JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRAGUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERONG

CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

ANALYSIS ON EARTHWORK EQUIPMENT PRODUCTIVITY USING ARTIFICIAL NEURAL NETWORK ON HIGHWAY PROJECTS IN ADDIS ABABA

A Thesis Submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree Master of Science in Construction Engineering and Management

By
Tofik Eshetu Hassen

August 2021

Jimma, Ethiopia

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Approved by Board of Examiners

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DECLARATION

I declare that this research entitled as Analysis on Earthwork Equipment Productivity Using Artificial Neural Networks on Highway Projects in Addis Ababa: is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.

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As research Adviser, I hereby certify that I have read and evaluated this thesis paper prepared under my guidance, by **TOFIK ESHETU HASSEN entitled "ANALAYSIS ON EARTHWORK EQUIPMENT PRODUCTIVITY USING ARTIFICIAL NEURAL NETWORK ON HIGHWAY PROJECTS IN ADDIS ABABA:"** We recommended that the thesis could be accepted as partial fulfilment of the requirements for the Degree of Master of science in Construction Engineering and Management

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ABSTRACT

Equipment productivity is a key element in determining the successful completion of construction project for maintaining the scheduled construction activities especially in highway projects. The overall aim of the research is to analyze earthwork equipment productivity on highway projects in Addis Ababa. The survey method of data collection was employed to collect data from the stakeholders of highway projects in Addis Ababa. The collected data was analyzed using relative importance index (RII) and artificial neural network (RII).

Accordingly, the research has identified three major factors which were the experience of the operator as human related factor, age of equipment as equipment related factors and interfacing of activities as management related factors. These factors were the common factors that affect the productivity of both excavator and truck while bucket capacity, height/depth of cut and horse power of the engine for the excavators only and size of truck and cycle time required for loading, hauling, damping and returning for the trucks only. After quantifying and measuring these factors, the mathematical forecasting model is developed for predicting the excavator and truck productivity of the future project with 0.000148 and 0.00116 of mean squared error (MSE) and 0.98131 and 0.96375 of correlation (R) for excavator and trucks respectively which indicate the high performance of the model to forecast the productivity. It also developed a model for excavator age with MSE = 0.00127 and R = 0.9647. Using the developed model sensitivity of factors were analyzed.

The analysis indicates bucket capacity, type of soil, time taken due to interfering activity such as waiting time for trucks, and equipment age are identified as high sensitive influencing factors for excavator and cycle time for trucks productivity. For this reason, these factors especially the equipment age for excavators and cycle time for the truck should be the major and continual concern of the construction practitioners for proper management of the productivity of excavator and truck productivity. Generally, this research properly analyzed the factors affecting the productivity of excavator and truck for improving productivity and the forecasting model is developed for better duration estimation, scheduling, cash flow planning and resource optimization for highway projects in Addis Ababa.

Key words: - *Artificial neural network, Equipment productivity, Mathematical forecasting model, Sensitivity analysis*

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ABBREVIATIONS

AACRA	Addis Ababa city road authority
AI	Artificial intelligence
ANN	Artificial neural network
CII	Construction industry institute
CLP	Construction labor productivity
EP	Equipment productivity
F j	Job management factor
F w	Effective working hour
GIS	Geographical information system
GPS	Geographical positioning system
MSE	Mean absolute error
NN	Neural network
Q a	Actual productivity
Q p	Peak productivity
R	Coefficient of correlation
RII	Relative importance index

CHAPTER ONE

1. INTRODUCTION

1.1 Back Ground of the Study

Modern construction execution is characterized by effective and efficient utilization of construction equipment to accomplish numerous construction activities. Construction equipment today is specifically designed by the manufacturer to perform certain mechanical operations that accomplish a work activity. Heavy construction work typically highway constructions require high-volume or high-capacity equipment. These requirements are driven by the large amount of work to be done and the amount of time to complete it. In highway projects, the total project execution is usually divided into sections or packages and further into sub-sections or sub-packages such as mass dirt and material excavating and moving, stabilizing and compacting, ground material moving and hoisting, concrete and asphalt paving, and finishing, for the ease of working and resource allocation (Douglas, D et al, 2006). The resources are generally allocated to the working teams/groups based on productivity and the total volume of work allocated to the respective teams.

Since most of these work packages are executed using equipment, these unique features make highway projects an equipment-intensive project. As a result, the desired product of highway projects is highly controlled by the productivity of such equipment.

The planning and estimates are done before the execution in any project; therefore, when equipment managers can achieve accuracy in terms of computing productivity offered by equipment and feasible way of acquiring equipment we can plan our project with more precision. Since equipment productivity is the main issue in construction projects in general and highway projects in particular, it should be the major and continual concern of the equipment managers (Ashish, S.and Pardeep, K., 2016).

The productivity of equipment is affected by numerous independent factors which should be identified and quantified for the better estimation of accuracy and maximization of productivity. Beyond defined scheduled rates and standards available, it is necessary to focus and identified factors that play the main role in the computation of productivity for better highway project planning and management of equipment production. Since equipment's being a necessity of any construction project still needs major research to maximize and improve the forecasting accuracy of productivity.

Researchers throughout the world adopted available productivity estimation techniques to develop a forecasting model for the estimation of equipment productivity. The first technique is statistic-based called the multivariable linear regression. It attempts to map the relationships between the influential factors and productivity with explicit mathematical functions. However, the statistical technique could oversimplify the relationships compared with the neural network technique. The second technique that has been widely used in recent research for identifying the relationships and modeling equipment productivity is the neural network. The neural network technique imitates a pattern recognition process of the human brain (Sonmez R, 1996).

Generally, the main aim of this study was to identify factors affecting equipment productivity and developing a mathematical forecasting model for the earth work equipment productivity using an artificial neural network (ANN) on Addis Ababa high way construction projects.

1.2 Statement of the Problem

Productivity loss is the sever and greatest problem in construction industry (CII, 2000). Estimating on-site productivity is essential for estimating the time and cost required to complete construction operations (O glesby et al. 1989). Production estimation in earthmoving operations is carried out manually. Using manual methods has been recognized to be time consuming, not necessarily accurate and can result in tardy corrective actions, leads to undesirable cost consequences (Sacks et al. 2002). Equipment’s being a necessity of any construction project still needs major research to improve pre-estimation accuracy for productivity and costs related to equipment (Ashish, S.and Pardeep, K., 2016). According to (Abebaw, 2014) he proposes for future study to identify factors in order of their impact on equipment productivity in highway projects.

Highway project’s success is greatly influenced by the equipment productivity performing the earthwork. Over estimation of equipment productivity causes incorrect project planning, scheduling and cash flow planning in Addis Ababa highway projects. The project stakeholders use ideal productivity parameters and long-lasting techniques rather than observed datasets and recurrent techniques to determine the productivity of equipment. In addition, it is observed that delaines problem is not always a real problem in Addis Ababa highway projects rather it is due to incorrect project duration estimation and scheduling.

The difference in expected level of outcome compared to the rated outcome leads Addis Ababa highway project to untimely completion, claims and cost overrun of the whole project. This is mainly due to not properly identifying and controlling factors affecting productivity and the lack of having recent equipment productivity forecasting models. Even though these problems handicap the highway projects in Addis Ababa, stakeholders fail to properly analyze equipment productivity.

Despite of the fact, there is no sufficient researches are conducted to analyze earthwork equipment productivity. For this reason, it is initiates to identify, develop mathematical forecasting model using artificial neural network (ANN) and analyze the sensitivity of factors of productivity of earthwork equipment's in Addis Ababa highway projects.

1.3 Research Questions

- What are the factors that affect the earthwork equipment productivity on highway projects in Addis Ababa?
- How to develop earthwork equipment productivity forecasting model using artificial neural network (ANN) for future highway projects in Addis Ababa?
- Which factor is sensitively affecting the earthwork equipment productivity on highway projects in Addis Ababa

1.4 Research Objectives

1.4.1 General Objective

The general objective of this research was to analyze earthwork equipment productivity using artificial neural networks on highway projects in Addis Ababa.

1.4.2 Specific Objectives

- To identify factors affecting productivity of earth work equipment's on highway projects in Addis Ababa
- To develop mathematical forecasting model for productivity of earthwork equipment's using artificial neural network (ANN) for future highway projects in Addis Ababa
- To analyze the sensitivity of factors affecting productivity of earthwork equipment's highway projects in Addis Ababa

1.5 Significance of the Research

Highway projects are equipment-intensive project in which the desired product of the projects is mainly controlled by the productivity of equipment. Since the factors are identified, the Addis Ababa highway project stakeholders can control and mange properly for better productivity of the equipment's. The developed model uses for forecasting the excavator and truck productivity easily and with better accuracy for determining the optimum allocation of the trucks for the given excavator which helps for best utilization of project resources. The study attempts to be the foundation on planning, scheduling and cash flow planning could be established for the future Addis Ababa highway project and any deviations can be best avoided.

According to Clients' perspective, shortens construction schedules, and achieves better returns on investments. From the contractors' perspective, increased productivity leads to more satisfied customer, leads faster turnover, and increased profits. Also from both Clients' and contractors' reduce unnecessary time claim due to incorrect duration estimation and dispute and improve good relation between them. Generally, this research will be used by the construction practitioners of the construction projects to take account of these factors and need management efforts at an early stage to minimize the time and cost overrun. Based on the investigated critical factors can serve as a checklist for construction practitioners to give attention to enhance the productivity and its accuracy of estimation. Therefore, the finding of the research contributes to the improvement of equipment productivity and better forecasting of productivity which helps project managers and project planners.

1.6 Scope of the Study

This study was conducted on highway projects in Addis Ababa, which were active projects and on the project status of earthwork. The data collected and the conclusions that are evolved from this study is only applicable for highway projects in Addis Ababa. The research focuses on a fleet or pair of excavator and truck types of earthwork equipment's which are mostly executing the earthworks highway projects in Addis Ababa. As a result, the factors affecting equipment productivity are identified, measured and quantified as well as actual productivity of excavators and trucks utilizes on earthwork status of highway projects in Addis Ababa are analyzed as a case study.

1.7 Limitation of the Study

The lack of time and budget allotted to the thesis was makes the research scope to focused only on the development of productivity forecasting model on the excavator and truck types of earthwork equipment.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 General

Construction Industry like any other heavy industries uses huge amount of resources off and on the field in the form of materials, plants and equipment and human resources along with money, time and space. However, construction industry unlike other organized manufacturing sectors does not execute same set of operations throughout its project cycle. In order to execute such varied works in different phases of project, any big construction company has to keep a number of various plants and equipment (Singh, 2018).

Construction equipment" (CE) or "Heavy equipment" refers to heavy-duty self-propelled vehicles, specially designed for executing construction tasks. Its use has significant importance in the successful realization of civil projects; it, therefore, represents a major capital investment for the construction industry. In this research, the term CE refers to the machinery that is used especially for earth moving operations (excavators, dump trucks, loaders, etc.Those earthworks mainly consist of two basic processes: excavating, hauling, (Peurifoy, R.L. & Ledbetter, W.B., 1985).

Similarly (Fu, 2013) states that heavy construction equipment (e.g. loaders, excavators, hauling trucks) has a significant role in earthmoving operations. Performance of equipment productivity reflects the whole project performance. Productivity is defined as the total output from the entire fleet. However, only examining the productivity is unsatisfactory for assessing the performance of an operation, extensive analysis is required to identify the different factors that could affect the productivity and its performance. Such extensive analysis comprises the collection and analysis of data concerning the performance of equipment.

Earthmoving is a key and crucial process in most infrastructure projects. Earthmoving operations represent a considerable portion of civil infrastructure projects such as highways, mines, and dams (A. Hassanien, 2002)Soil is usually moved from a location, in the case where it exceeds the required quantities, and carried to another location to be dumped or used as filling materials. The topological survey coupled with the construction of a new highway indicates several locations where cuts or fills are required. However, the surplus soil should be stored in an accessible area to be used if required otherwise; the remaining part of surplus soil is transported and dumped in a remote area (Patrick, 2001).

As earthmoving operations are common and crucial in civil infrastructure projects, many endeavors have been done to improve these operations. Productivity of earthmoving operations has been studied considerably over decades. Various factors affect the productivity of hauling equipment that has a vital role in the success of earthmoving operations (A. Salem, et al., 2017).

2.2 Earthwork Equipment's

This modern equipment can be completed with great pace and efficiently bringing down the total expenses for earthwork. A large initial investment is required for earthmoving machinery which can be economically advantageous only when fully utilized. The unit rate of earth work based on total expenditure falls progressively as the earthmoving equipment utilized for a longer period of its life and a job involving large quantities of earth work, spread over the lifetime of equipment machinery would be much cheaper than manual labor. Construction Equipment is not the only subject of mechanical engineers. Civil engineers also need to be acquainted with the subject. Civil engineers always look at the rate of production. He wants production at minimum cost so that he can control the rates of contractors (Shubhangi, et al.,2019).

a. Excavators

A hydraulic excavator is a power-driven digging machine. It is used primarily in road construction work for trenches or mass excavation below the natural ground surface, lifting of objects or soil, loading trucks with excavated materials, pipe placing, and sometimes for digging out buried objects. The production rate of the excavator is a function of the digging cycle; time required to load the bucket, the time required to swing with a loaded bucket, the time required to dump the bucket, and time required to swing with an empty bucket (Nunnally, 2007).

This is a basic earthmoving machine that can be used for different works with different types of front & back attachments. A basic shovel has the means of propulsion of the machine, of revolving the superstructure around, and of operating the head attached to it. Hydraulic excavators are classified by the digging motion of the boom and stick to which the bucket is attached. (Shubhangi, et al.,2019).

Excavators can accommodate numerous attachments such as pinchers for lifting logs or pipes, a jackhammer for busting up concrete or compacted soil, or a magnet for metal material moving. Excavator attachments are similar to backhoe attachments and are run by hydraulics. Along with the many

attachments, excavators can be equipped with long reach booms, demolition arrangements, different shoe selections, and different quick coupler systems. Bottom dump buckets permit more accurate loading of narrow trucks and reduce spillage.
Heaped bucket capacities range from very small (0.1 cy), to extremely large for mass excavation (over 7 cy). Most excavators accommodate a range of bucket sizes. Maximum digging depths range from about 7^0 to 34^0, depending on the boom and stick lengths and combinations. Lifting capacities over the front of the excavator range from about 1300 lbs. to over 64,000 lbs (Douglas D, et al., 2006).

Trucks

Trucks haul at relatively low costs because of their high travel speeds and moderate to large payload capacities. The productive capacity of a truck depends on the size of the load and the number of trips it can make in an hour. Highway load limits and truck weight capacity may, however, limit the load a truck can haul. The number of trips completed per hour is a function of speed and load/unload time. The number of trucks employed should be balanced with the loading equipment for a cost-effective operation. Tires for trucks and all haul units should be suitably matched to the job conditions.

In transporting excavated material, processed aggregates, and construction, and for moving other pieces of construction equipment trucks are used because their high travel speeds provide relatively low hauling costs. The use of trucks as the primary hauling unit provides a high degree of flexibility, as the number in service can usually be increased or decreased easily to permit modifications in the total hauling capacity of a fleet (Shubhangi, et al.,2019).

2.3 Overview of Equipment Productivity

Major Construction Projects are completed by huge input of manpower and equipment resources. Successful completion of these projects depends on the efficient utilization of these resources. The profitability and effectiveness of the project are the outcomes of better management and control of the manpower and equipment resources. Monitoring and maintaining the productivity of manpower and equipment resources in line with the standards determined is a challenge for the top management of the project and it makes or breaks the project (Venkatesh, M et al, 2019).

The utilization rate of construction equipment is concerned with identifying the total available time of the onsite equipment for production. The efficient utilization of construction equipment plays an indispe nsable role in the success of a construction project. It could contribute not only to support the construction equipment management but manage the project cost. To achieve the maximum equipment investment return, it is necessary to collect the utilization information of onsite equipment in a timely and accurate manner (Shubhangi, et al.,2019).

The expected work output per time unit (hour or day), usually termed productivity, determines the cost the duration of construction activities.

According to (Jose, 2001) productivity is the ratio of useful work out put to the time spent to complete that work. The productivity of modern construction equipment has increased with the increase in sophistication and modernizations, thus allowing the cost of operations to remain relatively stable. Inefficiencies and loss of productive time can increase the cost.

The equipment capability to perform an assigned task under a given situation can best be determined from the on-site actual trials or it can be assessed from its past performance records of operation under similar site conditions. The main factors which affect the performance of equipment/plant and for which allowance must be made when estimating output are of two types,

1) Factors affecting hourly output

2) Factors affecting overall output.

More importantly the earthwork is the first activity for any project and other activities are dependent on this. Here the planning managers will have to allocate the resources to complete the sector of earthwork in stipulated time. The factors affecting the output of excavators are numerous and such a study can help in identifying the factors and for assuming a realistic production figure. The cost of any project will vary from the purchase of equipment, so it is necessary to take a look at it with proper planning (Shubhangi B. et al 2019).

Better productivity management will produce significant improvement in meeting the predetermined targets of the project. Better productivity management includes measuring the actual productivity, comparing with benchmarks, identifying the factors affecting the productivity and implementing management tools for improving and increasing the productivity. Productivity Management has to be followed in every level with push from the top level of the project. Productivity hence is a driving force in a construction project (Venkatesh, M et al, 2019).

According to (Mohamed Abdelaal and Hassan Emam, 2016) study which was done with industry practitioners to find major factors which are impacting on equipment productivity. It includes some of the major factors like site working time, managing site equipment, communication, work schedule, working tasks types, safety measures, quality control, managerial factors, skilled laborers, motivation, scope change, availability of material, and over planning and work methodology.

2.4 Factors Affecting Equipment Productivity

Productivity is the outcome of several interrelated factors. Discussed below are various factors affecting construction productivity and are reviewed from past studies

Group I: Operators/ Human factors

1. Lack of experience
2. Disloyalty
3. Personal problems
4. Lack of training

Group II: Resource/ equipment factors

1. Delay in placing the equipment
2. Two or more groups sharing an equipment
3. Equipment breakdown
4. Lack of proper maintenance
5. Spares not available

Group III: Management factors

1. Lack of supervision
2. Improbable planning and expectation of labor execution
3. Communication between site administration and operator

4. Non-payment of charges/ Delay in payment

5. Interfacing of activities

Group IV: Environmental factors

1. Temperature and humidity effects

2. Rain, snow, wind effects and sandstorm

3. Type of soils

Group VI: Other factors

1. Rework

2. Compatibility and steady among contract records

3. Condition of haul road

4. Excess travel/ lifting

5. Obstacle on site

(Priyanka, M. et al, 2019)

The study appeared that all the 3 groups-contractors, clients, and specialists of members for the most part established that 10 impacting factors influencing equipment productivity organized in descending arrange of RII are:

- Lack of ability of operator
- Rework
- Lack of supervision
- Improbable planning and expectation of labor execution
- Delay in placing the equipment
- Two or more groups sharing an equipment
- Communication between site administration and operator
- Equipment breakdown
- Lack of proper maintenance
- Non- payment of charges/Delay in payment

According to (Venkatesh M.P and Saravana Natarajan P.S, 2019) the factors which affect the productivity of equipment's are

1. Non availability of work front (28%)- this is the important factor affecting the productivity of equipment in construction projects. When an excavator is ready for starting excavation, it is observed that the live wires and pipe lines that are in that area are not cleared.
2. Coordination between Equipment (22%)-This is one important aspect affecting the productivity of equipment in a major construction project. Eg – Transit mixer with concrete loaded fully is waiting for pump to be placed in position and started. Excavator doing excavation but there is no tipper for hauling etc.
3. No proper planning and No proper supervision (34%)- As observed in manpower productivity, proper planning of the operations of the equipment and proper supervision to implement the plans provide the platform for increasing the productivity of equipment to a considerable extent.
4. Other factors like Interfacing of different works (6%), Skill of the operator (6%) and Climatic factors (4%) leading to less efficiency of using the equipment also affects the productivity of equipment to a greater extent.

According to Makulsawatudom and Emsley (2001) following are main contributing factor for low equipment productivity in the construction industry

Human Factor

Lack of construction material: stated lack of construction material is the most critical factor affecting productivity. This is because if construction material is not available, machinery will not work at all. It occurs mainly due to "contractor liquidated problem" and when contractors have insufficient finance to procure the necessary materials. On the other hand, when suppliers have previous experience, as there is lack of payment, they hold material delivery. Lack of construction material may also occur due to "incompetent project manager", who give inadequate priority of material delivery and lack of knowledge about the material. Incompetent supervisor: The supervisor may be responsible for defective works and for using in appropriate equipment. One cause of this factor is "poor human resource management" where by inappropriate person care the supervision role.

Productivity can be affected if required materials, tools, or construction equipment are not available at the correct location and time. If the improper tools or equipment are provided, productivity may be negatively affected. The size of construction sites and material storage locations have a significant impact on productivity especially in infrastructure projects where there are often large space areas for work, and laborers spend time moving materials from inappropriate storage locations, thus resulting in productivity loss (Sanders and Thomas, 1991).

Rework: More rework needs more time and cost for construction. This problem mainly caused by incompetent artisan and incompetent supervisor. Lack of working skill and knowledge of drawings are character of incompetent artisans, while lack of experience and leading to deficient supervision is a characteristic of incompetent supervisor. Other causes for rework were change order and incomplete drawings.

Operator's efficiency: Operators work experience, motivation from the management to the operators and operator own capacity is one of the main human factors affecting equipment productivity in the construction work (Gashaw, 2009). A lack of labor experience is the factor which negatively affects labor productivity and proves that, to achieve good productivity, labor plays a significant role. Contractors should have sufficiently skilled laborers employed to be productive. If skilled labor is unavailable and a contractor is required to complete specific tasks with less-skilled labor, it is likely that productivity will be negatively impacted. Lack of compensation and increased laborer age negatively affect labor productivity because labor speed, agility, and strength decline over time and reduce productivity (Heizer J and Render B, 1990).The personal attributes of workers contribute more of the factors that directly affect the productivity. The factors are as.

1) Worker skills, experience, training and qualification,

2) Physical and mental ability,

3) Use of both skills and ability for the production process.

High skilled workers can achieve high ability than unskilled workers (Prachi R Ghate and Pravin R Minde, 2016) stated that skills and ability of workers are main factors that affect productivity.

(Vaishant Gupta and R Kansal, 2014) conducted and questionnaire survey of 37 construction industries and by using relative importance factor (RIF) found that 69.72% of skill and ability factors affects the productivity. There is increase in demand of skilled labor due to use of latest technology on construction sites as computerized and Hi-tech machines and plants increase productivity

Management Factor

Poor coordination between the site and the office is one of the main contributing factor for this problem. Project manager skills and attitudes influence construction productivity. In many organizations, productivity is low even though the latest technology and trained labor are made available. Low productivity is often because of inefficient and immature management. Advanced technology requires knowledgeable laborers who work under professionally capable leaders (Mohamed Abdelaal and Hassan Emam, 2016).

Inspection time frequency: The main cause of this factor is inadequate management. For example, insufficient numbers of supervisors employed to minimize cost of employees. As a result, repeated instructions occur to rectify defective works not stopped timely. This may cause construction equipment used repeatedly for the same work once and again.

Inspection delays: This factor has a considerable effect on productivity. It may cause equipment idleness. This in turn affects the equipment valuable production time. Inspection delay mainly occur due to "incompetent project manager" who does not prioritize job inspection and who does not realize job interdependency.

Poor Communication: It is the main factor for defective work and come from "incompetent communication skill". To minimize this problem, formal documentation, such as work procedure, manual, chart and guidelines are better than informal or verbal communication.

In contrast, Good communication is necessary to efficiently complete a project. Some of the more commonly used forms of work site communication include two-way radios, mobile phones and mobile wireless internet. Lack of communication can cause delays due to mistakes causing rework, lack of information causing downtime, and misinterpretation. Other common problems associated with communication on construction projects include understanding the chain of command and continuously communicating about the project and foreseeing potential problems in the future. This can be avoided by holding regular project management team meetings (Cingoranelli, 2007 Cited at (Kuykendal, 2007)). As stated in the Project Management Institute's Standard (PMI, 2009), about 90% of project manager time is spent in communication.

Lack of Equipment: To obtain the intended quality or output from the machines, the machines are need to be available at the required time. For example, ignorance of preventive or predictive maintenance program, shortage of spare parts and the use of old and obsolete equipment causes this problem. Beside to this overestimate of the capacity of the machine may result insufficient number of machine for utilization.

Managing site equipment:

The Construction Industry Institute states that material and equipment currently comprise 50-60% of construction project costs (TaskForceMaterialManagement, 2007). In addition, lack of suitable equipment is considered one of the major causes of construction delays.

Good equipment management begins at the time the equipment is purchased/hired. Purchasing/hiring the proper equipment that matches the need of assigned tasks, while achieving the lowest costs, is necessary to attain suitable equipment management. Proper record keeping provides information for planning maintenance/ replacement, ensuring that they occur at the proper time. Managing equipment includes preventative maintenance, planning maintenance, and replacement activities (O'Brien et al 2007).

Incomplete drawings: When there are incomplete, unclear and impractical drawings, it takes time for revision or clarification of drawings to meet specification. This leads to construction delay waiting for clarification and it is one of the main factors affecting productivity.

Poor site coordination: Poor site preparation is the cause of this factor, which may lead to difficulty and unsafe working condition. Work condition varies from site to site, type of job, material handled or soil to be compacted. Any hindrance or obstacles are work factors for loss of equipment productivity.

Machine Factor

Size of the machines: size of the machine is a machine related factors that affects equipment productivity in the construction work. The larger the bucket size more material can be handled with the bucket and the higher the engine capacity the more power to push material or more power to excavate stiff work condition. (MAkulsawatudom, A and Emsley, M , 2011)

External factors:

Various natural factors affecting equipment productivity collected from previous studies are weather conditions and geographical conditions. Others factors such as fuel, water, and minerals also affect productivity to a certain extent. Productivity is found to be highly affected if the weather is too extreme (too cold, heavy rainfall, or too hot.) (Mohamed Abdelaal and Hassan Emam, 2016).

There are some other issues than labor and management that harms productivity in high manner, such as social factor, economic factor, weather conditions, labor unions, legal issues etc (Shinde V. J., Hedaoo M. N., 2017).

Site working time:

During construction projects, working overtime initially results in increased production rates, but continuing overtime may lead to increased costs and reduced productivity (Hinze, 1999). Alinaitwe et al (2005) found that employees in the field only work effectively for 3.5 hours of an 8-hour shift and spend only 20% of time on direct value-adding activities.

Work schedules:

When there are early delays in projects, compression of the overall time frame for later activities is often used to compensate interruptions and to complete assigned tasks on schedule. From a professional scheduling perspective, schedule compression may be possible without accelerating individual work activities by utilizing float in project schedules; however, in many projects, schedules are not fully resource loaded. As a consequence, an updated schedule reflecting delays may show the project finishing on time without shortening individual activities (National Electrical Contractors Association, 1983). 2.13. Over planning and work methodology:

Improper scheduling of work, shortage of critical construction equipment or labor, may result in loss of productivity. Also, poor site layout can contribute to a loss of productivity (Mohamed Abdelaal and Hassan Emam, 2016).

Quality control:

Inefficiency of equipment, unskilled laborers and poor quality of raw material are factors which cause low productivity. The productivity rate of inefficient equipment is low. Old equipment is subject to a great number of breakdowns, and it takes a long time for laborers to complete the work, thus reducing productivity. Poor-quality material used for work is another reason for reducing productivity; also unskilled laborers causing rework, which leads to low productivity.

According to (Makulsawatudom and Emsley, 2001). the following are the top ten major factors which affect the productivity of equipment

- Incomplete drawing Incompetent supervisor
- Instruction time
- Lack of tools & equipment
- Poor communication
- Poor site layout
- Rework
- Occasional working overtime
- Tools/equipment breakdown
- Specification and
- Standardization

While excessive loads, road conditions, age of equipment and the condition of its engine are identified as the most important influencing factors of productivity of hauling equipment in earthmoving projects for hauling equipment (Moselhi, O. et al. 2017)'.

Sanchin, P. et al.2017 identify 35 factors and classified them in 4 different groups. The different contributed factors are as follows:

- ❖ For the soft consideration 17 factors were identified from the literature survey are: company policy, site ground condition, company project forecast, commercial consideration, procurement method, work night shift, site congestion, obstacle on site, project specialization, dependence on out sourcing, shifting responsibility to external party, progress plan, dependent on other equipment, previous experience, labor availability, heavy traffic, strong winds.
- ❖ For the hard consideration 4 factors were studied from literature work as: Physical Classification, Technical Specification, Equipment specification and Construction facilities.
- ❖ For the controllable condition 7 factors were identified from the previous study as: Operators Skill, Equipment repairs and maintenance facilities, Planning and level of motivation, Working facilities, Task efficiency factor life of equipment and control of equipment, Maneuverability of equipment

- For uncontrollable condition 7 factors were obtained from the literature survey as: property of soil, snow and wind effect, Effect of temperature, Rain, Effect of altitude on the performance of the engine, Condition of haul Roads, Specifications requirements and availability of working Space.

2.5 Factors Affecting Production of Excavator

The actual production of an excavator is affected mainly by the following factors,

a. Class of material handled

b. Bucket capacity: the heaped bucket load volume or capacity is obtained from the manufacturer's data sheet. This is a loose cubic yard (lcy) or loose cubic meter (lm3) value

c. Moisture content of materials

d. Angle of swing The motion that rotates on the substructure the excavator's upper frame to the left or right

e. Height / Depth of cut

f. Horse power of the engine

g. Operator's skill

h. Age of excavator (Shubhangi, et al. 2019)

2.6 Factor Affecting Truck Productivity

Truck production is similar to the other earthmoving equipment cycles. Trucks however are typically dependent on another piece of equipment for loading. The productivity of a truck depends on the size of its load and the number of trips it can make in a unit of time. The number of trips completed per hour is a function of cycle time. Haul truck cycle time has four components:

(1) load,

(2) haul,

(3) dump, and

(4) return.

Load time is a function of the number of bucket cycles required to fill the truck box. The haul and return times will depend on truck weight, engine horsepower, the haul and return distances, and the condition of the roads traversed. Dump time is a function of the type of support equipment in and the conditions of the dump area. Spotting to load or dump and wait or delay times are influenced by job conditions, work setup, and management of the process. The most important consideration when matching excavator and truck is finding equipment having compatible capacities. Matched capacities yield maximum loading efficiency (Robert, L. et al.,2018)

2.7 Productivity Forecasting Approaches

Several researchers have conducted a research about Construction Equipment (CE). The expected work output per time unit (hour or day), usually termed productivity, which ultimately determines the cost and the duration of construction activities. The different angles for measuring or estimating productivity were discussed. (Panas, A. and Pantouvakis, J.P., 2010) in their review research explored the different perspectives for measuring or estimating it; while Productivity estimation is heavily affected by the type of operational coefficients and the estimation methodologies taken into account. Based on this, they proposed a structured framework for comparing different productivity estimation methodologies and evaluating their sensitivity with operational coefficients variation for excavation operations.

Telematics and spatial technologies were also used for estimating productivity in near real time. earthmoving works. Some researches included that of who applied ANNs not only to predict productivity, but also to predict earthmoving machinery effectiveness ratios (K. Schabowicz, B. Hola, 2007).

2.8 Productivity Estimation Methods

a. Deterministic Analysis

Deterministic analysis was developed for simple calculation of the productivity of an earthmoving operation based on the equipment characteristics, equivalent grades, and the haul distance provided by performance handbooks published by most manufacturers. A deterministic model primarily focuses on the use of time durations that are fixed or constant values, with the assumption that any variability in the task duration is assumed to be ignored (Halpin et al. 1992).

Halpin et al. (1992) describes an example of a simple deterministic model for earthmoving operations, consisting of a scraper for a hauling and a pusher dozer for a loading. The deterministic durations for the scraper travel times to and from the fill location are available by using simple monographs. Deterministic analysis tends to overestimate actual field productivity.

A Peak Productivity (Q p): The ideal/theoretical productivity governed by design limitation only. It is the product of Volume carried/ bucket capacity (V), bank volume/ loss volume (fs) and bucket fill factor (ff) (i.e. Q p =V * f s * f f). Whereas actual productivity (Q a) is the productivity of an equipment after taking care of effective working hours (f w) and job management factors (f j) on peak productivity (i.e. Q a =Q p *f w * f j). These job management factors should be identified and followed up properly for accurate determination of actual productivity.

On the other hand, manufacturer specification provides the theoretical productivity of the construction equipment whereas actual productivity of the equipment obtained using the data from the field measurement or by applying job correction factors on the ideal productivity (Getaneh, 2012).

b. Multiple Regression Analysis

In compliance with the need for a new productivity estimation tool to overcome the limitations of both deterministic and simulation models, a multiple regression model has been developed. Regression analysis is the most commonly performed statistical procedure for prediction of certain tendencies based on observed datasets. The ultimate goal of regression analysis is not only to find the values of parameters, but also which type of mathematical function fits best. Using this tool, researchers have been able to investigate and understand the relationships between the so-called explanatory variables and a result called a response variable. In the linear regression model, the response variable is assumed to be a linear function of one or more explanatory variables associated with error. The response variable can also be estimated by curvilinear functions interacting with multiple explanatory variables in a nonlinear regression model.

In order to create a best-fitted multiple regression model, several concerns must be taken into account:

(1) correlation between explanatory variables;
(2) relationships between the predicted variable and the residuals;
(3) residual variance and R-square; and (4) correlation coefficient R (Devore, 2000).

Real time estimation of productivity was also studied with modern technologies like telemetric and spatial technologies. An automated method that utilizing GPS and Google Earth or Web based GPS and GIS integrated platform to extract the data needed to perform the estimation of real time productivity were developed. Utilization of soft computing technique lie Artificial Neural Network (ANNs) not only to predict productivity but also to predict earthmoving machinery effectiveness ratios were also reported (Schabowicz, K. et al, 2008).

c. Artificial Neural Networks

Artificial Neural Networks is one of the most common approaches to machine learning, and also is a technique for Artificial Intelligence (AI) program. These systems possess a "machine learning mechanisms form" that is considered fundamental for adaptive systems to work. In other words, the human brain is a basic model in fundamental approaches for neural networks that are created based on a biological concept (Negnevitsky, 2005).

Many definitions for the term machine learning have been devised by specialist researchers and scientists. Learning is system merit that denotes changes in the system based on its ability to achieve a similar task with more efficiency in the future (Frantz R and Simon H, 2003) Neural networks provide an effective tool for complex problems, such as modeling CLP where the relationships between inputs and output cannot be easily represented by mathematical functions (Moselhi et al. 1991). The NN was used to model individual activities and the complex relationship between productivity and influencing factors, associative, adaptive, competitive, multilayered method of associating variables. Through multiple connections called nodes, the input layer is connected through numerous nodes in the hidden layer to the output layer. Each node incorporates a weighted non-linear function such as a sigmoid function, although any non-linear function can be used successfully. The neural network algorithm then computes the difference (error) between the newly calculated predicted output and the actual observed value. Through a process called back-propagation, the weights at each node are adjusted to reduce the error (Mehrotra, K et al, 1997). It provides an effective tool for complex problems, such as modeling labor productivity where the relationships between inputs and output cannot be easily represented by mathematical functions (Moselhi, O. et al, 1991).

Artificial neural networks contain links between input and hidden layers and also between hidden and output layers that connect neurons in the model. It can be arranged in different layers: input, hidden, and output. The hidden layer has no connections to the outside world because they are connected only to the input and output layers. Each link has a numerical weight to identify the effect of each neuron. ANNs have long-term memory that considers weights essential in achieving the model goal and Moreover, these weights show then strength for each input; in other words, they show the importance each neuron has for the input layers. The repetitive style of the weights' adjustment processes leads to learning in a neural network (Negnevitsky, 2005).

Connecting links transfers a number of input signals to a hidden neuron, then neurons compute a new activation level to produce a result value, then it will be produced as output signal through output links (see fig 2.2). Neurons yields only a single output signal, which is a final solution to the problem, or an input to other neurons, regardless of the number of input signals (Hassanean, 2018)

Model development involves gathering and measuring of input parameters, and identify the key independent variables and to model the complex relationship between these variables and dependent variable (Waziri, B. et al. 2018). The main steps for building artificial neural networks are

1. The network architecture must be designed, which involves deciding on the number of neurons, how the neurons are to be connected to form a network, on kind of neuron to be used, and on the number of hidden layers the network will have.
2. The type of learning algorithm to use is decided.
3. Neural networks must be trained which involves initializing weights and then updated from a set of training examples. Finally, the model will be developed (Russel and Norving, 2010). A neuron with a single R-element input vector is shown below. Here the individual element inputs

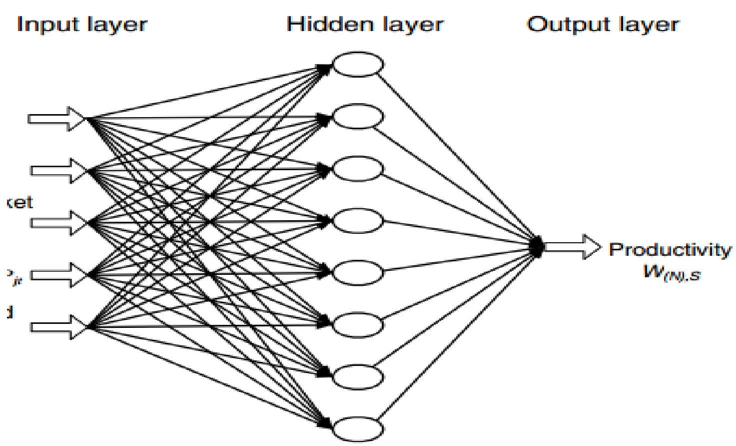

Figure 1: Structure of adopted unidirectional multilayer error backpropagation network

(K. Schabowicz, B. Hola, 2007)

In this network, each element of the input vector p is connected to each neuron input through the weight matrix W. The ith neuron has a summer that gathers its weighted inputs and bias to form its own scalar output. The various n taken together form an S-element net input vector n. Finally, the neuron layer outputs form a column vector a (Howard D, Mark M., 2004).

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Study Area

Addis Ababa city is the capital city of Ethiopia. It is also the largest city in the country by population with a total population of 3,384,569 according to the 2007 census. But it is believed that this number was accurate when recorded and under estimated the population. And the city divided into 10 sub-cities as shown on the figure below.

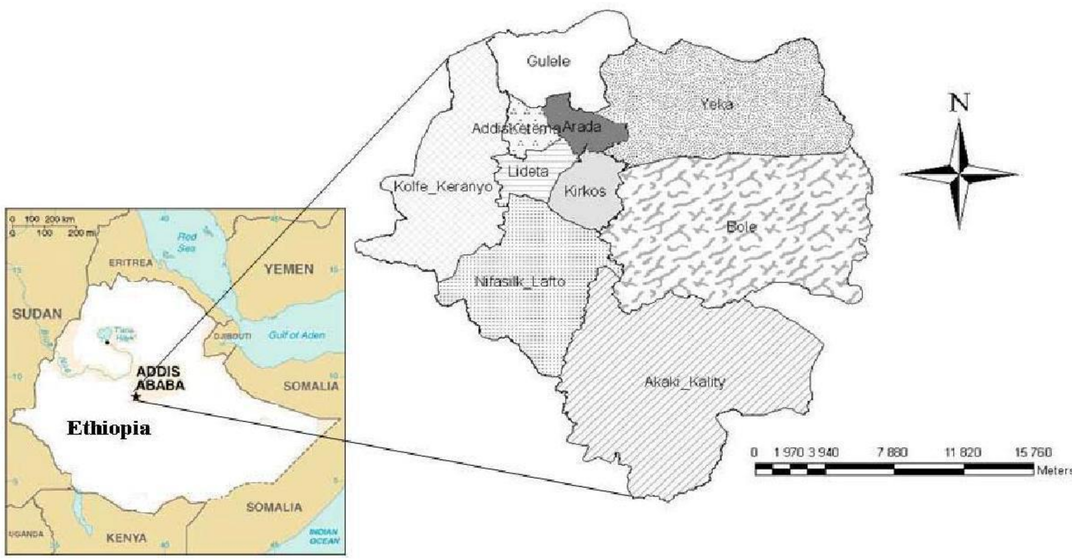

Figure 2 Addis Ababa city administration sub cities (Source Mapping of plantation forest in upper Catchment of AA)

3.2 Study Period

The study was conducted for 6 consecutive months started from October10/2020- March 30/2021 aims to develop a forecasting model and identify the critical factors affecting equipment productivity for earth work on highway construction projects in Addis Ababa, Ethiopia.

3.3 Study Design

The research adopts a combination of quantitative and qualitative methods. Because all quantitative data is based upon qualitative judgments, and all qualitative data can be described and manipulated numerically to draw conclusions and recommendations. It will be conducted in two stages. The first stage is conducted by using a qualitative method through a questionnaire survey to generate information from a large sample population on identifying the factors affecting the earthwork equipment productivity on Addis Ababa road highway projects. The second stage of the study is conducted by using the quantitative method using numerical data for developing a forecasting model using an artificial neural network (ANN) on MATLAB software.

3.4 Population

The research is conducted on highway construction projects executed in Addis Ababa city. The study populations for the research are highway construction project stakeholders such as Addis Ababa city road authority (AACRA)on the client side, the consultants, and contractors participate in highway projects in Addis Ababa city. Accordingly, several senior and junior office engineers of AACRA, the site and office engineers as well as operators of the equipment of twelve (12) contractors and seven (7) consultants of the projects was involved on identification of factors using questioner survey. Measuring and quantifying of the factors was collected on eleven (11) highway projects with project status of excavation (earthwork) in Addis Ababa city.

3.5 Sampling and Sample Size

In this study, due to the limited number of highway projects in general and highway projects with project status of earthwork in specific, purposive sampling is adopted as a sampling technique in the study area. As a result, the professionals who involve on behalf of the client, consultant, and contractor are selected. As well as, all highway projects at earthwork project status in Addis Ababa are identified. The data was collected using a field study to measure and quantify the factors which were identified.

3.6 Study Variables

The two basic which are dependent and independent variables are involved in this study. Equipment productivity will be the only dependent variable of this study while Operators factors, resource/equipment factors, management factors, environmental factors and other factors.

3.7 Data Collection

The data study was collected by using a questionnaires survey to identify factors affecting equipment productivity which to develop a productivity forecasting model on highway construction projects in Addis Ababa. After conducting a thorough literature review on different authors' work the factors which affect the productivity of equipment were identified and used for the preparation of the questionnaire survey.

A questionnaire survey was designed based on the objectives of the study. It was distributed for the professionals of Addis Ababa city road authority (AACRA)on the client-side, the consultants, contractors, and equipment operators involve participate in projects status with earthwork in Addis Ababa highway projects to achieve the first objective of study. After identifying the factors, the field study in terms of direct observation was used to collect, measure and quantify the factors to achieve the second objective.

3.8 Data Analysis and Presentation

This research was adopted statistical approaches such as the Relative Importance Index (RII) and artificial neural network (ANN) of Mat-Lab software. By using this statistical tool, first, the factors are identified to achieve the first objective of the study.

$$RII = \sum_{i=1}^{5} \frac{XiNi}{AN}$$ *Equation 1: Relative importance index*

Where:

Xi= Number of frequency response A= Highest weight (i.e. 5)

Ni = the variable expressing the frequency of the *i*th response. N = Total number of respondents

The priority levels of response using the Likert scale are**:**

Very low=1 High=4

Low=2 Very high=5

Moderate=3

The RII value of the factors ranges between 0-1. As the RII value of the factors increases its impact on the productivity of the equipment. After the factors res are identified and the first objective is achieved Mat-Lab software was used to compute regression analysis of the factors, determine their correlation develop a mathematical forecasting model through an artificial neural network (ANN). According to (Akadri.O.P, 2011)Akadiri , five important levels are transformed from RII values:

Table 1-Five important levels are transformed from RII values

RII value	Important level
$0.8 \leq RII \leq 1$	High
$0.8 \leq RII \leq 0.6$	High-medium
$0.6 \leq RII \leq 0.4$	Medium
$0.4 \leq RII \leq 0.2$	Low-medium
$0.2 \leq RII \leq 0$	low

As a result, the data obtained from questionnaires were analyzed using RII and ANN as well as presented in the form of tables, pie charts, and bar graphs to clearly illustrate the result and easily understand. To develop the productivity forecasting model MATLAB, 2017 is used for analyzing the inputs or productivity factors.

3.9 Data Quality Assurance

The quality of data obtained from the questioner survey is analyzed by using SPSS software to determine its reliability. Rovai, et al. (2012) Recommended measuring reliability using Cronbach's alpha (α) which generally ranges between 0 and 1. The greater Cronbach's alpha (α) coefficient is to 1 the grater the internal consistency of the items in the scale. Reliability tests resulting in an alpha of 0.7 are generally accepted as having high reliability Cronbach's alpha (α). The SPSS analyzes the reliability of data in terms of Cronbach's alpha (α). As the result the **(α)=0.924** which indicates the collected data assure high quality and reliability.

Table 2-: Reliability Statistics

Reliability Statistics

Cronbach's Alpha	N of Items
.924	28

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Respondent Background Information

The data was primarily collected through questioner survey. The questioner papers are distributed to the professionals of Addis Ababa city road authority (AACRA)on the client representative, the consultant's representative, contractor's representatives, and equipment operators involve in projects status with earthwork in Addis Ababa highway projects. A total of seventy-two (72) questionnaires were distributed to all clients, contractors, consultants, and equipment operators. Out of this seventeen (18) were distributed to the client, and twenty-one (21) to contractors and nine (9) to consultants, and twenty-four (24) to equipment operators in highway projects of Addis Ababa. Out of this seventy-two (72) distributed, fifty-nine (59) were collected from respondents.

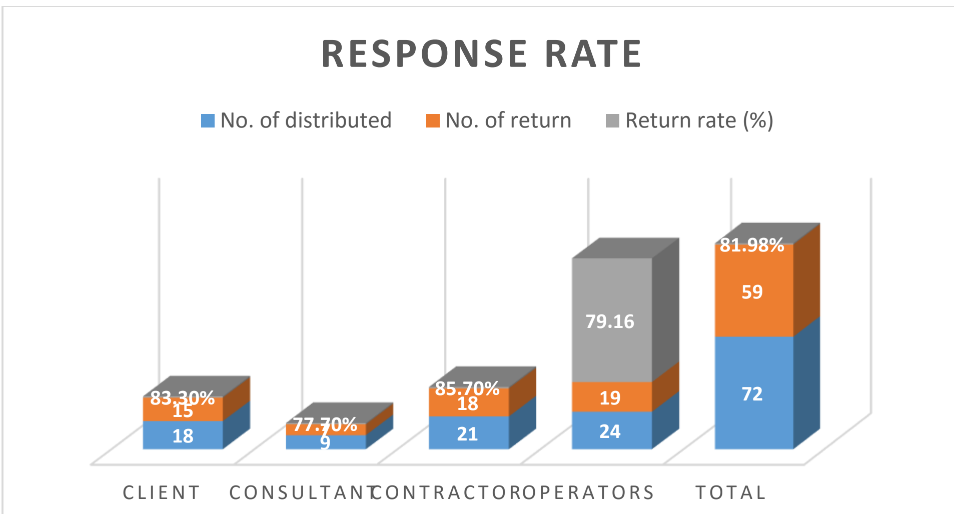

Chart 1:- The response rate of the questionnaire

As it was shown on chart 1, the total returned questionnaire composition of the respondent is 85.7% contractor, 77.7 % consultant, 83.3% client, and 79.16% operator. It is summarized the total response rate was 81.98% that shows the response rate achieves the minimum response rate of 80% according to (Draugalis, J. et al., 2008).

II Experience of the respondents

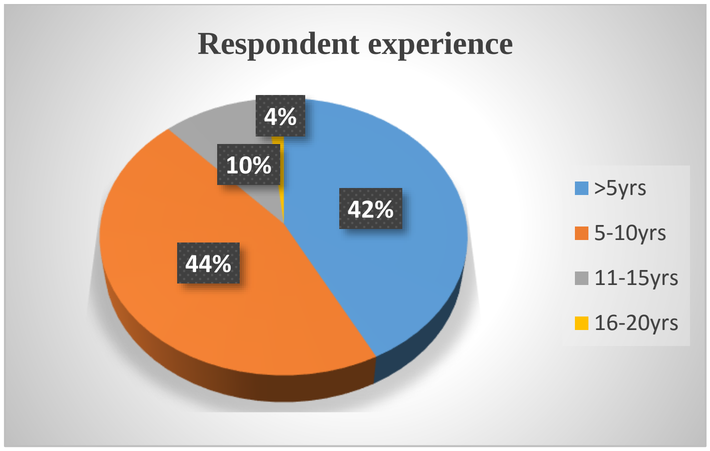

Chart 2: Respondent experience in the construction sector

The returned questionnaire survey also shows the experience of the respondent which is 44% of the respondent has less than 5 years' experience, 42 % respondent has the 6-10yeras experience, 10% of the respondent have10- 15 years and 4% of the respondent has 16-20% working experience in the construction sector. As a result, the chart shows that the study involves a respondent with the variety of the experience which incorporates a variety of attitude towards the productivity of earthwork equipment.

Respondent position in their organization

On the other hand, the professional composition of the respondent in the questionaries' survey is 4 project managers, 9 site engineers, 7 resident engineers, 20 office engineers, and 19 equipment operators. This is summarized below.

Table 3: Respondent position in their organization

Respondents position	No of respondents	Percentage
Project manager	4	6.77%
Site engineer	9	15.25%
Resident engineer	7	11.86%
Office engineer	20	33.89%
Equipment operators	19	32.2%

As it was shown on table 2, the professional composition of the respondent in the questionaries' survey is 6.77% project managers, 15.25% site engineers, 11.86% resident engineers, 33.89% office engineer and 32.2equipment operators which reflects that there are a number of professionals and highway projects practitioners in a wide range variety are involved in identifying the factors that affect the productivity of earthwork equipment's. these will increase the reliability of the data and analysis through increasing the incorporation of productivity perspective of different project stakeholders.

4.2 Factors Affecting the Earthwork Equipment Productivity

In order to identify the major factors which, affect the earthwork equipment productivity, the study uses the relative importance index (RII). According to (Akadri, 2011) the factors with an RII value of greater than 0.6 identified as the factors which have a significant medium to high impact on the productivity of the equipment.

Table 4: Factors affecting the earthwork equipment's productivity

Human Related Factors	
Experience	0.922
Equipment Related factors	
Equipment breakdown	0.738
Lack of proper maintenance	0.698
Spares not available	0.623
Age of equipment	0.905
Management Related factors	
Lack of supervision	0.762
Interfacing of activities	0.871
Environmental factors	
Temperature and humidity effects	0.769
Type of soils	0.864
Others	
Condition of haul road	0.823
Obstacle on site	0.881
Equipment specific factor	

Excavator	
Bucket capacity	0.812
Height / Depth of cut	0.608
Horse power of the engine	0.744
Truck	
Size of truck	0.982
Fixed cycle Time required for loading, hauling, damping and returning	0.978

As it was shown on table 3, the experience of the operator with the RII value equals 0.9 is identified as the only human-related factor which has a high impact on the productivity of earthwork equipment. Obviously, it has a great impact on productivity due to increasing the skill and ability of the operator wh ich is similar to the results of by Mohamed A. et al. In contrast, equipment breakdown with (RII =0.73), lack of proper maintenance (RII =0.69), spares not available (RII =0.62), age of equipment (RII =0.90) which is supported by (Seungwoo, H. and Daniel, W.2005). are identified as the factors that a medium to high impacts on the productivity of earthwork equipment and categorized under equipment-related factors.

Similarly, and recently, interfacing of activities (RII= 0.87) and temperature and humidity effects (RII=0.76) are identified by (Venkatesh M.P and Saravana N. P.S 2019). Lack of supervision with RII= 0.76 and Type of soils with RII=0.86 are identified as the management related and other environmental factors respectively. As well as, the condition of haul road with RII=0.82 and obstacle on-site with RII=0.88 are identified as other factors.

Regarding to equipment-specific factors, bucket capacity and horse power of the engine of an excavator with RII of 0.87 and 0.76 respectively has medium to high impacts. In addition, the height/depth of cut with the RII value of 0.61is identified as a factor with a medium impact on the productivity of the excavator. The factors are identified as the major factors and supported by the recent research work of (Shubhangi, B. k. et al 2019).

The size of the truck with an RII value of 0.94 and the cycle time required for loading, hauling, damping, and returning with an RII value of 0.98 is identified and they have a high impact on the productivity of the truck.

4.2.1 Correlation Between Factors and Equipment Productivity

Correlation is a statistical measure that indicates the extent to which two or more things fluctuate together. A positive relation indicates the extent to which those variables increase or decrease in parallel while a negative relation indicates the extent to which one variables increase as the other increases Always correlation coefficient ranges between -1 and +1. A strong relation between variables is identified by larger absolute coefficient values. An absolute R-value 1 specifies the perfect linear relationship between variables (Zaid, 2015).

Correlation between factors and excavator productivity

Table 5-: Correlation between factors and excavator productivity

Input factors	Correlation (R)
Experience	0.150352
Equipment age	**-0.42511**
Supervision	0.19034
Interfering activities	**-0.51009**
Temperature	-0.24327
Type of soil	**-0.72636**
Bucket capacity	0.29523
Depth of cut	-0.048821
Horse power	0.275531

As it is shown as table 5, type of soil and interfering activities have higher correlation coefficient (R) values than other factors with a value of 0.72636 and 0.51009 respectively. The higher negative values of correlation for type of soil and interfering activities indicates that the productivity of excavator has a high disproportional relationship with these factors. As the type of soil increases its hardness from smooth soil to hard rock and time taken due to interfering activities increases productivity of the excavator decreases.

Equipment age is the third most influencing factor to correlate with excavator productivity with an R-value of -0.42511. This correlation coefficient value shows a strong relationship with age of excavator but the sign indicates a decrease in productivity. As the lifetime of the excavators increases its productivity decrease.

Correlation between factors and truck productivity

Table 6-: Correlation between factors and truck productivity

Input factors	Correlation (R)
Experience	0.13341
Equipment age	-0.31372
Supervision	0.25331
Type of soil	-0.18239
Temperature	-0.21792
Cycle time	**-0.90402**

As it is shown on table 6, cycle time of the truck has highest correlation coefficient (R) values than other factors with a value of 0.90402. The highest negative values of correlation for cycle time of truck indicates that the productivity of truck has a highest disproportional relationship with cycle time. As the cycle time of truck increases the productivity of the truck highly decreases. It also shown that the cycle time is the controllable factor of productivity of truck.

Similarly, equipment age is the second higher correlated factor with R= 0.31372. the negative sign indicates that the productivity of truck has a disproportional relationship each other. As the equipment age of truck increases the productivity of the truck decreases.

In contrast the supervision level is the third higher and positively correlated factor with the productivity of truck with R=0.25331. It indicates that as the supervision level of trucks increases the productivity of truck increases. They have a proportional relation.

4.2.2 Productivity Forecasting Model Development

To develop a productivity forecasting model, the data of onsite productivity was collected through field study in terms of direct observation, in accordance with measuring and quantifying the factors which has an effect on on-site productivity of the equipment. Even though some of the factors are identified as a factor which affect the overall productivity rather than the on-site productivity and their difficulty to measure and quantify such as lack of proper maintenance and spare not available. Some of them are included in other factors such as equipment breakdown and obstacle on site are included the interfering activities which are measured by the time taken to correct and as well as the condition of haul road is related to time taken to haul.

As a result, experience of the operator , age of equipment, lack of supervision, interfacing of activities, temperature and humidity effects and type of soils are the common factors which affect the productivity of both excavator and truck while bucket capacity, height / depth of cut and horse power of the engine for the excavators only and size of truck and cycle time required for loading, hauling, damping and returning for the trucks only are identified, measured and quantified though interviewing the operators, field study and observation as indicated at the appendix 5. The excavators are used to both excavating and loading to the trucks.

The Mat lab 2017 is used for analyzing the input factors and developing the forecasting model. After the data are collected as shown in appendix 5. The row data changed to the normalizing data using standardization of the values of input factors in order to reduce the large variety of the magnitude of input factors and increase the computation ability of the model. This makes the values of all input factors in b/n 0 and 1 The formula is

$$X_{std} = \frac{X - Xmin}{Xmax - Xmin} \ldots\ldots\ldots\ldots\ldots\text{Equation 2:standard deviation}$$

Where X_std = standard deviation X_scaled= the normalize/scaling value data

Xmin= the minimum value of data Xmax= the maximum value of data

4.2.3 Optimal Data Division

Totally 55 and 67 data set input factors are collected from the road projects for both excavators and trucks respectively. This dataset was divided into training, validation, and test data sets for accurate modeling and for testing the performance of the model. The best data division for the productivity of the excavator is shown in table 5. This optimal number of data divisions was obtained by trial and error. Data was divided into different training, validation, and testing, to determine accurate data divisions and observed their performance. Therefore, the data division shown in the table performs best than other data divisions with less mean absolute error (MSE) and high correlation (R).

Table 7: Optimal data division

Data set type	No of data set for excavator	Percentage(%)	No of data set for excavator	Percentage(%)
Training	39	70	44	65
Validation	8	15	13	20
Testing	8	15	10	15
Total	55	100	67	100

After the data division, the number of neurons is determined based on the models' performance to predict with less mean absolute error (MSE) and high correlation (R). Mean Squared Error is the average squared difference between outputs and targets. Lower values are better. Zero means no error. Regression R Values measure the correlation between outputs and targets. An R-value of 1 means a close relationship, 0 a random relationship (Howard D, Mark M., 2004). Based on this, the following numbers of neurons are selected.

Table 8: Best parameters of neural network developed model

Equipment	No of neurons	MSE	R
Excavator	5	0.000148	0.98131
Truck	3	0.00116	0.96375

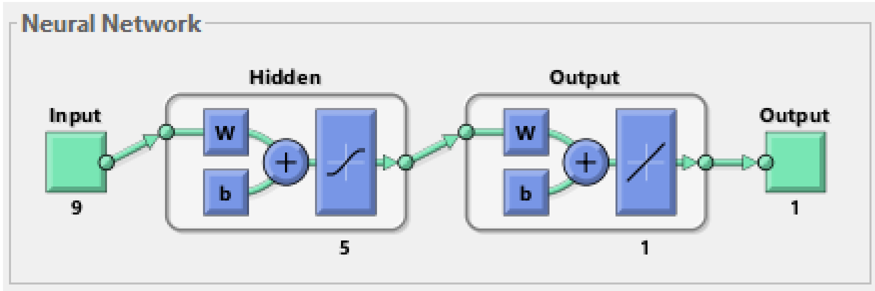

Figure 3: Neural network structure for excavator productivity

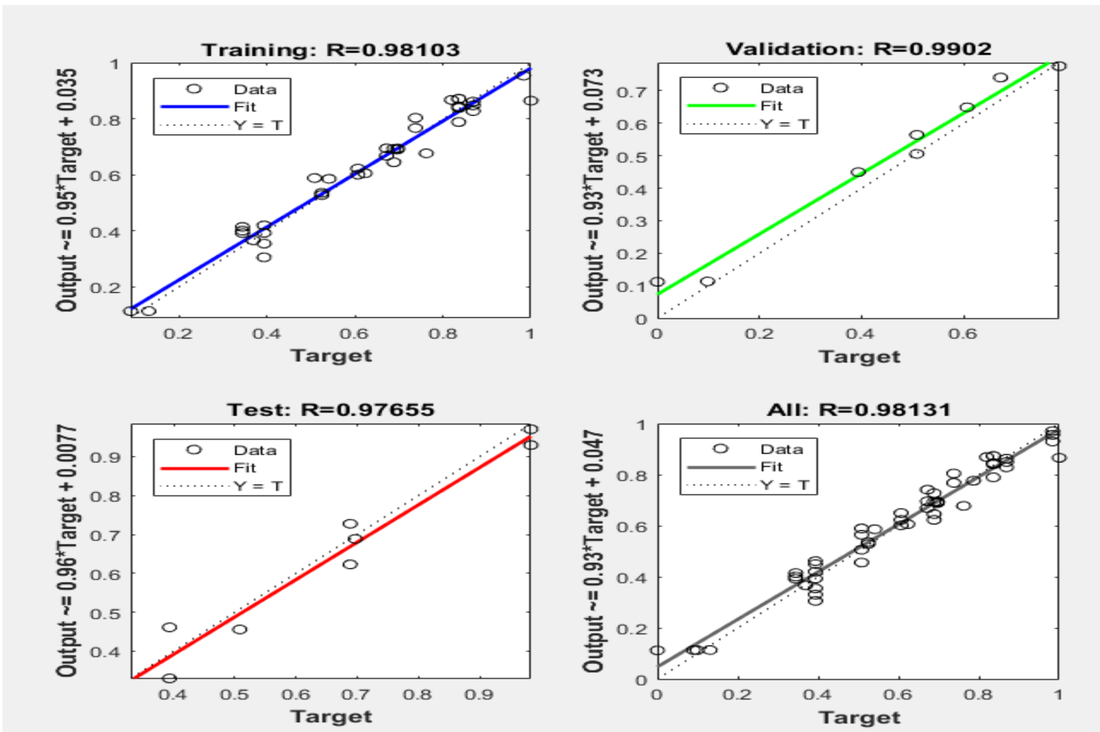

Figure 4:Coefficient of correlation for predicted truck productivity

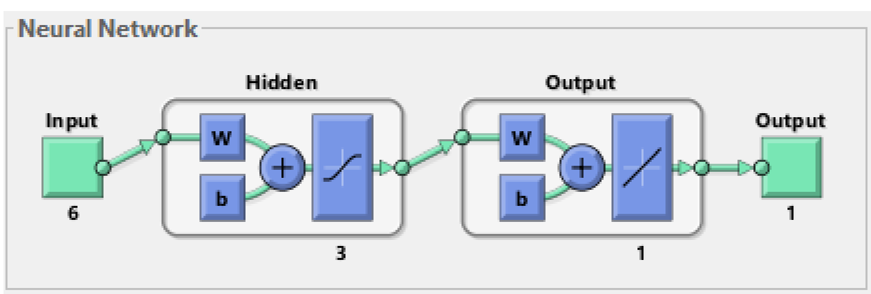

Figure 5: Neural network structure of truck productivity

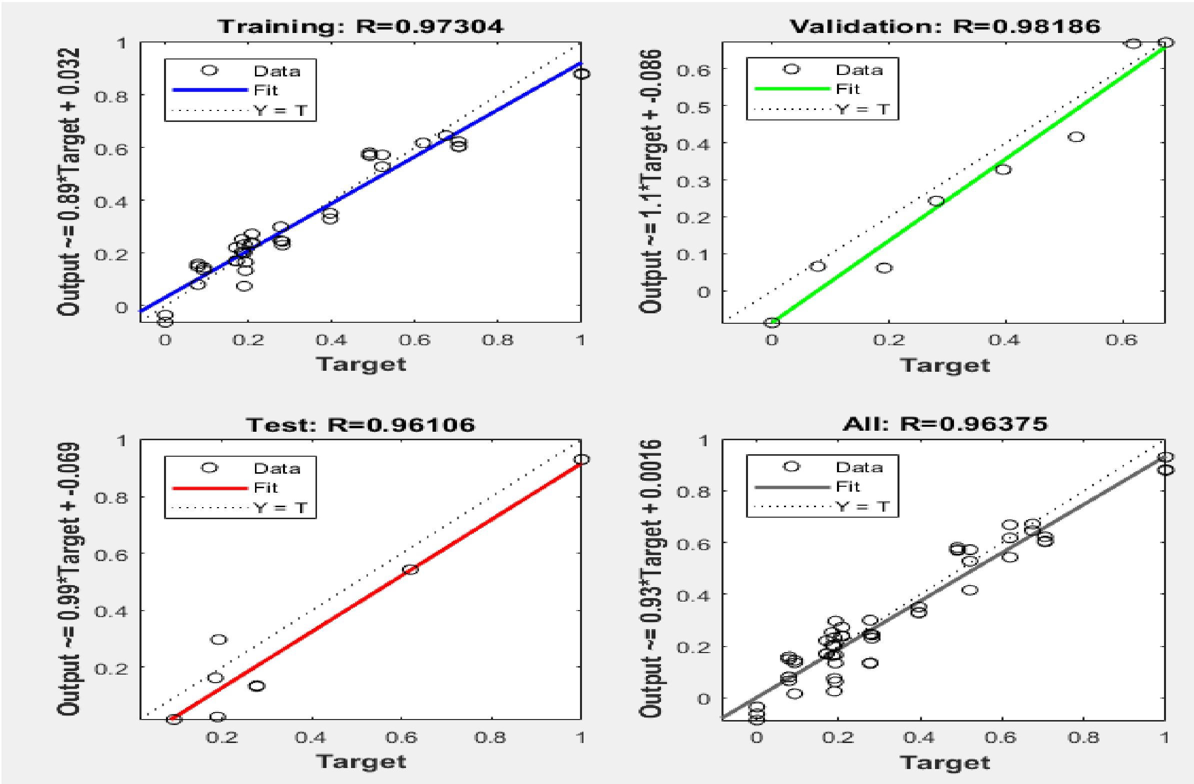

Figure 6: Coefficient of correlation for predicted truck productivity

The above all parameters indicate the developed ANN model have a higher capability to predict the productivity of excavator and truck.

4.2.4 Equation of the ANN Model

The equation of ANN gives the output value as a function of the values at the input values, bias, and connection weights. The connection weights and biases which are used for the final modeling are obtained from the optimal ANN models. Since the neural network structure is so constructed using two layers and activation function in b/n that it is calculated the first layer, activation function, and second layers separately on their order. It can be mathematically expressed using the connection weights and biases for the optimal model as follows:

Step 1: - First layer

$$a_1 = w_{1,1} * x_1 + b_1 \text{.. Equation 3}$$

where w11= 9*5 matrices multiplication of weights x1= normalized inputs (using standardize formulas on eqn.2)

b1= biases

Step 2: - Activation function

Then the values should be pass through **tansig activation** function as shown

$$n = (1/1+e(-2a1))-1 \qquad \text{Equation 4}$$

Step 3: - Second layer

$$a_2 = w_{2,1} * n + b_2 \qquad \text{Equation 5}$$

where $w_{2,1}$= dot product or matrices multiplication of weights

n= activation function

b_2= biases

then the scaled value of second layer output a_2 should be converted into the unscaled predicted value of output using min value scaler formula as discussed in section 4.2.2.

Step 4: - Out put

$$O = a_2(x_{max} - x_{min}) + x_{min} \qquad \text{Equation 6}$$

*The connection weights and biases are indicated on appendix 8 and 9 for excavator and truck respectively. However, it is possible to determine the productivity of that equipment manually using the weights, activation functions, and biases of the model, but it is very complicated due to presence of several matrices, activation functions, exponential functions, and other mathematical operations. As a result, there is the developed model or interface on mat lab and it is better to use this model. To make it easier and convenient for use for the construction professionals and road project stakeholders, the researcher develops the simulation on programmed excel format of manual computation. To forecast the productivity of both excavator and truck-only input data of factors is required so that the programmed Excel sheet automatically forecasts the productivity. The programmed Excel format is attached here in appendix 9,10 and 11.

4.3 Sensitivity Analysis on Factors Affecting Productivity

Sensitivity analysis is a technique used to determine how independent variable values will impact a particular dependent under a given set of assumptions (Kenton, 2020). In this research context, there are nine (9) independent variables which are identified by objective one and a dependent variable. By using the minimum, maximum, and average values of these variables or input factors through analyzing by the developed model, it is determined the sensitives of these variables. The following table will show the min and max values of the input factors and productivity change to determine the sensitivity of factors.

4.3.1 Sensitivity Analysis on Excavator Productivity

Table 9: Sensitivity analysis on excavator productivity

Factors	Input values		Productivity in m^3/hr.		Productivity change in m^3/hr.	Change type
	Min value	Max value	Min	Max		
Experience	5	22	71.839	94.934	23.095	Increase
Equipment hour	**121**	**22983**	**107.923**	**59.64753**	**48.276**	**Decrease**
Supervision	3	5	82.765	105.999	23.234	Increase
Interfering activities	**0**	**22**	**58.871**	**97.779**	**38.908**	**Decrease**
Temperature	16	23	75.504	101.234	25.73	Increase
Type of soil	**1**	**2**	**90.643**	**13.074**	**75.569**	**Decrease**
Bucket capacity	**0.93**	**2**	**50.012**	**92.386**	**42.374**	**Increase**
Depth of cut	0.7	1.75	97.203	84.352	12.851	Decrease
Horse power	153	209	84.893	107.582	22.689	Increase

Table 8 shows that among the nine identified factors the age of equipment, interfering activity time, bucket capacity of excavator, and type of soil have high sensitivity and impact on the productivity of the excavator. As the equipment age increases from 121 to 22983 hours, the productivity of the excavator decreases from 107.923 to 59.64753m^3/hr. which shows a reverse relationship b/n them. This is due to the performance and potential of the excavator decreases when it uses for a long time.

Similarly, when there is a delay or idleness of the excavator due to interfering activity such as delay of the truck to load the excavating materials, it directly affects the effective working hour and productivity time of the excavator. When the time taken for the interfering activities increases from 0 minute to 22 the productivity of the excavator decreases from 97.779 to 58.871m^3/hr. As a result, the productivity of the excavator increases when the time is taken to interfering with activities decreases and vice versa.

In contrast, as the bucket capacity of the excavator increases the productivity of the excavator will be increased. When the bucket capacity increases from 0.93 to 2m^3, the productivity of the excavator increases from 50.012 to 92.386m^3/hr. It is due to the increase in penetrating, excavating the soil, and holding capacity of the equipment These variables have a proportional relationship b/n them. Obviously, excavating and working with hard rocks type of soil highly decreases the productivity of the excavator due to the difficult nature of hard rocks to penetrate and excavating. As the type of soil becomes smooth the productivity of the excavator greatly increases.

Among these factors, it is believed that the type of soil is an uncontrolled factor, the bucket capacity is manufactured with fixed volume and the time taken due to interfering activity can be reducing by the optimized allocation of trucks. But the equipment age is a controlling factor, it can be determined to achieve the desired productivity. As a result, it is developed the model to forecast the maximum equipment age (hour) using five (5) neurons with **MSE = 0.00127 and R = 0.9647** and the excel programmed format is attached to the appendix.

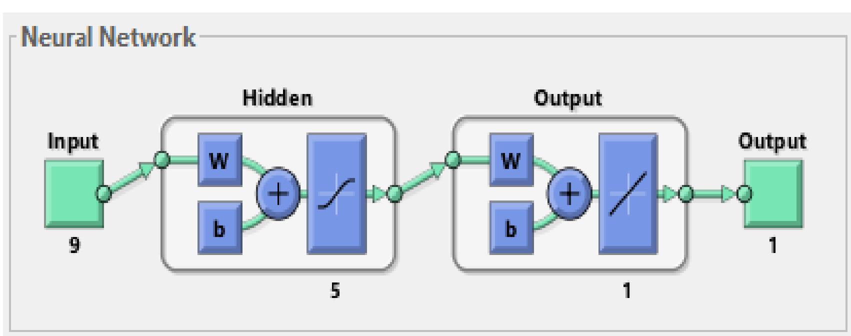

Figure 7: neural network structure for equipment age (excavator hour)

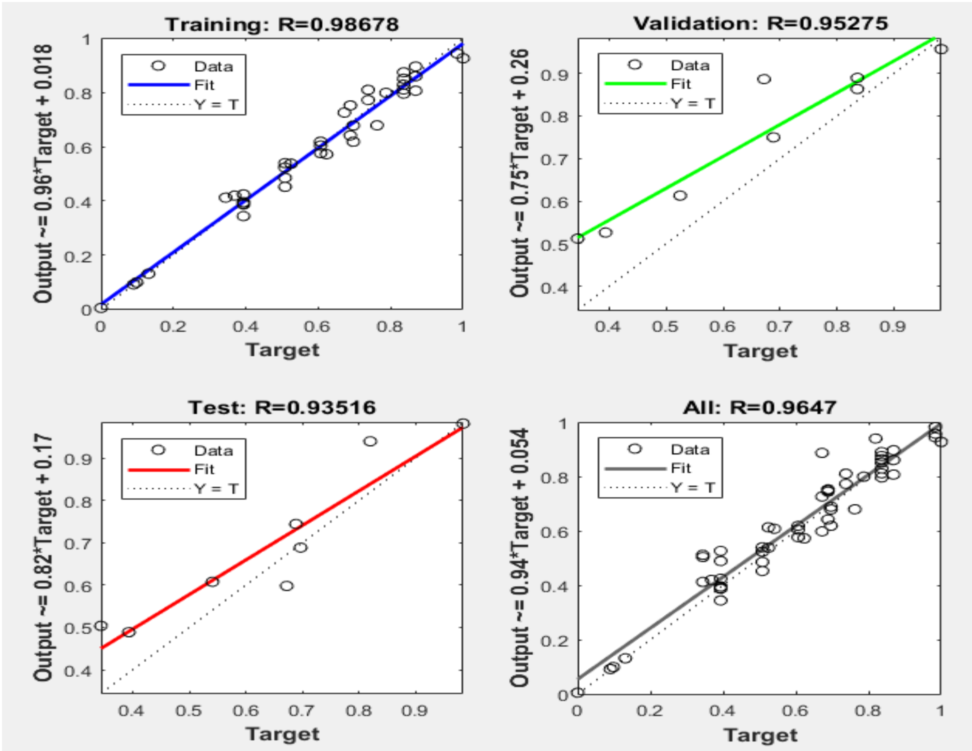

Figure 8: coefficient of correlation for predicted equipment age (excavator hour)

4.3.2 Sensitivity Analysis for Truck Productivity

Table 10: Sensitivity analysis on excavator productivity

Factors	Input parameters		Productivity in m^3/hr.		Productivity change in m^3/hr.	Change type
	Min value	Max value	Min	Max		
Experience	3	13	16.85	24.5404	7.69	Increase
Equipment age	2	7	19.54	16.47	3.07	Decrease
Supervision	3	5	20.49083	27.02369	6.532	Increase
Temperature	17	22	17.7688	20.0724	2.303	Increase
Type of soil	1	2	22.274	17.7219	4.552	Decrease
Cycle time	**29**	**89**	**30.23784**	**11.6478**	**18.59**	**Decrease**

According to table 9, it is found that the time taken to load, haul, dump, and return (cycle time) has a high impact on the productivity of the truck. This is due to increases in time taken to cycle the tuck which directly affects the effective working and productivity of the truck. Since most of the projects are executed on the central part of Addis Ababa city, the damping area for excavating materials is far away from the location of the project which results in more cycle time.

In addition to this, the very traffic jam of the town highly interrupted the movement of trucks which is the major cause for the longer time taken of truck movement. Generally, the productivity of the truck has a reverse relationship with the cycle time of the truck. As the truck cycle time decreases the productivity of the truck increases and vice versa.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The result of this research exposed that age of equipment, interfacing of activities, temperature and type of soils are the common factors that affect the productivity of both excavator and truck while bucket capacity for the excavators and size of truck and cycle time for the trucks are identified as the major factors. As the age of equipment increases, interfering activities takes much time, the temperature becomes adverse, type of soil becomes more harden results in decreasing the productivity of equipment's in general while volume of bucket capacity reduces and cycle time takes much time both excavator and truck productivity drops down in particular.

These factors were measured and quantified through observed dataset at job site actual productivity to develop the forecasting model. The optimal model uses nine (9) variables as input and five (5) neurons for excavators and six (6) variables with three (3) neurons shows the optimal structure of the productivity of excavators and trucks respectively in Addis Ababa road projects. The models can forecast the productivity of excavator and truck productivity with 0.000148 and 0.00116 of mean absolute error MSE which are high closer to 0 and 0.98131 0.96375 of correlation (R) which are high closer to 1. This result shows that the models have a higher ability to forecast the productivity of given equipment. Professionals can easily use the programmed Excel sheet to forecast these equipment productivities for better project planning, duration estimation, project scheduling, cash flow and controlling for their future projects.

The sensitivity of the factors is analyzed by using their minimum, maximum and average values of the variables on the developed model and it is found that equipment age, interfering activity, type of soil, and bucket capacity are sensitively affect excavator's productivity while cycle time is the major factor on the productivity of the truck. Therefore, bearing in mind these results construction stakeholders are expected to give due attention to properly control, manage and improve productivity.

Generally, the factors affecting productivity of equipment's are properly identified, productivity forecasting model with the best predicting performance is successfully developed and the sensitivity of factors is properly analyzed using the developed forecasting model.

5.2 Recommendation

It is well known that the productivity of equipment is the key element in the successful completion of road projects. For this reason, the Addis Ababa road project stakeholders should be controlling these identified factors which affect both the productivity of excavators and trucks to enhance and properly manage the excavation work. Especially, they should properly control the four factors which are high sensitivity with the job-site productivity of the fleets of both excavators and trucks.

The stakeholders should use the developed model to forecast the productivity of both excavators and trucks which helps to determine the optimum allocation of trucks for the given excavator. On many projects, it is seen that many excavators are been idle for several minutes waiting for the trucks to load on. Unless there is optimum allocation of trucks, the productivity of excavators which should be given priority and make zero (0) idle time is governed by the productivity of trucks. These will cause a decrease in the overall productivity of earthwork equipment and increasing the hourly cost of the excavator when it is rented.

The professionals should be determining the maximum equipment age (hour) which is analyzed as the highly sensitive factor. Since this factor is a controlled variable it can be computed by using the developed model to effectively achieve the desired productivity.

Since the productivity of trucks highly affected by the commutative of cycle time due to time taken for loading, hauling, damping, return, and interruption of movement of trucks due to high traffic jam in Addis Ababa town, it is better to shift the working time to the time which reduces the traffic jam such as night and weekend times.

To improve the accuracy of duration estimation for future projects project stakeholders should keep historical data of productivity in road projects. Therefore, this improved efficiency and accuracy of productivity forecasting rates will enhance their profitability and success in the construction industry.

The researchers should be focus on identifying, measuring, and quantifying factors that affect the productivity of other earthwork equipment such as loaders, graders, dozers for their future study. This will improve the overall productivity forecasting and accuracy of duration estimation of earthworks on Addis Ababa road projects.

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APPENDIX

Appendix 1: Questioner Survey

I am Tofik Eshetu. I am studying **to analyze earthwork equipment productivity Using Artificial Neural Networks for highway Projects in Addis Ababa town** from Jimma University, Jimma Institute of Technology, Department of Construction Engineering and Management. The overall objective of this study is to develop a mathematical forecasting model using Artificial Neural Networks for estimating the earthwork equipment productivity. I kindly ask you to participate in this study and give me a genuine answer to my quires. Your participation in this study is greatly helpful in **identifying the major factor or parameter which can affect earth work equipment productivity.** If you have any question you can contact through my phone number **+251920791966** or email: tofffik111@gmail.com

Respondent information

How many years have you worked in the construction industry?

a. Less than 5 years
b. 5 to 10 years
c. 11 to 20 years
d. 15 to 20years
e. 20 to 30 years
f. More than 30 yea

Type of organization you involved

a) Contractor
b. Client
c. Consultant
d. Operators

What is your job position or title in the company? Please specify below

a. Project manager
b. Site engineer
c. Office engineer
d. Resident engineer
e. Operators
f. If other, state _____

Please rate the following productivity influencing factors according to its priority level for affect in earthwork equipment productivity by ticking the appropriate number based on 1 to 5 point of Likert scale:

(1) Very low (2) Low (3) Moderate (4) High (5) Very high

Categories of Factors affect equipment productivity	Level of affect				
Human Related Factors					
	1	2	3	4	5
Experience					
Disloyalty					
Personal problems					
Lack of training					
Equipment Related factors					
Delay in placing the equipment					
Two or more groups sharing an equipment					
Equipment breakdown					
Lack of proper maintenance					
Spares not available					
Age of equipment					
Management Related factors					
Lack of supervision					
Improbable planning and expectation of labor execution					
Communication between site administration and operator					
Non-payment of charges/ Delay in payment					

Interfacing of activities					
Environmental factors					
Temperature and humidity effects					
Type of soils					
Others					
Rework					
Compatibility and steady among contract records					
Condition of haul road					
Excess travel/ lifting					
Obstacle on site					
Equipment specific factor **Excavator**					
Bucket capacity					
Angle of swing					
Height / Depth of cut					
Horse power of the engine					
Truck					
Size of truck					
Cycle time for (Load, Haul, Damp and Return)					

Appendix 2: Summery of Questionnaire Response and Relative Importance Index

Categories of Factors affect equipment productivity	level of affect					RII
	very low	low	moderate	high	very high	
Human Related Factors						
Experience	0	0	5	13	41	0.922034
Disloyalty	32	11	9	8	0	0.383051
Personal problems	15	23	12	4	6	0.484746
Lack of training	18	7	12	15	7	0.552542
Equipment Related factors						
Delay in placing the equipment	6	27	19	9	0	0.518644
Two or more groups sharing an equipment	31	22	5	1	0	0.318644
Equipment breakdown	0	8	16	21	14	0.738983
Lack of proper maintenance	4	16	8	9	22	0.698305
Spares not available	9	7	18	13	11	0.623729
Age of equipment	0	0	8	12	39	0.905085
Management Related factors						
Lack of supervision	3	6	11	18	21	0.762712
Improbable planning and expectation of labor execution	16	22	7	8	0	0.383051
Communication between site administration and operator	27	19	10	3	0	0.362712
Non-payment of charges/ Delay in payment	15	22	9	11	2	0.474576
Interfacing of activities	0	0	8	22	29	0.871186
Environmental factors						
Temperature and humidity effects	0	7	13	21	18	0.769492

Type of soils	3	7	0	7	42	0.864407
Others						
Rework	18	19	15	0	7	0.461017
Compatibility and steady among contract records	19	14	15	9	3	0.484746
Condition of haul road	0	0	12	28	19	0.823729
Excess travel/ lifting	9	12	22	9	7	0.576271
Obstacle on site	0	0	9	17	33	0.881356
Equipment specific factor-Excavator						
Bucket capacity	0	0	7	21	29	0.812
Angle of swing	12	13	13	7	5	0.468
Height / Depth of cut	5	14	6	18	7	0.608
Horse power of the engine	5	2	7	17	19	0.744
Truck						
Size of truck	0	0	0	4	43	0.982979
Fixed cycle Time required for loading, hauling, damping and returning	0	0	0	5	42	0.978723

Appendix 3: Data Collection Method for Excavator Productivity

Factors	Measurement scale	Data source
E= Experience	In years	Operators
A= Age of equipment	In engine hour	Excavator display
S= Supervision	Likert scale (very high=5, high=4, medium=3, low=2, very low=1)	Researcher observation
T= Temperature and humidity	In C^0	Addis Ababa weather history
Type of soils	Common excavation=1 and hard excavation=2	Researcher an Data collector
Bucket capacity	In m^3	Reading on excavator and company specification
HD= Height / Depth of cut	In Meter	Surveyors
Horse power of the engine	In horse power	Reading on excavator and company specification
Productivity	Loose volume In m^3	Researcher and Data collector

Appendix 4: Data Collection Method for Truck Productivity

Factors	Measurement scale	Data source
Experience	In years	Operators
Age of equipment	In engine hour	Organization
Supervision	Likert scale (very high=5, high=4, medium=3, low=2, very low=1)	Researcher observation
Temperature and humidity	In C^0	Addis Ababa weather history
Type of soils	Common excavation=1 and hard excavation=2	Researcher an Data collector
Cycle time	In minutes	Researcher and Data collector
Productivity	Loose volume In m^3	Researcher and Data collector

Appendix 5: Data Collection Sheet for Excavators' Productivity

ND= Number of data

E= Experience in years A= Age of equipment in engine hour

S= Supervision in Likert scale I= Interfacing of activities in minutes

T= Temperature and humidity in C^0 TS= Type of soils (common excavation=1 and hard excavation=2)

BC= Bucket capacity in m^3 HD= Height / Depth of cut in meter

HP= Horse power of the engine in horse power P= Productivity in m^3

ND	E	A	S	I	TH	TS	BC	HD	HP	P
1	11	4341	5	0	17	1	1.71	1.2	197	106
2	11	4341	5	13	20	1	1.71	1.2	197	88
3	11	4341	5	15	23	1	1.71	1.2	197	88
4	8	22983	5	0	17	1	1.44	1.2	209	72
5	8	22983	5	11	20	1	1.44	1.2	209	54
6	8	22983	5	9	23	1	1.44	1.2	209	54
7	9	6452	5	0	18	1	1.44	1.75	209	108
8	9	6452	5	0	19	1	1.44	1.75	209	108
9	9	6452	5	5	22	1	1.44	1.75	209	108
10	14	16232	3	0	18	1	1.44	1.2	209	90
11	14	16232	3	3	17	1	1.44	1.2	209	90
12	14	16232	3	0	19	1	1.44	1.2	209	90

13	9	6452	5	0	18	2	1.44	0.8	209	6
14	8	4873	5	0	16	1	1.71	1	197	108
15	8	4873	5	0	17	1	1.71	1	197	108
16	8	4873	5	0	19	1	1.71	1	197	108
17	13	14267	3	0	17	1	1.44	1	277	88
18	13	14267	3	16	19	1	1.44	1	277	70
19	13	14267	3	15	22	1	1.44	1	277	70
20	22	4451	5	0	17	1	1.71	1.2	197	128
21	22	4451	5	11	18	1	1.71	1.2	197	96
22	22	4451	5	17	22	1	1.71	1.2	197	80
23	5	4451	5	0	18	2	1.7	0.75	209	18
24	7	12031	5	0	18	1	1.7	1.1	209	96
25	7	12031	5	12	19	1	1.7	1.1	209	80
26	7	12031	5	11	19	1	1.7	1.1	209	80
27	11	1911	5	6	17	1	1.5	1.2	209	102
28	11	1911	5	17	19	1	1.5	1.2	209	68
29	11	1911	5	21	22	1	1.5	1.2	209	68
30	6	2234	5	8	17	1	1.5	1	209	99
31	6	2234	5	11	19	1	1.5	1	209	82
32	6	2234	5	21	22	1	1.5	1	209	51

33	11	1911	5	0	18	2	1.5	1	209	17
34	5	121	5	6	17	1	1.5	1	164	108
35	5	121	5	17	19	1	1.5	1	164	68
36	5	121	5	20	22	1	1.5	1	164	68
37	5	15533	4	5	17	1	1.5	0.8	209	90
38	5	15533	4	19	18	1	1.5	0.8	209	54
39	5	15533	4	22	22	1	1.5	0.8	209	54
40	12	11341	4	4	18	1	1.5	0.75	209	54
41	12	11341	4	3	20	1	1.5	0.75	209	54
42	12	11341	4	11	22	1	1.5	0.75	209	54
43	9	6554	3	4	16	1	1.71	1	197	126
44	9	6554	3	6	18	1	1.71	1	197	126
45	9	6554	3	4	20	1	1.71	1	197	126
46	8	9170	4	4	17	1	1.2	1	164	91
47	8	9170	4	3	18	1	1.2	1	164	91
48	8	9170	4	0	22	1	1.2	1	164	91
49	11	4012	4	5	17	1	0.93	0.7	153	48
50	11	4012	4	0	19	1	0.93	0.7	153	48
51	11	4012	4	0	22	1	0.93	0.7	153	48
52	15	4512	5	0	17	2	1.71	0.9	197	22

53	15	4512	5	0	16	1	1.71	0.9	197	112
54	15	4512	5	3	18	1	1.71	1.2	197	112
55	15	4512	5	0	21	1	1.71	1.2	197	112

Appendix 6: Data Collection Sheet for Trucks' Productivity

ND= Number of data

E= Experience in years A= Age of equipment in engine hour

S= Supervision in Likert scale T= Temperature and humidity in C^0

TS= Type of soils (common excavation=1 and hard excavation=2)

CT= cycle time P= Productivity in m^3

ND	E	A	S	TH	TS	CT	P
1	6	5	3	17	1	71	18
2	3	2	3	18	1	67	18
3	12	3	3	18	1	66	18
4	5	3	3	17	1	63	16
5	5	3	4	18	1	38	18
6	4	2	4	18	1	35	18
7	3	4	4	19	1	41	18
8	4	2	4	18	2	42	18
9	7	4	4	19	1	44	18
10	10	4	4	19	1	46	18
11	8	5	4	19	1	41	16
12	7	5	3	19	1	44	18

13	8	5	3	18	1	88	17
14	5	4	3	18	1	82	17
15	4	4	3	18	1	81	16
16	8	5	3	18	2	90	17
17	11	3	4	22	1	83	17
18	4	3	4	22	1	80	17
19	8	7	4	22	1	80	16
20	5	4	5	19	1	32	17
21	6	4	5	18	1	29	17
22	4	4	5	18	1	34	17
23	8	6	4	18	1	34	17
24	3	4	4	19	1	35	16
25	9	5	4	19	1	31	14
26	8	6	4	19	2	37	17
27	8	3	4	18	1	52	17
28	3	3	4	19	1	54	17
29	13	2	4	19	1	34	16
30	7	3	4	22	1	38	16
31	5	3	4	22	1	43	16
32	6	4	4	18	1	28	17

33	6	6	4	19	1	33	17
34	7	6	4	19	1	31	17
35	6	4	4	18	1	49	16
36	9	4	4	19	1	53	16
39	7	4	4	19	1	56	16
40	4	3	4	19	1	36	17
41	5	4	4	19	1	32	17
42	5	4	4	19	1	33	17
43	6	4	4	18	1	31	17
44	7	6	4	19	1	32	14
45	11	6	4	22	1	71	16
46	5	3	4	21	1	76	16
47	8	5	4	18	1	69	17
48	6	4	3	17	1	38	17
49	5	3	3	19	1	35	17
50	3	2	4	22	1	36	16
51	12	7	4	21	1	48	17
52	8	5	4	18	1	46	16
5	4	3	3	18	1	52	14
3	5	3	3	17	1	34	16

54	3	2	3	19	1	31	17
55	5	3	3	18	1	35	16
56	4	3	3	20	1	36	16
57	13	7	3	21	2	41	17
58	7	4	3	18	1	81	16
59	6	4	3	19	1	78	17
60	9	5	4	22	1	84	14
61	5	3	4	21	1	76	16
62	11	6	4	22	1	71	16
63	7	4	4	17	1	33	16
64	13	7	3	19	1	29	17
65	6	4	3	22	1	31	17
66	4	3	3	21	1	36	17
67	3	2	3	19	1	29	16

Appendix 7: Descriptions of Earthwork Status Road Projects in Addis Ababa

Projects	Earthwork Equipment's	Excavating material damping location
Awtobis terra- Mesalemia	2 Excavator and 7 trucks	Tor hayloch
Shiromeda-Kuskuam	2 Excavator and 6 trucks	Entoto
Kechene Medhanialum	2 Excavator and 6 trucks	Entoto
Sarbet-Kera section	2 Excavator and 7 trucks	Bole bulbula
Kera-Gotera section	3 Excavator and 15 trucks	Bole bulbula
Bole Michael-Bole bulbula	2 Excavator and 10 trucks	Bole bulbula
Kotebe-Ararat	2 Excavator and 10 trucks	Yeka abado
Semit junction-Goje mechael	1 Excavator and 5trucks	Bole bulbula
Jmo mechael Anbessa garaj-Jigjiga sefer	1 Excavator and 6 trucks	Tor hayloch
Weyira- Betel	1 Excavator and 5truks	Tor hayloch
Egzheira-Goro megenteya	1 Excavator and 4 trucks	Bole bulbula

Appendix 8: MATLAB Codes and Neural Network Functions for Forecasting Excavator Productivity

```
function [y1] = myNeuralNetworkFunction(x1)
%MYNEURALNETWORKFUNCTION neural network simulation function.
%
% Generated by Neural Network Toolbox function genFunction, 01-Jun-2021 22:46:35.
%
% [y1] = myNeuralNetworkFunction(x1) takes these arguments:
%   x = Qx9 matrix, input #1
% and returns:
%   y = Qx1 matrix, output #1
% where Q is the number of samples.

%#ok<*RPMT0>

% ===== NEURAL NETWORK CONSTANTS =====

% Input 1
x1_step1.xoffset = [0;0;0;0;0;0;0;0;0];
x1_step1.gain = [2;2;2;2;2;2;2;2;0.949152542437231];
x1_step1.ymin = -1;

% Layer 1
b1 = [-0.75296516775561639;0.39363407914914778;0.74170912042270942;-1.2206906100640198;1.56086283478863];
IW1_1 = [1.1813872275328021 0.47147798374041705 -0.2875987322153804 -0.37789611647269683 1.6182868966054413
-0.57756983059035205 0.057721397176315831 1.3920527453208245 -0.57994408561234168;0.61388280044382681 0.42094308216126608
-0.35891963334915222 0.90178109075100288 0.1582759629772498 -1.6551368521039747 -0.082708564732516088 -0.38847069409124901
-0.61665480480208157;-0.83060647459003234 -0.6251632364840608 0.097636340084366557 0.97637484609084546 -0.9196558364720897
0.049641176404648546 2.0190328033766862 -0.3409804515777432 1.0029870851649536;-0.79689132967763243 -0.68224961157234176
-0.29003616925907916 -0.48606880333973418 -0.59147903385407463 -0.69422483755303999 1.1787543246715406 1.0873572364749284
-1.1307202432200849;0.49114887329985563 -0.16185267861248678 -1.6995530652617177 -1.7579239625807634 -0.84093772932046296
0.87843335117919774 0.10487910889353227 -0.095865339977661584 0.23675302345072124];
```

```
% Layer 2
b2 = -0.036615508367400101;
LW2_1 = [0.31532783558731692 0.38673384185889048 0.23229011656227921 0.56664180171225176 0.1079931538372513];

% Output 1
y1_step1.ymin = -1;
y1_step1.gain = 2;
y1_step1.xoffset = 0;

% ===== SIMULATION ========

% Dimensions
Q = size(x1,1); % samples

% Input 1
x1 = x1';
xp1 = mapminmax_apply(x1,x1_step1);

% Layer 1
a1 = tansig_apply(repmat(b1,1,Q) + IW1_1*xp1);

% Layer 2
a2 = repmat(b2,1,Q) + LW2_1*a1;

% Output 1
y1 = mapminmax_reverse(a2,y1_step1);
y1 = y1';
end

% ===== MODULE FUNCTIONS ========
```

```
% Map Minimum and Maximum Input Processing Function
function y = mapminmax_apply(x,settings)
y = bsxfun(@minus,x,settings.xoffset);
y = bsxfun(@times,y,settings.gain);
y = bsxfun(@plus,y,settings.ymin);
end

% Sigmoid Symmetric Transfer Function
function a = tansig_apply(n,~)
a = 2 ./ (1 + exp(-2*n)) - 1;
end

% Map Minimum and Maximum Output Reverse-Processing Function
function x = mapminmax_reverse(y,settings)
x = bsxfun(@minus,y,settings.ymin);
x = bsxfun(@rdivide,x,settings.gain);
x = bsxfun(@plus,x,settings.xoffset);
end
```

Appendix 9: MATLAB Codes and Neural Network Functions for Forecasting Excavator Age (Hour) Productivity

```
function [y1] = myNeuralNetworkFunction(x1)
%MYNEURALNETWORKFUNCTION neural network simulation function.
%
% Generated by Neural Network Toolbox function genFunction, 01-Jun-2021 01:34:56.
%
% [y1] = myNeuralNetworkFunction(x1) takes these arguments:
%   x = Qx9 matrix, input #1
% and returns:
%   y = Qx1 matrix, output #1
% where Q is the number of samples.

%#ok<*RPMT0>

% ===== NEURAL NETWORK CONSTANTS =====

% Input 1
x1_step1.xoffset = [0;0;0;0;0;0;0;0;0];
x1_step1.gain = [2;2;2;2;2;2;2;2;2];
x1_step1.ymin = -1;

% Layer 1
b1 = [0.8677746005068736l;0.51858539759053801;-0.1566590636436955;-0.4209607411115055;1.6925420347234315];
IW1_1 = [-1.84906498109746 -1.0426126500872672 -0.2144772133272364 -0.27504798898818111 0.93370116922808366
-0.434428136651963 -1.0958160225173681 -0.74850506735339661 -2.0301723115304107;-1.2696972298714231 0.6221098353668254
0.87980227388979737 -0.42538994577366301 -1.0410995874135878 0.29966116856839781 1.0569609659109542 0.012801244819845591
0.92395815045300322;1.1747489563980229 0.21065452133222448 -0.62872241745400625 0.22830379441793108 -1.1740880458230885
1.579873260772686 -0.25605968491656472 1.3842870781505168 -1.5054965652932926;-1.7566698515281867 -0.66243530312900389
-0.69487040611126982 0.14381388781653989 -0.023621277[illegible]84588769755953 1.5045885683800697 0.56246664810821612
-0.78564192641719988;1.2240141217385696 0.878040421755[illegible]840102029791 0.15432636931189758 -0.70476957733242929
1.5032120139594383 0.050141723299408442 -0.15233639872[illegible]5922661895];
```

```
% Layer 2
b2 = 0.37725216444998222;
LW2_1 = [0.56135322148317179 0.97609839011010713 0.91036993368478414 0.61062569183340287 -1.5602428338537317];

% Output 1
y1_step1.ymin = -1;
y1_step1.gain = 2;
y1_step1.xoffset = 0;

% ===== SIMULATION ========

% Dimensions
Q = size(x1,1); % samples

% Input 1
x1 = x1';
xp1 = mapminmax_apply(x1,x1_step1);

% Layer 1
a1 = tansig_apply(repmat(b1,1,Q) + IW1_1*xp1);

% Layer 2
a2 = repmat(b2,1,Q) + LW2_1*a1;

% Output 1
y1 = mapminmax_reverse(a2,y1_step1);
y1 = y1';
end

% ===== MODULE FUNCTIONS ========
```

```
% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function
function y = mapminmax_apply(x,settings)
y = bsxfun(@minus,x,settings.xoffset);
y = bsxfun(@times,y,settings.gain);
y = bsxfun(@plus,y,settings.ymin);
end

% Sigmoid Symmetric Transfer Function
function a = tansig_apply(n,~)
a = 2 ./ (1 + exp(-2*n)) - 1;
end

% Map Minimum and Maximum Output Reverse-Processing Function
function x = mapminmax_reverse(y,settings)
x = bsxfun(@minus,y,settings.ymin);
x = bsxfun(@rdivide,x,settings.gain);
x = bsxfun(@plus,x,settings.xoffset);
end
```

Appendix 10: MATLAB Codes and Neural Network Functions for Forecasting Truck Productivity

```
function [y1] = myNeuralNetworkFunction(x1)
%MYNEURALNETWORKFUNCTION neural network simulation function.
%
% Generated by Neural Network Toolbox function genFunction, 31-May-2021 23:38:18.
%
% [y1] = myNeuralNetworkFunction(x1) takes these arguments:
%   x = Qx6 matrix, input #1
% and returns:
%   y = Qx1 matrix, output #1
% where Q is the number of samples.

%#ok<*RPMT0>

% ===== NEURAL NETWORK CONSTANTS =====

% Input 1
x1_step1.xoffset = [-0.1;0;0;-0.2;0;0];
x1_step1.gain = [1.81818181818182;0.909090909090909;2;1.42857142857143;2;2];
x1_step1.ymin = -1;

% Layer 1
b1 = [-1.9512773396266174;0.60581327611214431;-2.1533019027203011];
IW1_1 = [-1.5197646303589578 -0.19839482632001407 2.8787567969010652 -1.0903996705949695 -0.49238328389743252
-0.80600153940485131;-1.2379236090274919 0.51613444562171262 -0.19273196170258028 -0.67873335725810435 -0.61444610738784722
2.4658912023652948;-0.067470753904134761 -0.12344981787401745 -0.86143067845839039 -0.31731529927399188
-0.41115628783202707 -1.0300085927438583];

% Layer 2
b2 = 0.76162656470201062;
LW2_1 = [0.39738470471916609 -0.49245038613020248 0.83254612134178263];
```

```
% Output 1
y1_step1.ymin = -1;
y1_step1.gain = 1.99999988800001;
y1_step1.xoffset = 0;

% ===== SIMULATION ========

% Dimensions
Q = size(x1,1); % samples

% Input 1
x1 = x1';
xp1 = mapminmax_apply(x1,x1_step1);

% Layer 1
a1 = tansig_apply(repmat(b1,1,Q) + IW1_1*xp1);

% Layer 2
a2 = repmat(b2,1,Q) + LW2_1*a1;

% Output 1
y1 = mapminmax_reverse(a2,y1_step1);
y1 = y1';
end

% ===== MODULE FUNCTIONS ========
```

```
% Map Minimum and Maximum Input Processing Function
function y = mapminmax_apply(x,settings)
y = bsxfun(@minus,x,settings.xoffset);
y = bsxfun(@times,y,settings.gain);
y = bsxfun(@plus,y,settings.ymin);
end

% Sigmoid Symmetric Transfer Function
function a = tansig_apply(n,~)
a = 2 ./ (1 + exp(-2*n)) - 1;
end

% Map Minimum and Maximum Output Reverse-Processing Function
function x = mapminmax_reverse(y,settings)
x = bsxfun(@minus,y,settings.ymin);
x = bsxfun(@rdivide,x,settings.gain);
x = bsxfun(@plus,x,settings.xoffset);
end
```

Appendix 11: Excavator Productivity Forecasting Simulation Model

Excavator productivity forecasting simulation model

Factors	Input	Normali	Standardize			lormaliz	Weight1									B1
Experie	10.21818	0.307	0	2	-1	-0.386	1.1814	0.4715	-0.288	-0.378	1.6183	-0.578	0.0577	1.3921	-0.58	-0.753
Equipm	8006.90909	0.3449	0	2	-1	-0.31	0.6139	0.4209	-0.359	0.9018	0.1583	-1.655	-0.083	-0.388	-0.617	0.3936
Superv	4.45454545	0.7273	0	2	-1	0.4545	-0.831	-0.625	0.0976	0.9764	-0.92	0.0496	2.019	-0.341	1.003	0.7417
Interfac	6.50909091	0.2959	0	2	-1	-0.408	-0.797	-0.682	-0.29	-0.486	-0.591	-0.694	1.1788	1.0874	-1.131	-1.221
Tempre	18.9454545	0.4208	0	2	-1	-0.158	0.4911	-0.162	-1.7	-1.758	-0.841	0.8784	0.1049	-0.096	0.2368	1.5609
Type of	1.07272727	0.0727	0	2	-1	-0.855										
Bucket	1.54454545	0.5743	0	2	-1	0.1487										
Depth c	1.05545455	0.3385	0	2	-1	-0.323										
Horse p	200.927273	0.8558	0	0.9492	-1	-0.188										

Factors	Weight 2					B2	Output	First lay	Activat	Second	Normalize Out pu	
Experie	0.3153	0.3867	0.2323	0.5666	0.108	-0.037	-1	-1.427	-0.891	0.308	0.654	85.788
Equipm							2	1.113	0.8051			
Superv							0	1.2274	0.8418			
Interfac								0.0885	0.0882			
Tempre								0.7513	0.6359			

Appendix 12: Excavator Hour Forecasting Simulation Model

Excavator hour productivity forecasting simulation model

Factors	Input	Normali	Standardize			Normaliz	Weight1									B1
Experie	10.22	0.307	0	2	-1	-0.386	-1.849	-1.043	-0.214	-0.275	0.9337	-0.434	-1.096	-0.749	-2.03	0.8678
Supervi	4.455	0.7273	0	2	-1	0.4545	-1.27	0.6221	0.8798	-0.425	-1.041	0.2997	1.057	0.0128	0.924	0.5186
Interfac	6.509	0.2959	0	2	-1	-0.408	1.1747	0.2107	-0.629	0.2283	-1.174	1.5799	-0.256	1.3843	-1.505	-0.157
Tempre	18.95	0.4208	0	2	-1	-0.158	-1.757	-0.662	-0.695	0.1438	-0.024	-0.851	1.5046	0.5625	-0.786	-0.421
Type of	1.073	0.0727	0	2	-1	-0.855	1.224	0.878	-0.048	0.1543	-0.705	1.5032	0.0501	-0.152	0.5297	1.6925
Bucket	1.545	0.5743	0	2	-1	0.1487										
Depth c	1.055	0.3385	0	2	-1	-0.323										
Horse p	200.9	0.3033	0	2	-1	-0.393										
Produc	80.65	0.6119	0	2	-1	0.2238										

Factors	Weight 2					B2	Output	First lay	Activati	Second	Normalize Out put	
Experie	0.5614	0.9761	0.9104	0.6106	-1.56	0.3773	-1	0.5703	0.5156	-0.217	0.3914	9069.7
Supervi							2	1.7945	0.9462			
Interfac							0	0.1455	0.1445			
Tempre								-0.772	-0.648			
Type of								2.6024	0.9891			

Appendix 13: Truck Productivity Forecasting Simulation Model

Truck productivity forecasting simulation model

Factors	Input	Normalize	Standardize			Normalize	Weight1						B1	Weight 2			B2	Output sta	First layer	Activation	Second la	Normalize Out put	
Expriance	6.552239	0.355224	-0.1	1.818182	-1	-0.17232	-1.51976	-0.19839	2.878757	-1.0904	-0.49238	-0.806	-1.95128	0.397385	-0.49245	0.832546	0.761627	-1	-1.68252	-0.93319	-0.4551	0.272449	17.86185
Age of equ	4.537313	0.507463	0	0.909091	-1	-0.53867	-1.23792	0.516134	-0.19273	-0.67873	-0.61445	2.465891	0.605813					1.999999	0.399775	0.379756			
Supervisio	3.686567	0.343284	0	2	-1	-0.31343	-0.06747	-0.12345	-0.86143	-0.31732	-0.41116	-1.03001	-2.1533					0	-1.07519	-0.79141			
Tempratu	19.16418	0.432836	-0.2	1.428571	-1	-0.09595																	
Type of so	1.059701	0.059701	0	2	-1	-0.8806																	
Cycle time	49.1791	0.336176	0	2	-1	-0.32765																	