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**Research Paper**

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# Productivity Rate Affecting Factors for a Highway Project

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***Abstract*—** Prior determination of productivity rate has a practical impact on time and cost estimates of highway projects. The accuracy of productivity rate measurement is highly related to how successfully one identifies and uses the critical factors affecting the productivity rate. Hence it is crucial to distinguish the critical productivity factor in highway construction projects. This study was initiated to identify and study the impact of critical factors that are affecting the productivity rate of highway construction earthwork. Given the dynamic and context-dependent nature of productivity, the study reviewed exhaustive works of literature and employed multiple embedded case studies to address the mentioned objectives of the study. Based on the cross-case and statistical analysis, it was found that the critical factors affecting the productivity rate of soft excavation were allowable working space or width of clearance, working hour, weather conditions (temperature, atmospheric pressure, and rainfall). Whereas for hard excavation, the critical factors that affect productivity rate were terrain type, the width of clearance, working hour, weather conditions (temperature, and cloud cover).

***Keywords****—Productivity rate, productivity affecting factors, Highway earthwork construction*

## I. INTRODUCTION

Reduced productivity of construction is one of the most daunting problems for the success [1] of construction projects; this aggravates the impact on developing countries like Ethiopia, where there is a limited amount of resources. Ensuring high productivity also improves the economic well-being of countries [1]. As a result, maintaining a decent track and improvement of productivity rates becomes crucial to confirm the success of a project. However, before the intents of improving productivity, the first step is to have a clear and reasonably accurate record of the current productivity rate. Hence to estimate reasonably accurate productivity rates, factors affecting productivity rates and their related impacts on productivity should be analysed prudently [1], [4], [5], [6].

Highway construction is one of the largest sectors of the construction industry. Highway constructions are outdoor construction operations that involve various types of activities that are profoundly affected by various operational and environmental conditions. Project managers and schedulers, however, usually utilize and rely upon previous productivity rate charts as their primary source to estimate the production rates of construction activities. The main limitation of these approaches is not data-driven and subjective on top of that relative nature of labour productivity; in other words, the unique project factors and site conditions cannot be considered quantitatively. In general, one must be able to measure after clearly understanding and identifying parameters that affect productivity [3], [7].

The rest of the paper is organized as follows. Section-II contains some previous studies related to factors affecting productivity rates. In section-II, I cover the data collection protocol for the research. Section-IV presents how the research method was designed and followed by a detailed explanation of the descriptive statistics employed by the research. Section-V presents the research findings with explanations, and Section-VI concludes research work.

## II. PREVIOUS STUDIES ON FACTORS AFFECTING HIGHWAY CONSTRUCTION PRODUCTIVITY

Working conditions in a highway construction site are very different from those in the workplace in the manufacturing industry. Contrary to the manufacturing industry, in construction, it is widely recognized that productivity rates are affected by many factors. Such as weather, project size and type, geographical location, site conditions, terrain type, skills of the construction crew, equipment efficiency and workability condition of materials, monitoring of performance, and so forth. Such factors either speed up or slow down the productivity of an activity.

[1] project success usually refers to the excellence of projects and it is predominantly evaluated based on three parameters; cost, time and quality. If a construction project is not successful, poor performance is reflected in time delays, cost overruns and quality defects

 

Previous research has attempted to identify and account for the range of factors that affect construction productivity performance. For example, [7] selected and studied significant factors that affect the productivity rate of construction activities. The selected factors were technical, management factors, site conditions, environmental conditions, scheduling issues, coordination issues, change orders, project characteristics, labor characteristics, external conditions, non-productive activities, unavailability of suitable equipment, material factors, and safety factors. The study of [13] also identified the significant factors that affect highway construction activities. In this research, based on the statistical analysis, it was concluded that the significant (significant) factors that affect productivity rate of highway construction activities were weather conditions, the geographic location of highway projects; traffic conditions; the quantity of work; and soil type for earthwork activities. Besides, the type of route, number of lanes, and type of roadway were significant factors affecting production rates.

## III. DATA COLLECTION

From reviewed international prior studies, the study was able to conclude potential factors that may affect highway construction activities. The potential factors to be studied were selected because they were found to be significantly affecting factors in several studies with several countries. Starting with this perspective, they were selected to be studied if they have a significant impact on highway construction projects for Addis Ababa's perspective. Table.1 below summarized the factors that were adopted by this research after reviewing the above literature. Potential sources that can be used to extract relevant data to make the analysis are also presented in Table 1 below.

Table 1. Summary of key factors and potential sources of information

| Key factors | Potential source |
|---|---|
| Weather conditions<br>Temperature<br>Wind velocity (Gust)<br>Cloud<br>Humidity<br>Atmospheric air Pressure<br>Rainfall | Ethiopian National Metrology Agency. |
| Effect of season | Contractors daily work report |
| Congestion and accessibility (width of clearance) | Contractors daily work report |
| Length of working hour | Contractors daily work report |
| Soil Types | Engineering report |
| Traffic flow | Engineering report |
| Type of terrain | Engineering report |
| Effects of contractors | Feasibility studies |

## IV. RESEARCH METHOD

The research primarily reflects a utilitarian/pragmatical[2] standpoint. In this study, the researcher has a strong belief the study problem is best answered through objective experiments or other quantitative measures. A pragmatic standpoint positioning response to the research questions and belief of objectivity posed in this study results in assuming an embedded multiple case approaches to conducting research. Embedded[3] multiple case study design offered the opportunity to explore, in-depth, the nature of productivity rates. The detailed research analysis method is described below in the sub-sections.

### *a) Analysis of the significance of factors*

For those potential critical factors identified earlier and pose a significant relationship with productivity rates, two types of analysis approaches were used for further significance analysis.

1. The statistical t-test (pooled t-test) or ANOVA was used for categorical variables
2. Regression analysis was used for continuous variables to explore the relationship between drivers and production rates

Sample size selection. Several studies suggest different approaches ranging from the simple rule of thumbs to power effect size calculations to determine the minimum number of a sample size to run multiple regression analysis. This study uses a G-power based calculation to confirm the required amount of data points to run the regression analysis.

Data organization. After identification of potential factors affecting highway construction activities from literature review and exploration of the construction site diaries, factors were categorized for the convenience of data configuration and analysis. Table 2 demonstrates the categories of factors used for the analysis.

[2] Pragmatism is a school of thought that believes the function of thought is tool for prediction, action, and problem solving and not to describe, represent, or mirror reality.

[3] Embedded case studies involve more than one unit, or object, of analysis and usually are not limited to qualitative analysis alone. The multiplicity of evidence is investigated at least partly in subunits, which focus on different salient aspects of the case. In this study, the subunits of study are the factors that affect productivity

 

Table 2. Data collection category for project factors

| Factor | Sub factor Description |
|---|---|
| Soil types | 1 = Fat / Heavy Clayey |
| | 2 = Lean Clayey |
| | 3 = Fat / Heavy Silty Clay |
| | 4 = Lean Silty Clay |
| | 5 = Fat / Heavy Clayey Gravel & Sand |
| | 6 = Lean Clayey Gravel & Sand |
| | 7 = Rock / Hard |
| Terrain type | 1 = Flat |
| | 2 = Rolling |
| | 3 = Mountainous |
| | 4 = Escarpment |
| Season | 1 = Kiremt or Meher (Summer) |
| | 2 = Belg (Autumn) |
| | 3 = Bega (Winter) |
| | 4= Tseday (Spring) |
| Traffic flow | 1 = Rarely Congested |
| | 2 = Only Rush Hours Congested |
| | 3 = Most Hours Congested |
| Contractor type | 1 = A |
| | 2 = B |
| | 3 = C |
| | 4 = D |

After configurations of data, outlier data encoded to be analyzed were detected through Mahalanobis distance calculation was employed. Following that, to maximize the accuracy of identifying outlier data points form parent data set comparison of Mahalanobis with a chi-square distribution with the same degree of freedom was employed.

## V. RESULTS AND DISCUSSION

For the factors that are continuous and has numerical meaning, a scattered plot diagram was used to show the correlation of factors with the productivity rate. Nominal variables, the box-plot diagram was used to show how they are related to the dependent variable (productivity rate).

### *a) Case study cross-case analysis*

Form the comparison of percent unit productivity rate with the considered case studies. The analysis shows there is an overestimation of the average productivity rate of the AACRA's SPD manual when observed against the mean productivity of case studies. The overestimation is attributed to the factors that affect the productivity rate was not considered when the SPD manual was developed. Besides, the manual was developed, relying heavily on the expert's best judgment.

In the cross-case analysis of the study, a summary of findings and discussion on factors that appear to correlate with independent and dependent variables. The Pearson correlation of productivity rate with independent factors for each highway activities is presented in appendix B.

### *b) Effect of the width of clearance on productivity rate*

Using Pearson correlation, it was able to find out the factor width of clearance or allowable working space has a strong correlation with a productivity rate of highway earthwork activities.

Working space showed a positive effect on the productivity rate of highway excavation; this means as the working space increases, productivity rate also increases for all the case studies on both soft and hard excavation of highway construction. The result was explained by the fact that operators can work efficiently where increased working space is allowed as it creates the ease to manoeuvre and operate equipment efficiently.

As discussed in the literature review of this study, an understanding from previous studies like [9] and [11] productivity deteriorates as the congestion or lesser allowable working space is allowed. Similarly, form the analysis of case studies of this study, it is possible to conclude the width of clearance or allowable working space has a directly proportional effect with a productivity rate of highway soft and hard excavation. Hence findings of this research corroborated with existing theory and revealed there is a replication within cases.

### *c) Effect of a working hour on productivity rate*

Pearson correlation testing of a case study I soft excavation and case study III hard excavation showed a strong correlation between the working hour and productivity rate. However, an insignificant correlation was observed on a case study I hard excavation, case study II hard and soft excavation, and case study III soft excavation; this could be attributed to limited data points used for analysis. From the analysis of the case study-I, the productivity rate of soft excavation showed different trends. Likewise, findings of case study III hard excavation indicated different trends of productivity rate, which was explained by the fact that operation could be faster in the morning with new energy followed by fatigue after working 3 hours and again gained momentum after the break and intending to finish the started task.

On the contrary case study, II soft excavation and hard excavation of case study III showed a negative effect, i.e., as the working hour increases, the productivity rate decreases. Previous studies that conduct relationships of working hours with productivity rates noted that the productivity rate would deteriorate as the working hour goes beyond 50 hours per week [12]. Some of the case considered in this study shows an increase in the productivity rate. The finding of this study corroborates with existed knowledge or theory.

### *d) Effect of weather on productivity rate*

Based on the analysis, the productivity rate shows a decrease in value as cloud cover increases or (as the visibility decreases) for all the case studies considered in this study. Analysis of other variables reveals productivity rate shows a decrease in value as humidity increases for all the case studies considered in this study. Previous studies like [9] and [10] explained adversarial weather conditions

 

have a negative effect on the productivity rate. The same is valid for rainfall.

*e) Effect of temperature on productivity rate*

The effect of temperature on productivity rate revealed a correlation on case study III hard and soft excavation. This could be attributed to the recorded temperature amount in a due phase of construction was optimum and didn't affect working conditions that much.

In case-III, when soft excavation compared with hard excavation showed different results, this could be attributed to other factors that were affecting productivity predominantly, then temperature does. This can be explained further by the fact that the optimum temperature was recorded (on average, the temperature record ranges from 15-18°C).

*f) Effect of cloud cover on productivity rate*

Through Pearson correlation testing, the effect of cloud cover revealed a strong correlation on the productivity rate of highway earthwork activities in case study II hard and soft. This was explained by an insignificant amount of cloud cover that was recorded on a case study I and case study III.

The effect of cloud cover has an indirect relationship with the productivity rate of highway earthwork activities. This means productivity rate deteriorates as the cloud cover increases or visibility decreases. This finding replicates with existing theories of productivity rate deteriorate as visibility decreases.

*g) Effect of a gust on productivity rate*

Through Pearson correlation testing, the effect of gust revealed a correlation on the productivity rate of highway earthwork activities in case study II hard and soft excavation and also in case study III hard excavation.
Form the analysis finding effect of gust showed three trends in case study II and showed improvement on productivity rate in case study II soft excavation and case study III hard excavation this finding doesn't corroborate with existing theories of adversarial weather conditions affect productivity rate. This investigation may be attributed to the fact that the optimum amount of gust air is recorded in a due phase of construction. Therefore, it is hard to reach to a generalization of productivity rate improves as gust increases.

*h) Effect of rainfall on productivity rate*

Based on Pearson correlation productivity rate of highway earthwork activities showed and strong correlation with rainfall amount in case study II soft excavation. However, for the case study, I and the case study III rainfall amount weren't found to be highly correlative affecting factors this could be attributed to the project setting of the case sites.
Form the analysis finds, rainfall and precipitation amount have a negative relationship, this can be explained by the fact that when the moisture of the working site increases, site operation activities and manoeuvring will be affected.

*i) Effect of soil type on productivity rate*

Using the analysis of variance testing correlation, the productivity rate of highway activity and soil type confirm there is a strong relationship between them. This was evidenced by finding in the case study I of soft excavation. It was noticed that the productivity rate increase when the soil type was fat heavy clay while the lowest productivity was recorded when the soil type was lean clay gravel and sand. This finding contradicts with CAT performance manual and previous studies like investigations of [13]. This may be attributed to other factors are predominantly affect the production rate of highway construction soft excavation.

*j) Effect of seasonal change on productivity rate*

Form t-test correlation testing the effect of seasonal change sowed a correlation with productivity rate in case study II soft excavation. From this investigation, a higher productivity rate was recorded when the season was Belg, and a lower productivity rate was recorded when the season was Kiremt.

*k) Effect of terrain type on productivity rate*

Form a conducted analysis of the T-test for the case studies, the effect of a difference in terrain type showed a correlation with a productivity rate of highway construction earthwork activities. Form the analysis. It was able to notice there is a visible difference in production rate among different terrain type settings. Form the analysis conclusions productivity rate is more likely to increase in flat terrain type settings for both soft and hard excavations.

*l) Effect of contractor type on productivity rate*

Form a conducted analysis of the T-test for the case studies selected Contractor type showed a correlation with a productivity rate of highway construction earthwork activities. Form the analysis, it was able to notice there is a visible difference in production rate among the contractors, and inconsistencies of production rate were observed for different activities in a given contractor; this may be attributed by the methodology or the specialty of contractor types on some activities.

## VI. CONCLUSION

Based on the statistical analysis, it was found that the significant factors affecting production rates of soft excavation were allowable working space or Width of Clearance, Temperature, Pressure, Working hour, and Rainfall. While for hard excavation, the critical factors that affect productivity rate were Terrain type, Width of Clearance, Working hour, Temperature, and Cloud cover.

Form this study. It can be concluded that the estimation of the productivity rate should have an objective lens of measurement as it poses sufficiently enough affecting

 

factors to mislead the judgment of experts.

Engineers and schedulers should consider several factors while estimating production rates of highway activities. Engineers and schedulers can use the developed predictive model for progress tracking and future estimating & bidding guidelines.

The daily work reports are a tool for both managing the current project and planning future projects. Therefore, an innovative and standardized framework of data collection, storage, and record-keeping protocols should be developed. This can be achieved by; planning the level of detail required of in data collection and monitoring the efficiency of the developed standard DWRs data collection protocol.

The study reports and findings mentioned above and documents are worthless without accounting accurate daily work for this kind of research. Therefore, the daily work reporting system should have a standard and incorporate as many factors as possible to secure a consistent measure of actual productivity rates.

Form this study investigation. It is recommended to use the identified significant affecting factors into consideration while preparing or revising the SPD document.

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