Study of Factors Influencing Productivity of Hauling Equipment in Earthmoving Projects using Fuzzy Set Theory

A. Salem, A. Salah, M. Ibrahim, and O. Moselhi

Abstract—**Earthmoving operations and highway construction commonly entails extensive utilization of heavy construction equipment. Various factors affect directly and indirectly the efficient utilization of equipment and subsequently can lead to productivity decline in earthmoving operations. Efficient utilization of equipment is considered a crucial element towards the success of earthmoving project. This paper utilizes questionnaire-based method to investigate the factors that affect efficient utilization of hauling equipment including; fuel consumption, hauling and access roads conditions, labor, and soil properties. The paper presents a fuzzy-set based evaluation framework that is used for assessment and prioritization of the factors being considered. Output of the proposed framework provides early warning that highlights the underlying issues related to the efficient utilization of hauling equipment in earthmoving operations. This early warning is expected to assist owners and contractors to take proactive decisions instead of reactive ones in a manner that maximizes the efficient utilization of equipment. Finally, conclusions are drawn highlighting best practice recommendations that may assist owners and contractors not only in avoiding productivity losses, but also in efficient delivery of earthmoving projects.**

Index Terms—**Earthmoving, hauling equipment, fuzzy set theory, highway construction, productivity assessment.**

I. Introduction

Earthmoving is a key and crucial process in most of infrastructure projects. Earthmoving operations represent a considerable portion of civil infrastructure projects such as highways, mines, and dams [1]. Soil is usually moved from a location, in 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 a number of 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 remote area [2]. As the 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 vital role in success of earthmoving operations. Contractors utilize heavy construction equipment in earthmoving operations and road construction. Economic utilization of these equipment has a great impact on the contractor's profitability. Several factors can impact the productivity and cost of earthmoving operations such as; equipment utilization, fuel consumption, labor, and soil properties.

II. Literature Review

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 [3], extensive analysis is required to identify the different factors that could affect the productivity and its performance. Such extensive analysis comprises collection and analysis of data concerning the performance of equipment. Most of equipment-based researches considered fleet selection, analysis of equipment performance and productivity assessment. However, lack in identification and evaluation of equipment-based factors that can affect the productivity in earthmoving operations [4], [5] and [6]. Reference [4] presented a method for equipment fleet selection for earthmoving operations using computer model "FLSELECTOR" that utilizes the queuing theory.

The advancement in computers and sensing technology encouraged the utilization of different types of sensors for tracking construction equipment and acquiring the required data for analysis [5]. Another study [6] developed an automatic spatio-temporal analysis of construction site equipment operations using a low price commercial GPS data logger for continuous capturing of equipment location. Reference [7] introduced a tool for stochastic forecasting of productivity of earthmoving operations considering uncertainty using GPS/GIS technology to automate site data acquisition that assists in forecasting activity future performance using discreet event simulation (DES). Reference [5] developed an automated system for assessing the actual productivity of earthmoving operations in near real-time environment using latest advances in sensing technologies such as: microcontroller, GPS and different types of sensors and Bluetooth wireless communication. Reference [8] Presented a Bluetooth proximity detection and

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alerting system for preventing hazardous contact collisions between pedestrian workers and construction equipment in roadway work zones. Reference [9] developed a real-time magnetic field proximity detection and awareness system that alerts workers from being too close to an equipment. Reference [10] presented an automated web-based system for estimating productivity, time and cost of earthmoving operations. The system utilizes samples of collected GPS data to develop realistic probability distribution curves for actual duration of open cut excavation using fleet of loaders and trucks. Reference [11] developed a vision based method for tracking labor and equipment in construction sites using particle filtering to solve the issues raised from occlusion in visual tracking.

Literature is worthy with the identification of various factors that could affect the productivity of earthmoving operations. There is a need for prioritizing those factors that influence the productivity in earthmoving projects.

III. Methods

Literature has been investigated in order to identify the factors that mostly influencing the productivity of hauling trucks in earthmoving projects. Consequently, a questionnaire has been distributed on eighty (80) construction specialists whom are involved in earthmoving and highway construction projects. Twenty six (26) responses have been received from experts of different positions as shown in Fig. 1. This questionnaire gathers experts' evaluations for the equipment-based factors that affect the productivity in earthmoving operations as shown in Table I. Fuzzy set theory [12] can be used regardless of the availability of historical data [13]. Also, fuzzy theory eases the utilization of linguistic evaluation, or natural language terms, which is complicated to express with probability theory [14]. Therefore, fuzzy set theory was selected to model the uncertainty associated with input of the developed model [13] for the identification, assessment and prioritization of the factors influencing the efficiency and productivity of hauling trucks in earthmoving operations and highway construction. Quantitative assessment methodology utilized for conversion of expert linguistic evaluation into a numeric fuzzy numbers [15]. Fig. 2 shows the Fuzzy Linguistic-Numeric Conversion Scheme (FLNCS) that is used for converting the linguistic evaluations of experts on a no-effect to extreme-effect scale into numeric ones on a 1 to 10 scale as shown in Table II.

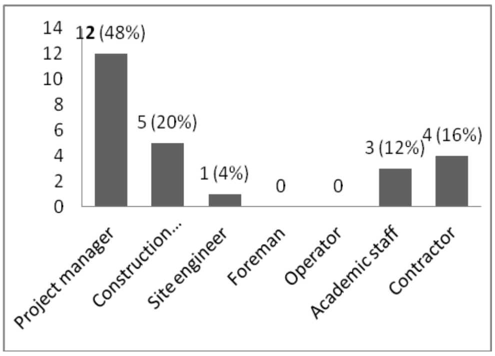

Fig. 1. Respondents' classification by position.

TABLE I: Expert Evaluation for Each Influencing Factor

Sr.	Influencing Factor	NE	LE	ME	HE	EE
1	Loosely soil road	1	4	10	6	4
2	Road with up or down-hills	0	4	11	8	2
3	Muddy road	0	1	5	17	2
4	Snowy road	1	1	5	10	8
5	Operator skills	1	3	4	14	3
6	Excessive loads	0	0	7	14	4
7	Wind resistance	0	4	12	8	1
8	Bad road conditions	0	2	5	15	3
9	Cold weather	0	4	11	8	2
10	Frequent short trips	0	4	12	8	1
11	Wheel slippage and excessive torque	1	2	16	6	0
12	Engine tuning / maintenance	0	0	12	8	5
13	Power of machine	0	3	7	11	4
14	Tire pressure	1	2	9	12	1
15	Age of equipment	0	2	3	16	4

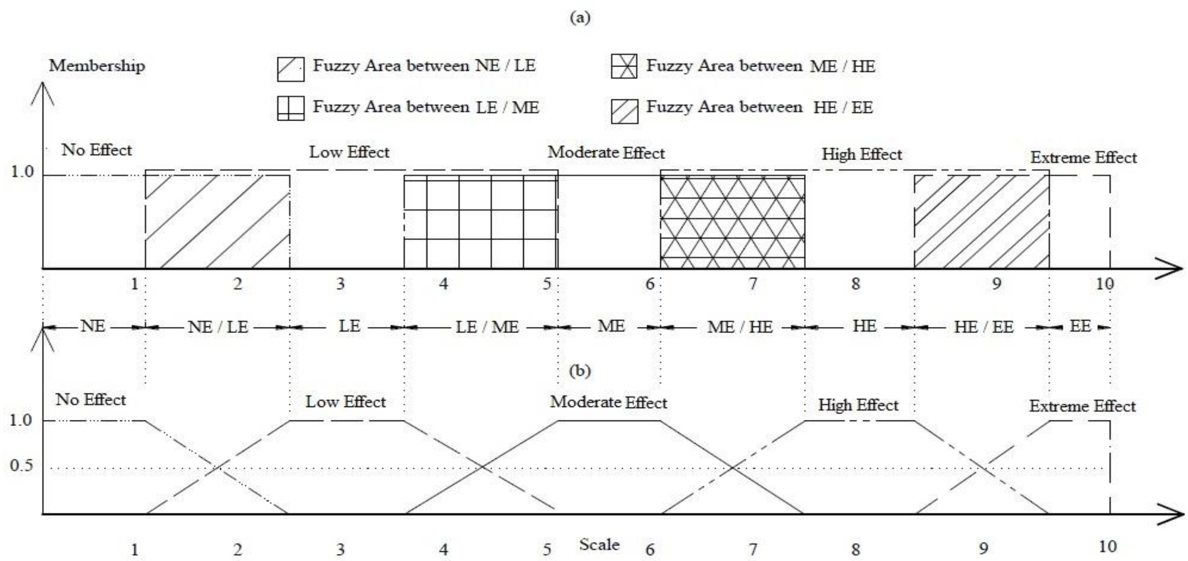

Fig. 2. Fuzzy linguistic - numeric conversion scheme: preliminary (a) and final (b) [15].

This scheme generated once for each affecting factor to represent the expert responses. Based on this scheme, the numerical fuzzy numbers can be acquired as shown in Table II.

TABLE II: NUMERICAL FUZZY NUMBER FOR EACH FUZZY ATTRIBUTE

Linguistic Evaluation	Numerical Fuzzy Numbers
No Effect	[0 0 1 2.5]
Low Effect	[1 2.5 3.5 5]
Moderate Effect	[3.5 5 6 7.5]
High Effect	[6 7.5 8.5 9.5]
Extreme Effect	[8.5 9.5 10 10]

The results of responses are converted from linguistic into numeric using the fuzzy Linguistic-Numeric conversion scheme shown in Fig. 2. The numeric fuzzy numbers are combined using (1) to calculate the fuzzy number that represents each factor influencing the productivity of hauling equipment as shown in Table III.

$$\widetilde{F}_i = \frac{N_r}{N_T} \times \widetilde{NoEffect} + \frac{N_r}{N_T} \times \widetilde{Minor} + \frac{N_r}{N_T} \times \widetilde{Moderate} + \frac{N_r}{N_T} \times \widetilde{High} + \frac{N_r}{N_T} \times \widetilde{Extreme} \quad (1)$$

where:

$\widetilde{F}_i$, represents the fuzzy number of factor i=1...15

N_r, represents the number of responses for each attribute A (e.g. No Effect)

N_T, represents the total number of responses for each factor

$$F_i = \frac{\int x \, \mu_A dx}{\int \mu_A dx} \quad (2)$$

where:

F_i, represents the defuzzified value of fuzzy number $\widetilde{F}_i$

μ_A, represents the membership function for each attribute A (e.g. No Effect)

IV. RESULTS AND DISCUSSION

Each fuzzy number is defuzzified using (2) to convert the fuzzy number into crisp number that represents the score of each factor. Accordingly, the factors are ranked from high to low score as presented in Table III.

TABLE III: RANKING OF FACTORS INFLUENCING PRODUCTIVITY OF HAULING TRUCK IN EARTHMOVING USING PROPOSED METHODOLOGY

Rank	Influencing Factors	Fuzzy Numbers	Defuzzification
1	Excessive loads	[5.70 7.12 8.04 9.02]	7.47
2	Snowy road	[5.86 7.18 7.98 8.80]	7.46
2	Age of equipment	[5.70 7.12 8.04 8.98]	7.46
4	Muddy road	[5.50 6.96 7.92 8.96]	7.34
5	Bad road conditions	[5.40 6.84 7.78 8.80]	7.21
6	Engine tuning / maintenance	[5.30 6.70 7.60 8.64]	7.06
7	Power of machine	[5.10 6.52 7.44 8.48]	6.89
8	Operator skills	[5.06 6.48 7.38 8.42]	6.84
9	Tire pressure	[4.56 6.02 6.96 8.16]	6.43
10	Road with up or down hills	[4.30 5.75 6.72 7.94]	6.18
10	Cold weather	[4.30 5.76 6.72 7.94]	6.18
12	Loosely soil road	[4.36 5.75 6.64 7.78]	6.14
13	Wind resistance	[4.10 5.58 6.56 7.84]	6.02
13	Frequent short trips	[4.10 5.58 6.56 7.84]	6.02
15	Wheel slippage and excessive torque	[3.76 5.24 6.20 7.58]	5.70

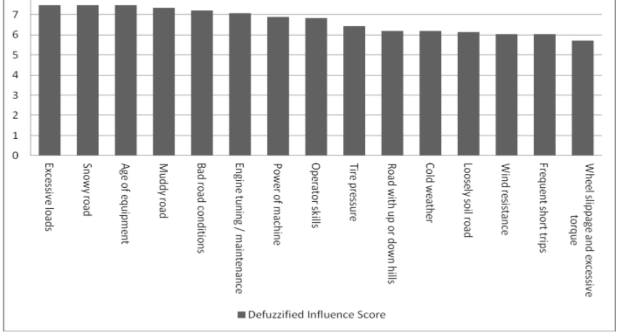

Fig. 3. Ranked defuzzified influence score.

Results shown in Table III and Fig. 3 represent the prioritization of the factors influencing productivity of hauling equipment in earthmoving projects. The analysis shows that excessive loads, snowy hauling roads condition and age of equipment are the most effective factors that could impact the productivity of hauling equipment. The effect scores are gradually decreased, while the wheel slippage came in the last position.

V. CONCLUSION

This paper introduces a new system that identifies, evaluates and prioritizes the factors affecting the productivity of hauling equipment in earthmoving projects. Questionnaire-based method is used tin this study. The responses are analyzed using fuzzy set theory and are then ranked based on score calculated using the developed defuzzification method. Excessive loads, road conditions, age of equipment and the condition of its engine are identified as the most important factors. The developed method represents an early warning to assist owners and contractors to identify the most influencing factors and, accordingly allow them to make proactive decisions in a manner that maximizes efficient utilization of their hauling equipment in earthmoving projects. The developed methodology is flexible and can account factors beyond those considered in this study to generate scenarios affecting the productivity throughout the various cycles of earthmoving operations.

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