them are part of the same team and giving the constructive feedback part of the continuous improvement process.

7. Lack of Organization of the Site

- Storing material in improper places resulted from poor site layout planning
- Unavailability of adequate tools and breakdown
- Assigning suitable people for the tasks as to match their worker performance

Recommendations

- The suitable storage places need to be selected considering less damage to material and tools and less disturbance to the working area
- Proper estimation of the crew ratio which based on the required time periods for different trades is essential to ensure continuous work flow.
    - Tilers : Painters : Plastering
- Proper pre-planning with a proper idea about the nature of the activities (required quality, the methods of material delivery, contractors allocation, days to complete the works etc.) and organizing the activities with the big picture in mind to ensure proper work flow. This is step is essential to keep the safety, quality and schedule targets in a higher level.

8. The Attitude of The Lower Management Staff

- Lack of appreciation of the laborers for the work done

- Less focus on developing the skills and working capacity of the laborers at below hierarchy level
- Lack of discussion and less communication between lower management staff and laborers. This is mainly resultant from the attitude issues of the management staff. When laborers are not convinced about the solutions they do not take the ownership of the work carrying out.
- Lack of focus and motivation on the methods of saving money to the company
    - Not motivating workers to implement strategies like “ Let’s do it first time”
    - Thorough and careful supervision to prevent errors
- Lack of understanding about the big picture and shared vision
- Lack of continuous improvement of the staff

Recommendations

- As the role of workers is very important in achieving set targets, it is necessary to pay more attention to identify their real issues and provide any help as required
- It is important to give the credit to the workers when necessary to make them own the work. If contractors get succeeded, many people will be benefited from them
- When trying to implement strategies such as “Let’s do it first time” it is important to clearly communicate and direct the laborers on the ways to achieve that. Display posters given in Annex at the public places.
- Importance of career planning of the staff members who are in the lower levels of the hierarchy and taking efforts to improve the flow of knowledge and experience sharing
- Everyone should encourage to perform better and create a working culture

9. Top Management Involvement in Site Matters and Inspection

- Frequent visits of top management personnel to the sites and monitoring of progress is identified as one motivator for the middle management and lower management. Moreover, this will help the top management to understand the real situation at the sites
- Lack of application of new technology and innovative methods for track the progress (it is hard to track back and difficult to visualize using the tools developed in MS Excel)

- Top management by passing the middle management and directly approaching the lower levels, creates a confusion among the bottom level workers and will lead to dissatisfaction of middle level managers. Sometimes, different information sources will disturb the continuous work flow.
- Giving less attention to the opinions of junior management when making decisions and plans

Recommendations

- Always better to push the management staff to achieve the highest performance levels, as most of the time workers trying to perform within a safe margin
    - If focus is to achieve 3 floors, target should be given as 4. At the same time capacity should be developed to meet that target
- It is better to keep the communication channels from top management to the bottom level through the middle level management and keep them in the loop of the information flow
- Appreciation of the middle level management and giving them the due recognition
- It is important to explore the application of new technologies to the site management. Furthermore, the ERP systems need to enhance with the project management module. So that top management can track the site progress and stay up to date.

10. Errors and Reworks due to Lack of Instructions, Details and Supervision

- Pre-planning and identifying the risks that can occur
- Identify the possible errors and reworks that may occur
- Not having a database of errors and reworks

Recommendations

- Prepare clear and structured instructions notices
- Enhance the input of QA/QC team to deliver quality work. It is essential to convince the required quality to the staff as well as workers
- The engineer should have the mindset of consultant and should try to minimize the errors and achieve the quality
- Maintaining a database of errors and reworks (For a sample template please refer progress review 2)
- Displaying designed posters for error reduction (Please refer annex) in public places

REFERENCES

[1]. Fiume, O. & Cunningham, J. (2003) Real Numbers: Management accounting in a lean organization. Durham, NC: Managing Time Press.

[2]. Patkure & Kulkarni,” Practical Solutions For Improvement In Labor Productivity” Proceedings of 4th RIT Post Graduates Conference (Rit Pg Con-18) Novateur Publications Journal NX- A Multidisciplinary Peer Reviewed Journal (ISSN No:2581-4230) April, 13th, 2018

[3]. Chye LIM 1996 The Analysis Of Productivity Inbuilding Construction, Thesis

[4]. Mbora Lema, 1996, Construction Labour Productivity Analysis And Benchmarking - The Case Of Tanzania, Thesis,

[5]. Gouett, M. C. (2010). Activity Analysis for Continuous Productivity Improvement in Construction, 159.

[6]. Park, H.-S. (2006). Conceptual framework of construction productivity estimation. KSCE Journal of Civil Engineering, 10(5), 311–317.

[7]. N. De Silva, K.Bandara, & R. Rajakaruna. (2008). Challenges faced by the construction industry in Sri Lanka: perspective of clients and contractors, 12.

[8]. Jayalath, A., & Gunawardhana, T. (2017). Towards Sustainable Constructions: Trends in Sri Lankan Construction Industry-A Review.

[9]. Jarkas Abdulaziz M., & Bitar Camille G. (2012). Factors Affecting Construction Labor Productivity in Kuwait. Journal of Construction Engineering and Management, 138(7), 811–820.

[10]. Amarasekera, E. (2011). Accurate estimating on labour productivity in Sri Lankan construction industry. Retrieved from

[11]. Raftery, J., Pasadilla, B., Chiang, Y. H., Hui, E. C. M., & Tang, B.-S. (1998). Globalization and construction industry development: implications of recent developments in the construction sector in Asia. Construction Management and Economics, 16(6), 729–737.

[12]. Raftery, J., Pasadilla, B., Chiang, Y. H., Hui, E. C. M., & Tang, B.-S. (1998). Globalization and construction industry development: implications of recent developments in the construction sector in Asia. Construction Management and Economics, 16(6), 729–737.

[13]. Summanth D. J., 1985. Productivity and Management. McGraw Hill Book Company, New York

[14]. "A framework for Total Productivity Measurement of Construction Projects" by Construction Owners Association of Alberta (2018)

[15]. Guide to Activity Analysis- Construction Industry Institute(2010) Retrieved May 14, 2018, from https://www.constructioninstitute.org/resources/knowledgebase/more-filter-options/result/topics/rt-252/pubs/ir252-2a

[16]. Nasir, H., Haas, C., Rankin, J., Fayek, A.R., Forgues, D., and Ruwanpura, J. (2012) "Development and Implementation of a Benchmarking and Metrics Program for Construction Performance and Productivity Improvement." Canadian Journal of Civil Engineering, Special Issue on Construction Engineering and Management, Vol. 39(9),

[17]. Noor, I (1998) "Measuring construction labour productivity by daily visits". In: Proceedings of the 42nd annual meeting of AACE, American Association of Cost Engineers, Cincinnati, Ohio, Prod.05.01 – 06

[18]. Huang, A. L., Chapman, R. E., & Butry, D. T. (2009). Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations. Special Publication (NIST SP) - 1101.

[19]. Sink, D.S., (1985). Productivity Management: Planning, Measurement and Evaluation, Control and Improvement. John Wiley and Sons, New York

[20]. Bresnen, M. J., Haslam, C. 0.. Beardworth A. D., Bryman, A. E. and Keil, E. T., 1990. Performance on Site and the Building Client, CIOB, Ascot, UK.

[21]. Rodriguez, J. (2014). Top Saas Construction Products. About.com Construction. Retrieved March 14, 2014, from http://construction.about.com/od/New-Software/tp/Top-SaasConstruction-Products.htm

[22]. Thomas, H.R, Maloney, W.F., Homer, R.M.W., Smith, G.R., Handa, V.K. and Sanders, S.R., (1990). Modelling Construction Labour Productivity. Journal of Construction Engineering and Management, ASCE, Vol. 116, No. 4, December, pp 705-726.

[23]. Rayburn, L. M. (1989). Productivity Database and Job Cost Control Using Microcomputers. Journal of Construction Engineering and Management, 115(4), 585-601.

[24]. Dozzi, S.P.; AbouRizk, S.M., G. of C. N. R. C. (1993, December). Productivity in Construction - NRC Publications Archive - National Research Council Canada.

[25]. Weerasinghe, I. P. T. R. (2013). Automated Construction Worker Performance and Tool-time Measuring Model Using RGB Depth Camera and Audio Microphone Array System (Thesis). University of Calgary.

[26]. Shounak, G. H. A. (2016, August). Extension of activity analysis methodology to maintenance, shutdown, and turnarounds in petrochemical facilities (Thesis). https://doi.org/10.15781/T2ZP3W23W

[27]. Teicholz, P. (2013, March 14). Labor-Productivity Declines in the Construction Industry: Causes and Remedies (Another Look) Viewpoint #67. AECbytes. Retrieved January 14, 2014, from http://www.aecbytes.com/viewpoint/2013/issue_67.html

[28]. Kim S. (2009). Development of a Wireless Real-Time Productivity Measurement System for Rapid Construction Operations (Thesis). University of Kansas

[29]. Peddi A. (2009). Development of Human Pose Analyzing Algorithms for the Determination of Construction Productivity in Real-time (Thesis). University of Kansas

[30]. Canada Research Chair of ProjectManagement Systems (CRCPM), <http://www.wcmprod2.ucalgary.ca/crcpm/research/productivity> (April 17, 2009).

[31]. Improving Construction Productivity on Alberta Oil and Gas Capital Projects Dr. George Jergeas PEng ucalgary

[32]. Tabachnick, B. G., & Fidell, L. S. (1983). Using multivariate statistics. New York: Harper & Row.

[33]. Borcherding, J.D., (1976). Improving Productivity in Industrial Construction. Journal of the Construction Division, ASCE, Vol. 102, No. C04, December, pp 599-614

[34]. Tucker, R.L., Rogge, D.F., Hayes, W.R. and Hendrickson, F.P., (1982). Implementation of Foreman Delay Surveys. Journal of the Construction Division, ASCE, Vol. 108, No. C04, December, pp 577-591

[35]. Gladstein, D. L. (1984). Groups in context:Amodel of task group effectiveness.Administrative Science Quarterly, 29, 499-517

[36]. J.Y. Ruwanpura a,1 , K.N. Hewage b,⁎, L.P. Silva a,2 Evolution of the i-Booth© onsite information management kiosk –Thesis

[37]. Improving project management performance of large contractors using benchmarking approach - Van Truong Luu et al, International Journal of Project Management 26 (2008) 758–769

[38]. Karunarathna, D. M. T. G. N. M., &Siriwardana, C.S. A. (2018). A Tool to Assess Construction Worker Productivity. In 2018 Moratuwa Engineering Research Conference (MERCon) (pp. 577–582). https://doi.org/10.1109/MERCon.2018.842 1909

[39]. Roman Titov 2014 Relationship Between The Ratio Of Direct And Support Work With Productivity For Slab Formwork – Thesis

[40]. Varajao, J., and Cruz-Cunha, M.M., Using AHP and the IPMA competence baseline in the project managers selection process., Int.J.Prod. Res.,51(11)(2013),pp.3342–3354

[41]. Vroom, V. H. (1964). Work and motivation. Wiley, New York.

[42]. NuhuBraimah - Construction Delay Analysis Techniques—A Review of Application Issues and Improvement Needs Buildings 2013, 3, 506-531; doi:10.3390/buildings3030506

[43]. Kaijianliu 2014 crowdsourcing construction activity analysis from jobsite video Streams- Thesis

[44]. Y. Ou, (2014). Study on Cultivation of Motivation Hygiene Factors in Construction Enterprise, Applied Mechanics and Materials, Vols. 501-504, pp. 2628-2631

[45]. Aduagyei, F. and Ruwanpura, J.Y. (2008). “Optimization of Resources in Construction Work area through Effective Process Planning." Proceedings of the CSCE Annual Conferences, Quebec City, QC.

[46]. Choy, E. and Ruwanpura, J.Y. (2006). “Modeling construction site productivity using situation based modeling.” Canadian Journal of Civil Engineering, Special Issue in Construction.

[47]. Siriwardana, C. S. A. (2016). An Integrated Framework for Worker Planning and Supervision in Construction (Thesis). University of Calgary.

[48]. Gannoruwa, A. (2008). Development of an Efficiency Model for Optimum Construction Productivity through Effective Supervision on Worker

Performances. M.Sc. Dissertation, Department of Civil Engineering, The University of Calgary at Alberta, Canada. 255

[49]. Love, P. E. D., & Edwards, D. J. (2004). Forensic project management: The underlying causes of rework in construction projects.Civil Engineering and Environmental Systems, 21(3), 207–228

[50]. Construction Industry Institute (CII), Costs of quality deviations in design and construction, The Univ. of Texas at Austin, Austin, Texas, 1989, RS 10–1 (Jan.)

[51]. P.E.D. Love, H. Li, Quantifying the causes and costs of rework in construction, Constr. Mgmt. Econ. 18 (4) (2000) 479–490

[52]. Hewage, K. N., (2007). Construction Productivity Improvement by Worker Motivation and IT Based Communication. Ph.D. Dissertation, Department of Civil Engineering, The University of Calgary at Alberta, Canada.

[53]. Abiola, R. O. (2000). Management implications of trends in the construction cost in Nigeria.The Quantity Surveyor, 30, 35–40

[54]. Hackman, J. R. (2002). Leading Teams: Setting the Stage for Great Performances. Harvard Business Press.

[55]. Hofstede, G., Hofstede, G. J., & Minkov, M. (2010). Cultures and Organizations: Software of the Mind, Third Edition. McGraw Hill Professional.

[56]. Kozlowski, S. W. J., & Ilgen, D. R. (2006). Enhancing the Effectiveness of Work Groups and Teams. Psychological Science in the Public Interest, 7(3), 77–124. doi:10.1111/j.1529-1006.2006.00030.x

[57]. Landsberg, Max (2003). The tao of coaching: boost your effectiveness at work by inspiring and developing those around you. London: Profile Books. ISBN 9781861976505. OCLC 223636717

[58]. Love, P. E. D., & Edwards, D. J. (2004). Forensic project management: The underlying causes of rework in construction projects.Civil Engineering and Environmental Systems, 21(3), 207–228

[59]. Levine, J. M., & Moreland, R. L. (1998). Small groups. In D. Gilbert, S. Fiske, & G. Lindzey (Eds.), Handbook of social psychology (4th. ed., Vol. 2, pp. 415-469).Boston: McGraw-Hill.

[60]. Love, P. E. D., Davis, P., Ellis, J., & Cheung, S. O. (2010). Dispute causation: Identification of pathogenic influences in construction. Engineering, Construction and Architectural Management, 17(4), 404–423

[61]. Cohen, S., & Bailey, D. E. (1997). What makes teams work: Group effectiveness research from the shop floor to the executive suite. Journal of Management, 23, 239-290.

[62]. Statistics Canada. (2013, December 6). Table 383-0012 Indexes of labour productivity and related variables, by North American Industry Classification System (NAICS), seasonally adjusted. Statistics Canada. Retrieved January 13, 2014, from http://www5.statcan.gc.ca/cansim/pick-choisir?lang=eng&p2=33&id=3830012

[63]. Improving project management performance of large contractors using benchmarking approach - Van Truong Luu et al, International Journal of Project Management 26 (2008) 758–769

[64]. Abdullah, M.A., Khalid, H.N., Shuib, M., Md Nor, N., Muhammad, Z., Jauhar, J., 2007.

[65]. Job satisfaction amongst employees in small and medium industries (SMIs) in the manufacturing sector: a Malaysian case. J. Asia Pacific Bus. 8 (4), 39e66.

[66]. Daniel, D. W. (1990). Hard problems in a soft world.International Journal of Project Management, 8(2), 79–83.

[67]. Shikdar, A.A., Sawaqued, N.M., 2003. Worker productivity, and occupational health and safety issues in selected industries. Comput. Ind. Eng. 45 (4), 563e572.

[68]. Smith, P.C., Kendall, L.M., Hulin, C.L., 1969. The Measurement of Satisfaction in Work

[69]. Rayburn, L. M. (1989). Productivity Database and Job Cost Control Using Microcomputers. Journal of Construction Engineering and Management, 115(4), 585-601.

[70]. Ruwanpura, J., Hewage, K., Da Silva, S. P., & Smith, D. (2006, Fall). Tool Time Analysis to Improve Construction Productivity in Alberta. Canadian Civil Engineer, 23, 18-22.

[71]. Siriwardana, C. S. A., & Ruwanpura, J. Y. (2012). A Conceptual Model to Develop a Worker Performance Measurement Tool to Improve

Construction Productivity (pp. 179–188). American Society of Civil Engineers. doi:10.1061/9780784412329.019

[72]. Siriwardana C. S. A., Ruwanpura J. Y. (2013). Worker Crew Planning as an Important. Aspect of Improving Construction Productivity CSCE 10th International/ 4th Construction Specialty Conference. May 29-June 1, 2013, Montreal, Canada

[73]. Lozon, J. and Jergeas, G. (2008).“Best Practices – Too Much of a Good Thing?.” Proceedings of the CSCE Annual Conferences, Quebec City, QC. CO-395, 1-8.

[74]. Roman Titov 2014 Relationship Between The Ratio Of Direct And Support Work With Productivity For Slab Formwork – Thesis

[75]. Tuckman, B. W. (1965). Developmental sequence in small groups. Psychological Bulletin, 63, 384-399.

[76]. Viswesvaran C, Ones DS. Perspectives on models of job performance..Int J Select Assessm. 2000;8:216–226

[77]. ewe chyelim 1996, Analysis of productivity in building construction – Thesis

[78]. Sundstrom, E., De Meuse, K.,&Futrell, D. (1990).Work teams: Applications and effectiveness. American Psychologist, 45, 120-133

[79]. Improving project management performance of large contractors using benchmarking approach - Van Truong Luuet al., International Journal of Project Management 26 (2008) 758–769

[80]. The Construction Users Roundtable. (2005). Construction Labour: Managing the Construction Workforce. The Construction Users Roundtable, 4100 Executive Park Drive, Suite 210, Cincinnati, Ohio 45241

[81]. Chan DC. Core competencies and performance management in Canadian public libraries.Library Manag. 2006;27:144

[82]. Hedge JW, Borman WC, Bruskiewicz KT, Bourne MJ. The development of an integrated performance category system for supervisory jobs in the US Navy.Milit Psychol.2004;16:231–243

[83]. Rankin, L.K., Lozon, J.P., Jergeas, G.F. (2005). “Detailed Execution Planning Model for Large Oil and Gas Construction Projects.” Proceedings of CSCE 6thConstruction Specialty Conference, Toronto, CT-130, 1-9.

[84]. Koskinen, K. U. (2000). Tacit knowledge as a promoter of project success. European Journal of Purchasing & Supply Management, 6, 41–47.

[85]. Pinto, J. K., Slevin, D. P., & English, B. (2009). Trust in projects: An empirical assessment of owner/contractor relationships. International Journal of Project Management, 27, 638–648

[86]. Briscoe, G., Dainty, A. R., & Millett, S. (2001). Construction supply chain partnerships: Skills, knowledge and attitudinal requirements. European Journal of Purchasing & Supply Management, 7, 243–255.

[87]. Rollins T, Fruge M. Performance dimensions: competencies with a twist. Training. 1992;29:47–51

[88]. Arvey RD, Mussio SJ. A test of expectancy theory in a field setting using female clerical employees' Vocat Behav. 1973;3:421–432

[89]. Ramanathan, R., Ganesh, L. (1994) Group preference aggregation methods employed in AHP: An evaluation and an intrinsic process for deriving members' weightages European Journal of Operational Research, 79, pp. 249–265

[90]. Abiola, R. O. (2000). Management implications of trends in the construction cost in Nigeria.The Quantity Surveyor, 30, 35–40

[91]. Rojas, M., and Aramvareekul, P. 2003. Labour productivity drivers and opportunities in the construction industry. J. Manage. Eng., 192, 78–82.

[92]. Aje, I. O., Odusami, K., & Ogunsemi, D. (2009). The impact of contractors' management capability on cost and time performance of construction projects in Nigeria. Journal of Financial Management of Property and Construction, 14, 171–187.

[93]. Huang, X. (2011). An analysis of the selection of project contractor in the construction management process. International Journal of Business and Management, 6, 184.

[94]. Park, H. S., Thomas, S. R., and Tucker, R. L. (2005), Benchmarking of construction productivity, Journal of Construction Engineering and Management, 131(7), 772-778.

[95]. Pant, I., & Baroudi, B. (2008). Project management education: The human skills imperative. International Journal of Project Management, 26, 124–128

[96]. Edum-Fotwe, F., & McCaffer, R. (2000). Developing project management competency: Perspectives from the construction industry. International Journal of Project Management, 18, 111–124

[97]. Baykasoglu, A., Dereli, T., & Das, S. (2007). Project team selection using fuzzy optimization approach.Cybernetics and Systems: An International Journal, 38, 155–185

[98]. Odusami, K. (2002). Perceptions of construction professionals concerning important skills of effective project leaders.Journal of Management in Engineering, 18, 61–67

[99]. Tjosvold, D., Yu, Z. Y., & Hui, C. (2004). Team learning from mistakes: The contribution of cooperative goals and problem-solving.Journal of Management Studies, 41(7), 1223–1245

[100]. Malisiovas, Andreas N. (2010). Construction Productivity: From measurement to improvement. Advancing Project Management for the 21st Century Concepts, Tools & Techniques for Managing Successful Projects, Heraklion, Crete, Greece

[101]. Merrow, E.W., Sonnhalter, K.A., Somanchi, R., and Griffith, A.F. (2009). Productivity in the uk engineering construction industry. Independent Project Analysis, Incorporated, Wellington House, First Floor, Worton Drive, Reading RG2 0TG.

[102]. Turner, J. R., & Müller, R. (2005). The project manager's leadership style as a success factor on projects: A literature review.Project Management Journal, 36, 49–61.

[103]. Morgan, B. B., Glickman, A. S., Woodard, E. A., Blaiwes, A. S., & Salas, E. (1986). Measurement of team behavior in a Navy training environment (Tech. Rep. TR-86-014). Orlando, FL: Naval Training Systems Center, Human Factors Division

[104]. Borcherding, J.D., (1976). Improving Productivity in Industrial Construction. Journal of the Construction Division, ASCE, Vol. 102, No. C04, December, pp 599-614

APPENDIX A – Developed Productivity Improvement Posters


ඵලදායිතාව සඳහා
අවම කරන්න
1 අමුද්‍රව්‍ය නොමැති නිසා වැඩ කටයුතු ප්‍රමාද වීම
2 සේවක සගයින් ප්‍රමාද වී වැඩ බිමට පැමිණීම
3 හිස් අතින්/උපකරණ හෝ අමුද්‍රව්‍ය නොමැතිව ඇවිදීම
4 විවේක කාලයන්ට නියමිත වෙලාවට ප්‍රථම ගමන් කිරීම සහ පසුව පැමිණීම
5 අනවශ්‍ය ලෙස ජංගම දුරකථන භාවිතය
6 අවසර නොලත් විවේකයන් ගැනීම සහ වැඩ කරන කාලය තුල නවාතැන් වලට ගමන් කිරීම
7 වැඩ කටයුතු අතරතුර එයට අදාළ නොවූ පෞද්ගලික කතාබහ
8 වැඩ අතරතුර දුම් බීම/ බුලත්විට කැම/ මත් ද්‍රව්‍ය භාවිතය


ඔබගේ හිතවතුන්ගෙන්
ඈත් වී කරන කැපවීමට
උපරිම වටිනාකමක්
ලබාගැනීමට ඔබගේ
කාලය අපතේ
නොයවන්න


කාර්යාල කටයුතු සදහා ඔබගේ වැඩ කරන කාලය තුල ගමන් කිරීමෙන් වලකින්න. එය ඔබට දවසේ නිම කල හැකි වැඩ ප්‍රමාණය සීමා කරයි.
ගබඩාවේ බඩු ලබා ගත හැකි වේලාවන් සහ කාර්යාල කටයුතු සදහා පැමිණිය හැකි වේලාවන්
o පෙ. ව 7:30 ට පෙර
o ප. ව 12:00 සිට ප. ව 1:00 දක්වා
o ප. ව 5:00 පසු පමණි

මේ පිළිබඳව ඔබ

දැනුවත්ද?

ඔබගේ දවස තුළ

උපරිම කරගන්න

සෘජු කාර්යයන් : ඔබ මුදල් උපයන කාර්යයන්

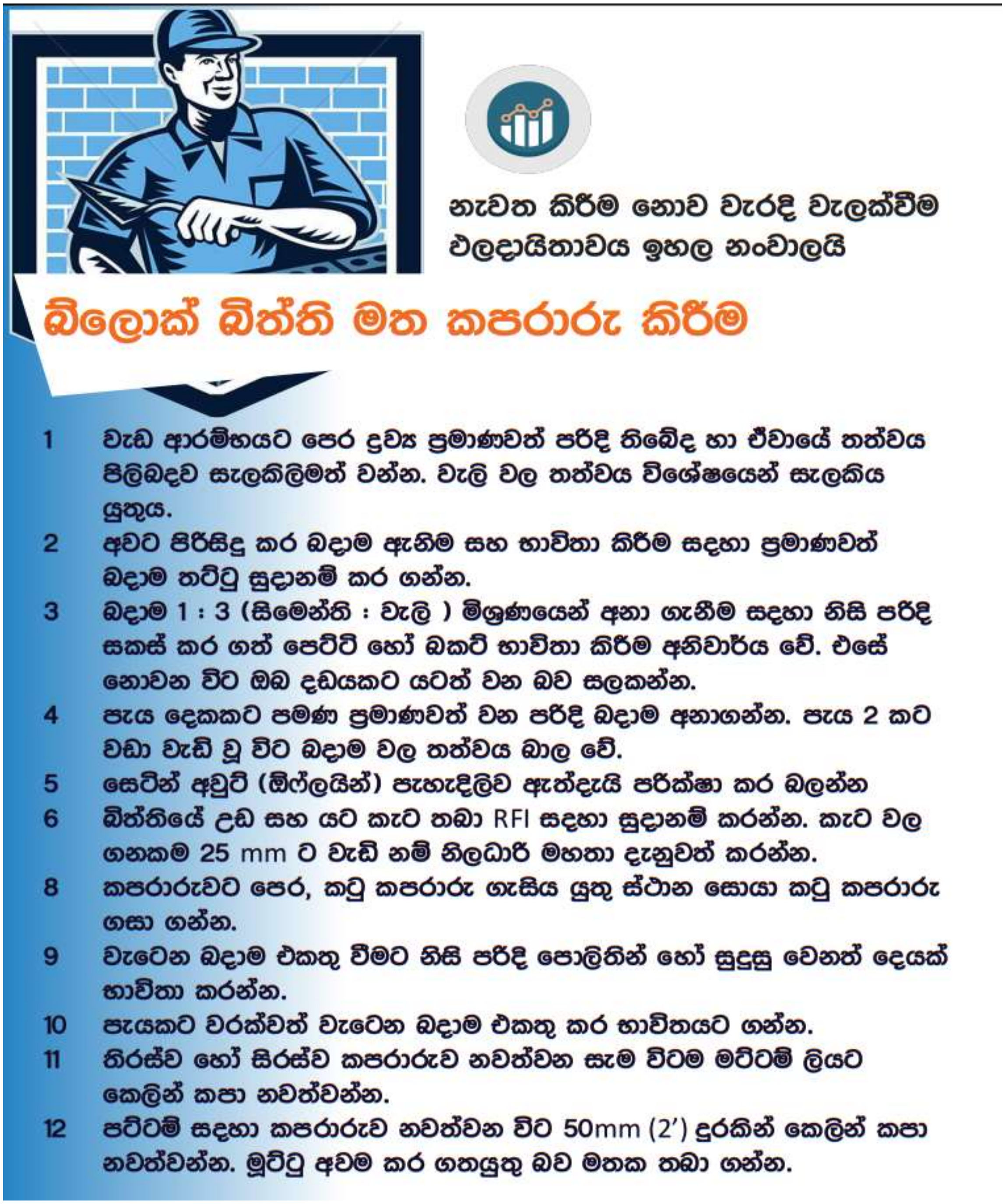
සීමා කරන්න

උපකාරක කාර්යන් : සූදානම් වීමේ කාර්යයන්
උපකරණ භාවිතය
අමුද්‍රව්‍ය හැසිරවීම/පිළියෙළ කිරීම

අවම කරන්න

ඵලදායී නොවන කාර්යයන් : බලා සිටීම
ඇවිදීම
පෞද්ගලික කටයුතු

Designed Posters for Error Reduction



නිවසක කපරාදුව නිම කිරීමේදී සිදුවන

දළ වැරදි ප්‍රමාණය

බිත්ති වල තිරස් සහ සිරස් බව නොතිබීම

වර්ග අඩි 172

මුළු සහ දාර වල අංශක 90 නොතිබීම

දික් අඩි 90.58

කපලාරුව බෝල් වීම සහ ඉරි තැලීම්

වර්ග අඩි 7

මිනුම් වල වැරදි (දිග/ පළල/ඝනකම)

12 වරක්

සියලුම ඉදිකිරීම් අවස්ථාවල ඇතිවිය හැකි වැරදි/ දෝෂ සහ ඒවා ඇතිවිය හැකි ස්ථාන කල්තියා තීරණය කර හදුනා ගන්න.


LET'S DO IT
RIGHT
THE FIRST TIME
ICC
සෑම කටයුත්තක්ම පළමුවරින්ම නිම කරන්න.
සෑම විටම වැඩවල අවශ්‍ය ප්‍රමිතිය නඩත්තු කිරීමෙන්
ඔබගේ වටිනා කාලය ඉතිරී වන අතර
වැඩි මුදල් ප්‍රමාණයක් උපාය ගත හැක.
ඔබ භාවිත කල උපකරණ සහ වැඩ බිම
වැඩ නිම වීමෙන් පසු පිරිසිදු කරන්න.
එමගින් පසු දින ඒ සදහා වැයවන අමතර
කාලය අඩු වේ.

ටයිල් ඇතිරීම සඳහා උපදෙස්

1 ටයිල් ඇතිරීමට පෙර ටයිල් බෙඩ් එක පරීක්ෂා කර බොල් තිබේ නම් නිලධාරී මහතා දැනුවත් කරන්න.
2 ටයිල් බෙඩ් එක පිරිසිදු කර ජලය ඉස තෙමා ගන්න.
3 නිවැරදි ටයිල් වර්ගය තෝරා හැසිරවීමට පහසු තැනකින් නිසි පරිදි අසුරා ගන්න.
4 පෝසිලෙන් ටයිල් ඇල්ලීම සඳහා ටයිල් adhesive භාවිත කරන්න.
5 ටයිල් ලයින් සලකුණු කර ඇත්ද යන්නත්, එම පිලිවෙලට ඇතිරූ විට සපයා ඇති සැලැස්මට අනුව තිබේද යන්නත් පිලිබඳව සැලකිලිමත් වන්න.
6 කොලපු / ඇඩිසිව් ආලේප කිරීමට කටු හැන්ද භාවිත කරන්න.
7 බිත්ති ටයිල් සඳහා කටු හැන්ද භාවිතා නොකරන්නේ නම් ටයිල් මත සම්පූර්ණයෙන්ම පැතිරෙන ලෙස කොලපු තවරා ගන්න.
8 ටයිල් අතර පරතරය සමාන්තරව පවත්වා ගැනීමට කුරුස (Tile spacer) භාවිත කරන්න.
9 ටයිල් උඩ මට්ටම සහ ටයිල් අතර පරතරය සමාතරව ක්‍රමානුකූලව පවත්වා ගන්න. ඒ සඳහා මට්ටම් ලෑලි ස්ප්‍රිතු ලෙවලය භාවිත කරන්න.
10 පලුදු වූ, ඇදවූ හෝ ප්‍රමිතියෙන් අඩු ටයිල් ඇතොත් ඒවා ඉවත් කර අසුරා තබන්න.
11 ටයිල් ඇල්ලීමෙන් පසු ටයිල් මත ඇති කොලපු / ඇඩිසිව් පිස දමා පිරිසිදු කර ගන්න.
12 ටයිල් සවිවන තුරු ඒ මත ගමන් කිරීම හෝ පෑගීම වැලක් වීමට ආරක්ෂණ ක්‍රියාමාර්ගයක් යොදන්න

ටයිල් ඇතිරීමේදී සුලබව සිදුවන වැරදි

1 ටයිල් බොල් වීම
2 ටයිල් අතර දාර සමාන නොවීම
3 ටයිල් පලුදු වීම
4 ටයිල් කොනේ/ දාර එකම මට්ටමේ නොපිහිටීම
5 මිනුම්/ පරතර නිසි පරිදි නොතිබීම

APPENDIX B – Factor Based Initial Assessment Benchmarking

The selected Measurable Indicators have been benchmarked as follows such that each indicator gives maximum to minimum mark range according to the maximum and minimum marks assigned for the factor from the previous tool. Further, the sources for the required data have been identified to modify the sources and make it easy for users to identify the data required. The source general will be the overall data collected on-site at the commencement of the project and will change some data at the milestones of the project.

Benchmarked Levels of Measurable Criteria and Data Source

Measurable Indicator	Data Source					
A 1) Suitability or quality of plant, equipment, and tools						
Next service dates, Functionality, Age	General	Available for all	Available for larger Tools and Equipment	Available for few	Not Availabl e	
Equipment manual	General	More than 8hrs	less than 8 hrs	8 to 5 hrs	5 to 2 hrs	less than 2 hrs
	General	More than Required	As required	Adequate level	Few	None
Equipment manual	General	More than 8 hrs	8 to 4 hrs	4 to 1 hrs	1hr to 30mnts	less than 30 mins
Sizes, Functions	General	In all size	In required size	Adequate size	Few sizes	None
A 2) Breakdown and damages to the plant and equipment(machinery)						
Availability/Not	General	Available for all	Available for larger Tools and Equipment	Available for few	Not Availabl e	
Break down hours from daily reports	Mainten ance records	No loss	Below 2 hours	2-5 hours	5 - 10 hours	More than 10
Breakdown frequency	Mainten ance records	None	1	2	3	More than 3
A 3) Shortage/Inefficiency of tools and equipment						

Number of tools available and requirement	Stores records	100%	100%-80%	80%-70%	70%-60%	Less than 60%
Inefficiencies and shortages found	Daily report	Available with More details	Available with substantial detail	Available with few details	Available	Not available
Grading of the company	General	CS2	CS1	C1	C2	C3 or lower
Activity duration from labor records	Labor records	More than 8hrs	less than 8 hrs	8 to 5 hrs	5 to 2 hrs	less than 2 hrs
Categorized / Not	General	Categorized	Not			
Supplier payments	Procurement	Owned	Leased	Hired		
A 4) Effective Monitoring of plant and equipment utilization						
Maintenance record availability	General	Available for all	Available for larger Tools and Equipment	Available for few	Not Available	
Break Down hours' availability	General	Available with details	Available	Not Available		
Break down frequency availability	General	Available	Available	Not Available		
Delay of work records in the daily report	Daily report	No waiting	Below 5 minutes	Less than 10 minutes	Less than 30 minutes	More than 30 minute
B 1) Unavailability of material/ Late deliveries of material/material supply						
Number of unavailable items recorded	Stores records	None	Less than 2	Less than 5	Less than 10	More than 10
Delays in supply as per stores records	Stores records	None	Below one day	1 - 2 day	2 - 3day	More than three days
Delay of work records in the daily report	Daily report	None	Below 1 hour	1 - 2 hour	2 - 3 hour	More than 3 hour
Percentage of wastage	General	None	less than 4%	Less than 10%	More than 10%	
Number of requests from records	Stores records	1 to 2	3 to 5	6 to 10	More than 10	

Adequacy of material at the site	General	More than Required	Required Amount	Adequate amount	None	
Availability of inventory	General	For more than seven days	Less than seven days	Less than three days	One day	None
Trade wise material issuing records	Store records	More details available	Required details available	Available with few details	None	
B 2) Quality or suitability of the material						
Quality adequacy by quality assurance	General	More than required quality	As required	Acceptable quality	Not Acceptab le	
Reworks recorded in daily reports	Daily report	None	1	2	3	More than 3
Wastage percentage	General	None	less than 4%	Less than 10%	More than 10%	
B 3) Suitability of storage location						
Distance	General	less than 10m	Less than 20m	Less than 30m	Less than 50m	More than 50m
Delay of work records in the daily report	Daily report	None	Less than 30 mints	less than 1hr	Less than 2hr	Less than 5hr
Issue quantity per day	Stores records	Higher	High	Moderate	Less	Lesser
Number of documents per issue	General	None	1	2	More than 2	
Number of Daily issuing	Stores records	less than 10	Less than 20	Less than 25	less than 30	More than 30
C 1) Communication between site management and labors						
Number of meetings	General	None	1	2	3	More than 3
Number of proficient languages	General	Three languages with writing	Three languages	Two languages with writing	Two language s	One languag e with writing
Number of hierarchies in upward level	General	1	2	3	More than 3	
Number of reworks due to poor instruction	Daily report	None	1	2	3	More than 3
C 2) Leadership qualities of the engineer and staff						

People-oriented or task oriented	General	Cognitive style	Being Person-oriented	Being Task oriented	No effect	
Level of attitudes	General	Good	Acceptable	Bad		
Worse/ Acceptable	General	Good	Acceptable	Bad	Worse	
Friendly / Normal / Strict	General	Normal	Friendly	Strict		
Number of reworks due to poor instruction	Daily reports	None	1	2	3	More than 3
Grading for interpersonal skills	General	Higher	High	Moderate	Less	Lesser
Educational qualification	General	Charted Eng.	BSc	Diploma	NVQ level	
Number of activities	General	Highly involved	Actively participate	Moderate	Participat ive	Do not
Past profit percentage, Variance percentage	General	Excellent	Good	Ordinary	Bad	
C 3) Construction manager's ability to manage people and Project planning ability						
Earned value, Number of reworks	site status report	Greater than 1.1	1.1-1	1-0.9	0.9-0.8	less than 0.8
Profit margins	General	More than 8%	8%-6%	6%-3%	3%-0%	Loss
Number of reworks due to poor instruction	Daily reports	None	1	2	3	More than 3
Level of Availability	General	Available with more detail	Available with adequate details	Available with acceptable detail	Not Availabl e	
Project lagging time, Earned value ratio	site status report	Greater than 1.1	1.1-1	1-0.9	0.9-0.8	less than 0.8
Level of interpersonal skills	General	Higher	High	Moderate	Less	Lesser
Number of activities	General	Highly involved	Actively participate	Moderate	Participat ive	Do not
C 4) Supervisory incompetence/ Instructions delay						
Professional qualification level	General	Degree	Diploma	NVQ level	No higher educatio n	

Number of attempts	quality reports	First attempt	Second attempt	Third attempt	More than 3	
Earned value ratio	General	Greater than 1.1	1.1-1	1-0.9	0.9-0.8	less than 0.8
Number of reworks	Daily reports	Less Defect	Acceptable defect	High Error	Severe error	
RFI frequency	General	None	1	2	3	More than 3
C 5) Crew size and composition /Distribution of labor						
Number of skilled and unskilled workers	Labor records	3 to 2	3 to 1	2 to 1	1 to 1	
Labor requirement vs actual	Labor records	More than required	As required	Acceptable	Not Acceptab le	
Labor attendance	Labor records	100%	100%-90%	90%-85%	85%-80%	Less than 80%
Trade wise worker percentage	Labor records	More than 20%	Less than 20%	less than 15%	Less than 10%	less than 5%
Number in crew	Labor records	More than 75	50 -75	25 - 50	Below 25	Below 25
C 6) Reworks/Reworks due to construction errors						
Earned value	site status report	Greater than 1.1	1.1-1	1-0.9	0.9-0.8	less than 0.8
Amount due to rework	Daily reports	Higher	High	Moderate	Less	Lesser
Number of attempts	quality reports	First attempt	Second attempt	Third attempt	More than 3	
Frequency	General	None	1	2	3	More than 3
C 7) Sequencing problem in the schedule work						
Earned value ratio	site status report	Greater than 1.1	1.1-1	1-0.9	0.9-0.8	less than 0.8
Number of failures	quality reports	None	1	2	3	More than 3
Delay due to reworks	Daily reports	None	Less than 4hrs	less than 1 day	less than 2 days	More than 2 days
Delay time	Daily reports	Less than 1 day	Less than 3 days	Less than 5 days	Less than 10days	More than 10 days

Delay time in activities	Daily reports	Less than 1 day	Less than 3 days	Less than 5 days	Less than 10days	More than 10 days
C 8) Unrealistic scheduling and expectations of labor performance						
Number of overtime hours	labor records	None	Less than 2hr	Less than 3hrs	Less than 5 hrs	More than 5hrs
Earned value ratio	Site status report	Greater than 1.1	1.1-1	1-0.9	0.9-0.8	less than 0.8
Percentage of work than base level	Site status report	More than 50%	50%-45%	45%-40%	40%-30%	Less than 30%
Work completion percentage	Site status report	100%	100%-95%	95%-85%	85%-80%	Less than 80%
C 9) Lack of periodic meeting with labor						
Number of hierarchies in upward level	General	1	2	3	More than 3	
Number of meetings	General	None	1	2	3	More than 3
Attendance percentage for meetings	General	100%	100%-95%	95%-85%	85%-80%	Less than 80%
Number of proficient languages	General	3 languages with writing	3 languages	2 languages with writing	2 languages	1 language with writing
C 10) Inspection delay by authorities (Engineer/site manager)						
Delay time between completion and request	Daily reports	None	1 hour	2 hours	More than 2	
Availability	General	Available	Not			
C 11) Relationship between management and workers						
Number of hierarchies upwards	General	1	2	3	More than 3	
Number of meetings	General	More than4	3 and 4	2	1	None
Accessibility by calls	General	Available at any working time	Available at permitted time	Not Available		
Availability of details	General	All details available	Only required detail available	Few details available	No detail	

C 12) Coordination among design disciplines /site management coordination ability						
Frequency	General	None	Less than 1 day	2 days	3 days	More than 3 days
Number of meetings	General	3	2	1	None	
Number of subordinates and levels	General	1	2	3	More than 3	
Delay time	General	3	2	1	None	
C 13) Proportion of work subcontracted and unreliable subcontractors						
Percentage	General	Full	Less than 75%	Less than 50%	Below 50%	
Grading	General	C1	C2	C3	Below grading	
Value of work, Percentage of work	General	More than 50Mn	Less than 50Mn	Less than 10Mn	Less than 1 Mn	Less than 0.5Mn
Number of workers in trade wise by labor records	Labor Records	More than 100	50 - 100	Below 50	None	
Number of gangs	General	More than 100	50 - 100	Below 50	None	
C 14) Stringent inspection by the engineer						
Number of documents need signature	General	1	2	3	More than 3	
Number of meetings present	Daily Report	More than 3	3	2	1	None
Number of visits	General	More than 3	3	2	1	None
Number of sessions	General	More than 2	2	1	None	
D 1) Skill of labor						
Professional qualifications	General	NVQ Qualified	CIDA trained	Highly trained/Skilled	Skilled	
Number of skilled labors	Labor records	More than 65%	65%-55%	55%-45%	45%-40%	less than 40%
Ratio to skilled and unskilled	Labor records	3 to 2	3 to 1	2 to 1	1 to 1	
D 2) Labor experience						
Number of years	Labor Records	More than 5	2-5 years	1 – 2 years	Below 6 months	

Number of projects worked	Labor Records	More than 4	2 - 4 Project	1 project	None	
D 3) Motivation of labor						
Level of satisfaction	General	Higher	High	Moderate	Less	Lesser
Wage	General	Higher	High	Moderate	Less	Lesser
Level of accommodation	General	Separate rooms	separate beds	Platform	Floor mats	Worse
Number of facilities	General	Higher	High	Moderate	Less	Lesser
D 4) Working overtime (provision of extra money after normal work						
Overtime premium	General	Satisfied	Acceptable	General	Not satisfied	
Number of hours	Labor Records	More than 4	2 – 4 hours	2 hours	None	
D 5) Working for long periods without holiday/shift work						
Frequency	General	less than 25 days	25days	26 days	27 days	More than 27 days
Level of schedule	General	Available	Not			
Number of holidays	General	More than 4 days	2 – 4 days	1 – 2 days	None	
Number of average working days	General	Below 28 days	23 – 28 days	28 – 30 days	30 days	
D 6) Labor personal problems						
Number employed, Wages	Labor records	More than 4	4	3	2	1
Number of members	Labor records	2	3 to 4	5	6 to 7	More than 7
Type of family (Extended, Nuclear)	Labor records	Extended	Nuclear			
Distance to home	Labor records	Less than 10km	less than 20km	less than 50km	less than 100 km	More than 100 km
D 7) Workforce absenteeism						
Attendance	Labor records	Higher	High	Moderate	Less	Lesser
Number of leaves	Labor records	None	1	2	More than 2	
D 8) Walkouts or strikes						

Number of walkouts and strikes	General	None	1	2	More than 2	
Number of Reassignments	General	None	1	2	More than 2	Lesser
Attendance	General	Higher	High	Moderate	Less	Lesser
E 1) Amount of wages/unfair wages of construction workers						
Rates different to categories	General	Available for all trades	Available for some trades other than sub cont	Available for sub cont trades only	Availabl e for few trades	Not Availab le
Amount	General	Higher	High	Moderate	Less	Lesser
Number of hours working	Labour Records	8 hrs	10hrs	12hrs	More than 12	
E 2) Accommodation						
Provided capacity	General	For all	For Distant workers	For Direct workers	More than 50% workers	For Selecte d
Number of facilities provided	General	Higher	High	Moderate	Less	Lesser
E 3) Love and belongingness, labors recognition and respect						
Number of complains	Labor records	None	Few	General	Frequent	
Availability and amount of details	Labor records	High Availability	Moderate Availability	Less Availabilit y	Only required	None
Number of feedbacks	Labor records	Good	Average	None	Bad	
E 4) Incentive payments/bonus at the end of project or year						
Increment amount in salary, Salary increment frequency	General	Each Year	2 yrs	3 yrs	5 yrs	More than 5 yrs
Bonus premium or percentage	General	More than 2 times	2 times salary	1 time salary	Fixed amount	None
E 5) Opportunity to undertake challenging tasks/targets, giving responsibility						
Number of leaders	Labour records	3	2	1	None	
Proportion of work done relative to target	Labour records	More than 50	50-45	44-40	39-35	Lesser than 35
E 6) Late payment of salaries and wages						

Salary date announcement	General	Fixed date available	Will announce on start of month	will Announced after 2 weeks	Will not announced	
Salary advances offered	General	Available At request	Available every month	Available on selected months	Not available	
Number of delay days	General	None	1 Day	2 days	3 days	More than 3 days
E 7) Lack of training sessions, recognition to the job						
Number of trainings per year	General	3	2	1	Will have	No raining
Availability of job description, assigned tasks, and level of details	General	Available with specific full details	Available with fixed details	Not available		
E 8) Medical care/health and safety provision						
Level of medical facility	General	Available of MC with trained Medical personnel	Available of MC	Availability of fully equipped first aid box	Available with first aid box	None
Amount of insurance	General	Over 1 Mn	1Mn-0.5Mn	0.5Mn-0.1 Mn	Less than 0.1Mn	None
E 9) Lack of places eating and relaxation						
Capacity provided	General	Separate Place for all	Separate place to eat for all	separate place to eat for without congestion	Provided space	None
Number of laborers at site	Labor Records	More than 5	5	3	1	Lesser than 1
Adequacy of capacity provided	General	More than Required	Required level	Adequate level	Less	
E 10) Job security (permanent job, job all the time, payment)						
Proportion of permanent workers	Labour records	All	All with More than 1yr	All with more than3	Only selected	Lesser
Number of years required to be permanent	General	More than 1	More than 2	More than 3	More than 5	More than 10
Stability of company bond	General	High	Moderate	None		
E 11) Transport facilities for the workers						

Distance	General	Below 1km	More than1km	More than2 km	More than 3km	More than 5km
Capacity provided with transport	General	For all	For direct workers	for distant ones	None	
Amount for the allowance	General	Daily allowance	Monthly allowance	No allowance		
E 12) Competition with colleagues and project team						
Number of intensives or premium	Labour Records	Provided highly for targets	Provided for mentioned targets	Provided for special situation	None	
Amount payable	General	More than 1Mn	More than 0.5Mn	More than 0.3Mn	More than 0.1Mn	Lesser than 0.1Mn
E 13)Social activity opportunities (sports and entertainment)/welfare condition						
Number of activities	General	More than 5	More than 3	2	1	None
Number of trips	General	More than 2	2	1	None	
Number of day outs / Get together	General	More than 2	2	1	None	
F 1) Technical ability & construction knowledge of engineer and staff						
Level of qualification	General	Available with other qualification	Available with few other qualificatio n	None		
Level of education	General	Post Graduate with more than 10yrs exp	Bsc with more than 10yr exp	Bsc with more than 2 yrexp	Diploma level	NV level
Amount minimized by additional costs	From Enginee r/Daily report	More than 1Mn	More than2 Mn	More than 0.5 Mn	Less Than 0.5 Mn	None
Number of reworks due to errors	Daily Report	None	1	2	3	More than 3
F 2) Technology employed and new project techniques						
Number of manuals, Version of manual	General	Use more than 2	2	1	None	

Level of quality control procedure	General	Higher	High	Moderate	Less	Lesser
F 3) Construction method used						
Availability	General	Available even at site	Available for every activity at office	Available for some activities	Available on request	None
Number of reworks due to changes	Daily report	None	1	2	3	More than 3
F 4) Incomplete drawings, missing details in drawings						
Number of design changes	General	None	1	2	3	More than 3
Number of RFI per month	General	None	1 to 3	4 to 7	7 to 10	More than10
F 5) Delay in responding to request for information (RFI)						
Delay time	Daily report/Site status report	None	1day	2days	3 to 5 days	More than 5 days
Number of dates for response	General	None	1day	2days	3 to 5 days	More than 5 days
F 6) Poor site layout and organization						
	General	Before half a day	Before one hr	Before 30mnts	At work	After commencement
Wide of access road	general	More than 7m wide	More than 6mwide	More than 5m wide	More than 4m wide	Lesser than 4m wide
Distance to plant	General	No need of plant	less than 200 m	less than 500m	less than 1 km	More than 1km
Number of documents gone for requesting	General /Stores record	1	2	3	4	More than 4
F 7) Changes order by client/change order causing additional work/Alterations of schedule						
Amount	Daliy reports/ Site Status report	None	Less than 1% of project value	less than 3%	Less than 10% of project value	More than 10% of Project value
Number of design changes	Daily report	None	1	2	3	4

F 8) Alteration of design during project execution						
Number of changes	General	None	Less than 1% of project value	less than 3%	Less than 10% of project value	More than 10% of Project value
Amount or proportion	Daily report	None	1	2	3	4
G 1) Quality control/standard and specifications						
Level of practicing of QA/QC	General	Higher	High	Moderate	Less	Lesser
Number of certificates obtain	General	More than 3	3	2	1	None
Number of staffs assigned	General	More than required	Up to requirement	Few	None	
Number of reworks	Daily report	None	1	2	3	More than 3
G 2) Working environment/insufficient lightning						
Light condition	Site Status report	Higher	High	Moderate	Less	Lesser
Working space adequacy	By staff	Excellent	Adequate	Acceptable	Bad	
Availability of resources	General	Available More than	Adequate	Available at acceptable	Available on request	Not available
G 3) Project complexity and design complexity/compatibility among documents						
Advance method availability	General	Higher	High	Moderate	Less	Lesser
Project value, Floor area	General	Less than 100 Mn	More than 100mn	More than 300 Mn	Less than 1 Bn	More than 1 Bn
Project value	General	Less than 100 Mn	More than 100mn	More than 300 Mn	Less than 1 Bn	More than 1 Bn
Project duration	General	Less than 1 yr	More than 1yr	More than 2 year	Less than 5 Years	More than 5 years
G 4) Site condition, access, subsoil, topography						
Sub soil condition	General	Good	Moderate	Poor		
Accessibility	General	Main A class road	Main road	Sub urb road	Gravel road	Separate road

Terrain conditions	General	Flat	Hilly			
G 5) Site congestion/over crowding						
Number of workers	Labour Records	More than 250	100 - 250	50 - 100	Below 50	
Number of hoists and lifts	General	More than required	As required	Acceptable level	None	
Level of Material supply system	By Enginee r	Excellent	Good	Acceptable level	Bad	
G 6) Site layout						
Distance from entrance	General	Less than 20m	More than 20 m	More than 50m	less than 100m	More than 100m
Distance to stores and office	General	Less than 20m	More than 20 m	More than 50m	less than 100m	More than 100m
H 1) Inclement weather/rain						
Return period	Daily report	less than 1 hr	more than 1 hr	More than 3hr	Less than 8 hrs	More than a day
Suitability of weather to current construction stage	Site status report	Internal Finishes only	Finishes	Structural	Sub structure	
Rainfall	Daily report	Higher	High	Moderate	Less	Lesser
Number of works affected by weather	Daily report	None	1	2	3	More than 3
H 2) On site accidents, stop work due to accidents						
Number of accidents	Daily Reports /Site Status report	None	1	2	3	More than 3
Delay time proportion due to accidents	Daily Report	less than 1 hr	more than 1hr	More than 2hr	less than a day	More than a day
H 3) High temperature						
Number of facilities provided	General	High	Moderate	Less		
Temperature	Daily Report	Below 25°	25° to 30°	30° to 35°	Above 35°	

Availability of water	General	Water from NWSDB to every floor	Water from NWSDB to few floors	Water for every floor from a site well	Water for few floors from a site well	Remote
H 4) Safety laws and their execution						
Level of following safety precautions	General	Higher	High	Moderate	Less	Lesser
Number of accidents	Daily report/Site Status Report	None	1	2	3	More than 3
Number of awards achieved	General	More than 2	2	1	None	
H 5) Inflation/fluctuation of material prices, interest rate/cost of capital						
Rate of inflation	General	Higher	High	Moderate	Less	Lesser
Range of variation	Stores Records	High	Moderate	Less		
H 6) Claim situation/high wind						
Proportion of exposed work	General	None	Below 25%	25% to 50%	More than 50%	More than 50%
Speed of wind	Daily report	Higher	High	Moderate	Less	Lesser

APPENDIX C – Activity Analysis Detailed Category Work Definition

Three Categories

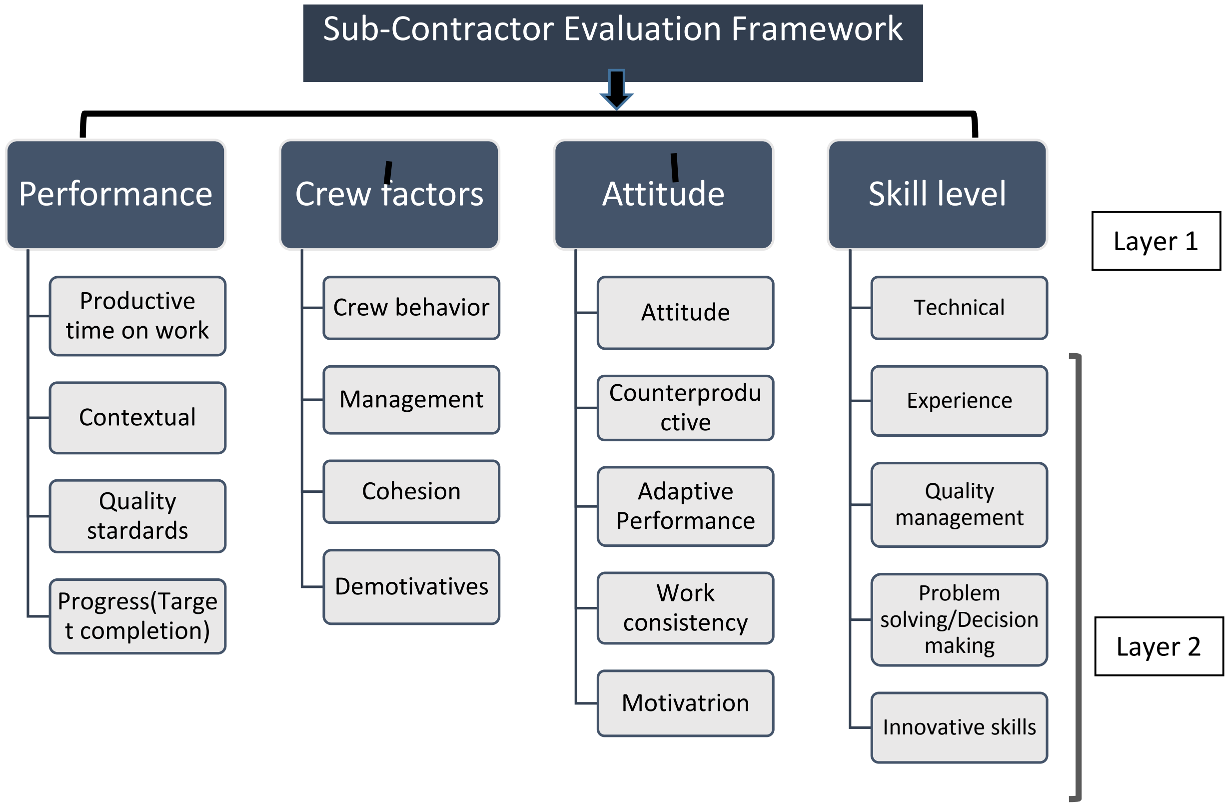
- Direct Work
- Supportive Work = Preparatory Work + Tools and Equipment + Material Handling
- Delay = Waiting + Travel + Personal

	General Activity Identification
Direct work	All physical productive work Picking up or laying down plumb bob, speed level, towel while doing the works Taking or marking up measurements immediately before performing direct work Holding tools, equipment, materials, or parts that are necessary for performing direct work Putting on or taking off gloves, belts, safety packs Cleaning or putting away tools and safety equipment during or after the completion of a task Necessary work area clean up or personal clean up, during or after the completion of a task Necessary supervision and direction of other crew members or technicians (e.g., directing an equipment operator when backfilling a trench) Reading prints or instructions before performing complex
Preparatory Work	Getting equipment - Getting tools or equipment from a location outside the immediate work area - Searching for tool or equipment at any of the above location Equipment travel -Traveling outside of the immediate work area with tool or equipment -Transporting tools or equipment to or from the area of the task assigned Getting material -Getting materials or parts from a location that is outside of the immediate work area Material travel -Traveling outside of the work area with or for materials or parts Planning -Receiving, giving, writing, or interpreting instructions

Material Handling	Transportation of materials from one part of the facility to another, not including items moved in the general area of the task or into their final position Ineffective Material Handling Activities - (Zhang 2008): Waiting for Materials, Searching for Materials, Double Handling, Improper Storage, Workforce Materials Congestion, Surplus/Waste/Housekeeping, Improper Positioning of Toolbox
Waiting	Equipment delay -Waiting for tools or equipment (must be ready and available for work) -waiting in line at a tool room window -waiting for another crew or technician to finish using tools or equipment -a long period searching for tools or equipment Material delay -waiting for another crew/technician to deliver materials -a long period searching for materials Crew delay -Wait while other crew members assigned to the same task work -an ironworker up on the steel waits for a crew member to “sling” a beam -crew members stand by while another member receives instructions from a supervisor -a helper stands by while a millwright refurbishes a pump Supervisor delay -Wait for instructions to begin, continue, or complete the task assigned -waiting to be assigned or lined out -waiting for permits or waiting to be signed off the task Miscellaneous delay -waits for reasons not related to any other delay activity -waiting for elevator -attending safety meeting, department meeting, or another kind of site meeting -meet with supervisors to discuss vacation, review, or personal matters -changing cloths that have become contaminated -personnel or vehicle security checks -delays that cannot be identified -waiting for a weld, material, or equipment to cool
Too ls	Obtaining, transporting, and adjusting tool or equipment in preparation for performing direct work

Travel	Walking or riding either empty-handed or without tools, materials, or technical information -traveling empty-handed -traveling with drawings, prints, or work packages -traveling between tasks with tools or equipment that form part of the tasks -traveling to or from breaks and lunch
Personal	Breaks; shower and wash up the allowance, rest -rest -smoke breaks -unauthorized breaks -visit the rest room -personal conversation not related to the assigned task -late starts and early quits -personal clean-up time, either before lunch or at the end of the shift -a technician working on an unauthorized personal task This category excludes normal breaks and lunch periods

APPENDIX D – Sub-Contractor Framework Criteria Ranking Questionnaire



This is to weigh the criteria to assess the sub-contractors performance.

Layer One Weightings

Please weigh the main four categories which assess the sub-contractor performance. Provide a percentage on each criterion based on the affectability.

Category	Weightage										
1. Performance	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
2. Crew Factors	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
3. Attitude	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
4. Skill Level	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%

Layer Two Weightings

Please weigh the sub factors under each main category which assess the sub-contractor performance.

1. Performance	1.1 Average Productive time on work	5	4	3	2	1
	1.2 Contextual performance	5	4	3	2	1
	1.3 Quality standards – Errors and reworks	5	4	3	2	1
	1.4 Progress (Target completion)	5	4	3	2	1
2. Crew factors	2.1 Crew behavior	5	4	3	2	1
	2.2 Team development	5	4	3	2	1
	2.3 Management	5	4	3	2	1
	2.4 Cohesion	5	4	3	2	1
	2.5 Demotivates	5	4	3	2	1
3. Attitude	3.1 Attitude	5	4	3	2	1
	3.2 Counterproductive behavior	5	4	3	2	1
	3.3 Adaptive behavior	5	4	3	2	1
	3.4 Work consistency	5	4	3	2	1
	3.5 Motivation	5	4	3	2	1
4. Skill level	4.1 Technical skills	5	4	3	2	1
	4.2 Experience	5	4	3	2	1
	4.3 Quality management	5	4	3	2	1
	4.4 Problem solving / Decision making	5	4	3	2	1
	4.5 Innovative skills	5	4	3	2	1

APPENDIX E – Error Survey Observation Sheet in Masonry Stage

			Masonry stage																													
Block			90* edges and corners			Horizontality & Vertical			Hollow			Dimension			Skirting line			Alignment/ Position			Thickness			Top reveil finishing			Completeness (Plaster)		
Floor																																
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Living area	walls	Wall																														
		DB wall																														
	Sofit																															
	Door frame																															
	Balcony	Bay w																														
		Wall																														
		Sofit																														
Bed room 1	walls																															
	Soffit	Sofit																														
		Ceiling																														
		Be plaster																														
	Do & Wind	Door fr																														
		Window fr																														
		Sunshade																														
Bed room 2	walls																															
	Soffit	Sofit																														
		Be plaster																														

	Do & Wind	Door fr																											
		Window																											
		Sunshade																											
Bed room 3	walls																												
	Soffit	**Sofit**																											
		Be plaster																											
	Do & Wind	**Door fr**																											
		Window																											
		Sunshade																											
Bath room 1	Wall																												
	Door																												
	Floor	Drop																											
		Kerb																											
Bath room 2	Wall																												
	Door																												
	Floor	Drop																											
		Kerb																											
Kitchen	walls																												
	Soffit																												
	Door																												
Store	Walls																												
	Door																												