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Impact Variables of Dump Truck Cycle Time for Heavy Excavation Construction Projects

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Abstract: The cycle time of construction equipment for earthwork operations has a significant impact on project productivity. Elements that directly impact a haul vehicle's cycle time must be identified in order to accurately quantify the haul cycle time and implement strategies to decrease it. The objective of this research is to scientifically identify and quantify variables that have a significant impact on the cycle time of a dump truck used for earthwork. Real-time location data collected by GPS devices deployed in an active earthwork moving construction site was analyzed using statistical regression. External data including environmental components and haul road conditions were also collected periodically throughout the study duration. Several statistical analyses including a variance analysis and regression analysis were completed on the dump truck location data. Collected data was categorized by stage of the dump truck cycle. Results indicate that a dump truck's enter idle time, exit idle time, moving speed and driver visibility can significantly impact the dump truck cycle time. The contribution of this research is the identification and analysis of statistically significant correlations of variables within the cycle time.

Keywords: Construction productivity, dump truck, cycle time, location-based data, construction project management

I. Introduction

The U.S. construction industry represents approximately 4% of the gross domestic product [1] and currently involves over 6 million workers employed by an estimated 750,000 construction firms [2]. Within this industry, productivity is a key driver for economic growth and strongly affects prosperity for the country [3]. More specifically, higher construction productivity translates into higher wages and increased profits [3]. Currently, skilled labor shortages in the U.S. are driving an urgent need to optimize equipment resources to increase productivity on US construction sites [4,5].

Dump truck cycle time can be defined as the summation of time for loading, hauling, idle and dumping for a truck [6]. Productivity has historically been a significant standard index in construction worker measurement [7]. Dump truck cycle time has been identified as a key component in the assessment of construction productivity [8]. Because of the significant impact of dump truck cycle time on the overall productivity of a construction project, it is the goal of this study to identify and analyze significant variables that influence this cycle time. To achieve this goal, location-based data of dump trucks and environmental data were collected on an active earthwork moving construction site over three months. During these three months, twelve days of actual construction production were measured. Other days in the three months were not included due to minimal productivity resulting from weather delays.

Global Positioning System (GPS) devices were deployed on dump trucks during their time on site. The dump trucks were transporting excavated clay from a desired foundation location for an academic building. GPS was selected to automatically detect and store location-based information including latitude and longitudinal coordinates, elevation and equipment at a one Hz frequency [9]. The raw data collected from GPS and environmental observation was analyzed using statistical applications to identify the impact of each variable on the overall dump truck cycle time. A commonly-used statistical processing software was used to perform a variance regression and regression analysis on the analyzed data. Internal and external techniques were implemented to validate the data collection method as well as analysis methodology.

II. Literature Review

The following review explores aspects of construction equipment productivity including measurement methods and analysis. The review also specifically investigates industry methods and academic research in equipment cycle time measurement and location-based tracking of construction equipment. This section concludes with a research needs statement derived from the literature review.

A. Construction Equipment Productivity Measurement

Due to the elevated impacts of productivity on the success of construction projects, a multitude of research has been performed in construction productivity. Multiple broad factors including environmental conditions, site attributes, management strategies and design components have been determined to impact construction productivity

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[10]. Statistical models have been developed to predict construction productivity given some input factors [11].

Case studies in construction productivity have indicated a recent upward trend in productivity largely due to advances in technology [12, 13]. Specifically, technological advancements in construction equipment can explain a segment of the increase in partial factor productivity [14]. In fact, much of the increase in labor productivity can be attributed to the advancement of construction equipment technology [13]. For example, one study identified a modification in the activity code structure of a piping and conduit section significantly increased the accuracy of labor productivity unit rate measurements [15]. Many changes in overall construction productivity can be explained by construction equipment modifications [16].

A strong relationship has been identified between construction equipment operating conditions and earthmoving productivity [17]. This relationship was found after modeling factors such as the number of dump trucks, excavator buckets per load, excavator bucket volume, dump truck travel time and haul length [17]. More detailed aspects, such as the payload of a dump truck, also impact construction productivity [18]. A more general study realized the consequence of relationships between productivity and input parameters such as excavator bucket volume [19]. A need exists to identify and compare such input parameters in order to understand the impact on construction productivity.

B. Construction Equipment Cycle Time

One widely implemented strategy to estimate equipment productivity is a set of equations and standard values of haul vehicles and excavation equipment [20]. The basic production equation implemented for one excavator and multiple dump trucks is shown in Equation 1. Although this system of equations provides a simple and plausible prediction for equipment productivity, it lacks the causation relationship between initial input variables, dump truck cycle time and overall productivity.

$$P = TL(NT)(60/TCT) \qquad \textit{Equation 1}$$

P is Production in loose cubic yards
TL is Truck Load in loose cubic yards
NT is Number of Trucks
TCT is Truck Cycle Times in minutes

Another theory, known as Little's Law, calculates the number of trucks for a given work of unit time. This equation uses a metric of work in progress divided by a single truck cycle time to determine the number of trucks required [21]. Little's Law indicates a strong relationship between construction equipment cycle time and overall productivity. Based on the principles of Little's Law, a model was developed to predict the cycle time of haul equipment based on a single hydraulic excavator [22]. Similarly to this model, a mining truck in an open-pit was evaluated for cycle-time measurements to understand the impact of external variables on the equipment's daily productivity [23]. Although these studies are helpful in identifying the importance of measuring cycle time of construction equipment, they lack the analysis and origin of input variables. More specifically, the studies failed to perform analysis on data collected as well as failure to analyze variables that originate with that actual construction operation cycle time. Furthermore, cycle time and throughput have been ignored in the current management system due to a lack of understanding of the correlation between input variables of construction equipment cycle time and overall productivity [24].

C. Construction Hauling Equipment

A variety of options are available for transporting material relatively long distances on construction sites including dump trucks and scrapers. Dump trucks were chosen as the haul equipment for this research because they can be more economical and are widely implemented [25]. Other studies have identified a few variables as potentially impacting the productivity of a dump truck including payload [18], available electronics [26] and travel time [27]. Although these studies investigate various aspects of dump truck cycle time, a need exists to collect active site location-based data to better understand impact factors of dump truck haul cycles.

D. Location-Based Tracking of Construction Equipment

Location-based tracking technologies can quantify and store the location of different pieces of construction equipment and assist in productivity management of construction sites [28]. Selection of technological systems depends on the capabilities of that system as well as the desired data collection [29]. For example, knowing the location of haul vehicles and travel trajectory are essential data points for tracking and collision detection [30]. Various technology systems exist to collect such data including GPS, Wireless Local Area Network (WLAN), Ultra-wideband (UWB) and others that have unique detection and communication strategies [29]. For example, GPS have been implemented for transportation management, facility delivery, urban planning, and site safety monitoring [31]. WLAN has been deployed for point-based indoor position tracking because of its 0.1 meter accuracy [32]. Furthermore, UWB has been used to improve work zone safety, job site monitoring and outdoor resource tracking [33].

GPS has been identified as the most suitable location-tracking technology for construction equipment in large open areas when very high accuracy is not of primary concern [29, 34]. Construction equipment locations and trajectories were tracked using GPS to assess productivity and safety [35]. GPS was identified as a technology that can provide real-time data on vehicle position and velocity [36]. GPS has the capability to provide a large amount of individual time, position and speed data points at rapid frequencies [36, 37, 38]. Location tracking with GPS-based systems can increase productivity and decrease cost through management decisions based on analyzed tracking data [39].

E. Research Needs Statement

The review of existing literature shows gaps in research for collecting and analyzing data for the cycle time of a dump truck. One research need is to investigate the implementation of location-based automated systems for assessing dump truck cycle times on construction sites. Data collected by this technology can be used to identify significant impact variables on the cycle time of haul equipment on construction sites. This technology equips construction managers to quantify several variables related to a cycle time of a construction site by creating a previously unavailable database for construction haul equipment.

III. Methodology and Results

An active construction site of an academic research and educational building in Atlanta, GA was employed as a collection test bed for location-based dump truck cycle time data. The project objective was to construct an academic research facility with laboratory and classrooms. The building is 1,891 square meters and the construction site had a surface area of 11,150 square meters 10,800 square meters (120 meters by 90 meters). Dump truck operators were required to drive 6 miles from the construction site to unload the excavated material at the fill location. Because dump truck operators requested that researchers not record their location-based information outside of the construction site, research were unable to provide travel information to and from the fill location.

Data was collected for a total of twelve days between November 2012 and January 2013 during the excavation phase of the construction project. The time period and specific days were times in which the excavation contractor permitted members of the research team to collect location-based data on their resources. The excavation was performed using hydraulic excavators and dump trucks. The construction site contained one entrance and one exit site with a commonly used travel path connecting both. Figure 1 presents an overview of the selected construction site.

FIGURE I
Active experimental testbed

A. Data Collection

A GPS location system with a measured error value of plus or minus three meters was installed on dump trucks part of the excavation cycle [35]. GPS data loggers were attached to plastic mounts on each dump truck. The number of trucks on the construction site is shown in Figure 2. The dashed line in Figure 2 represents a trending average of trucks on the site through the evaluation period.

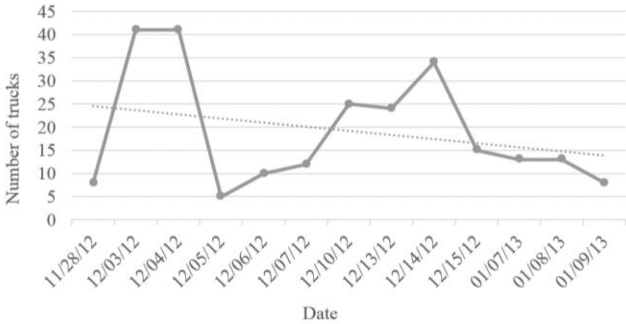

FIGURE II
Daily totals of dump trucks on the construction site

A total of fifteen GPS data loggers were attached to the dump trucks entering the construction site. One GPS device was temporarily attached to one dump truck to record and store the latitude, longitude, elevation, date, time and estimated speed. Each dump truck had a unique GPS data logger mounted on the driver door. The commonly used truck cycle time components are defined and used for data analysis [20].

<u>Load time</u>: Duration of time for the excavator to load earth material into a single dump truck.
<u>Haul time</u>: Duration of time for a single dump truck to travel from the excavation area to the fill area with a loaded payload.
<u>Dump time</u>: Duration of time for a single dump truck to empty the payload.
<u>Return time</u>: Duration of time for a single dump truck to travel from the fill area to the excavation area with an empty payload.

These cycle time components provided analysis categories for the GPS tracking data collected. Specifically, GPS data was segments into various cycle-time categories to identify which category impacted the overall excavation productivity. The flow path of dump trucks in this excavation project is shown in Figure 3.

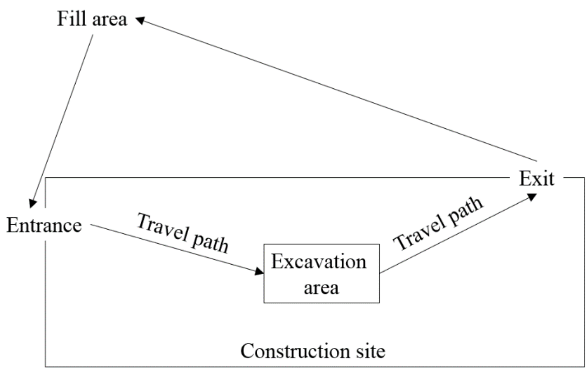

FIGURE III
Cycle time categories for dump trucks

Although many exist, candidate variables were selected that were thought to potentially have an impact on a dump truck's cycle time. The selection criteria for these variables included: 1) Variables were identified in existing literature, 2) variables were used for existing cycle time productivity calculations, 3) ability of deployed sensing technology to automatically capture the variable and 4) privacy considerations of dump truck operators. For example, dump truck operators chose not to allow researchers to track their location outside of the construction site due to cited privacy issues. This consideration limited researchers from collecting probably impact variables including traffic conditions and number of individual cycles completed per day. One complete dump truck cycle is defined as the summation of the enter duration, enter idle time, load duration, exit duration, exit idle time and haul duration.

Fifteen internal cycle time variables were identified as potentially impactful to a dump truck's cycle time. The dependent variables include: enter duration, load duration, exit duration and haul duration. The independent cycle time variables are enter idle time duration, enter elevation, enter elevation change, enter maximum speed, enter average speed, exit idle time duration, exit elevation, exit elevation change, exit maximum speed and exit average speed. Idle time durations for both the entrance and exit were separated from their respective enter and exit durations in an attempt to assess their individual impact on the overall dump truck cycle time.

The following independent external variables thought to impact a dump truck's cycle time were also assessed: temperature, dew point, humidity, visibility, wind direction, wind speed, haul road material and haul road conditions. The driving surface for the dump truck in transit was considered to be negligible because all should be smooth surfaces made of concrete or asphalt. Most construction sites do not provide smooth surface haul roads for dump trucks during excavation, so this was not included in the study. All internal variables were collected by the deployed GPS system which external variables were gathered through site visits, site pictures and historical weather sites [40]. The external variables were collected at the end of the data analysis phase for each day of data collection in the experimental testbed. Table I provides the definition of each variable assessed for an individual dump truck's cycle time. Analyzed data values idle time, load duration, exit duration and haul duration are calculated from the raw GPS data.

TABLE I
Variables for Data Collection of Dump Truck Cycle Time

Variables	Units	Definitions
Enter truck duration	Second	Travel time duration from entrance to excavation area
Truck Load duration	Second	Time duration for excavator to load the truck payload
Exit truck duration	Second	Travel time duration from excavation area to the exit
Haul truck duration	Second	Travel time duration from the exit to the entrance
Enter truck idle time duration	Second	All static time during the enter duration
Truck enter elevation	meter	Ground elevation at the entrance
Truck enter elevation change	meter	Difference in elevation experienced when traveling from the entrance to excavation area
Enter maximum speed	meter/ second	Maximum speed during enter duration
Truck enter average speed	meter/ second	Average speed during enter duration
Truck exit idle time duration	Second	All static time during the exit duration
Exit truck elevation	meter	Ground elevation at the exit
Truck exit elevation change	meter	Difference in elevation experienced when traveling from the excavation area to the exit
Truck exit maximum speed	meter/ second	Maximum speed during exit duration
Truck exit average speed	meter/ second	Average speed during exit duration
Site outdoor Temperature	degrees Celsius	Average daily temperature on the construction site
Site outdoor Dew point	degrees Celsius	Daily dew point at the construction site
Site outdoor Humidity	percent	Daily amount of water vapor in the environment at the site
Site outdoor Visibility	meters	Distance at which an objective or light can be identified
Site outdoor Wind direction	cardinal direction	Average direction of wind direction on the site
Site outdoor Wind speed	meters/ second	Average value of wind speed on the site
Haul road material for trucks	Soil type	Type of material used for constructing the haul road
Haul road condition for trucks	Visual observation	Daily observation of dump truck travel path

B. Data Analysis

Data collected from the GPS loggers provided the raw data points for analysis. The GPS data loggers provided the latitude, longitude, elevation (in meters), date, distance from start (in meters), distance from last (in meters), bearing and speed (in meters per second). The internal variables were analyzed from these raw data sets through various calculations. The GPS update rate was 1 Hz and the GPS data loggers only record when movement is detected. Wintec was the company that produced the deployed GPS devices [41]. Figure 4 provides an example of the GPS raw data set.

Elevation	Time	Dist. from Start	Dist. from Last	Bearing	Speed
272	10:03:25 AM	0.022	0.002	281	6.51
272	10:03:26 AM	0.023	0.001	270	4.26
272	10:03:27 AM	0.024	0.001	270	4.26
272	10:03:28 AM	0.026	0.002	270	6.38
272	10:03:29 AM	0.027	0.001	253	4.44
272	10:03:30 AM	0.029	0.002	270	6.38
273	10:03:31 AM	0.03	0.003	253	4.44
273	10:03:32 AM	0.031	0.003	270	4.26
273	10:03:33 AM	0.033	0.005	259	6.51
273	10:03:34 AM	0.035	0.006	259	6.51

FIGURE IV
Example of GPS raw data set

The data collection effort resulted in approximately 250 data points across the 22 variables shown in Table 1. In order to identify the most impactful variables on a dump truck's cycle time, several regression analysis were performed on the collected data. A commonly-used statistical analysis computer program, called Statistical Analysis Software (SAS), allowed for storage, modification, simple and complex statistical analysis and reports of data values [42]. The maximum outlying value for all gathered variables represented less than 2% of all data collected for that specific variable. Extreme outliers (values greater than three times the fourth spread from the quartile values) were removed from the analysis. These extreme outliers were defined as values greater than three times the fourth spread from each quartile value. A stepwise regression analysis was used to quantify the weighted impact of each variable on the overall dump truck cycle time. The stepwise regression is an iterative process in which the correlation of each independent variable to the dependent variable is assessed. Independent variables with the highest correlation are entered into the regression equation at each iteration. The regression analysis ends when all variables are entered into the equation or the correlation between remaining independent variables are dependent variables is considered insignificant [43]. For this research, all independent variables that entered the model were deemed significant at the correlation coefficient of 0.05. No other independent variable met the correlation coefficient value of 0.10 for entry into the model.

The dump truck cycle time was previously defined as the summation of the enter duration, load duration, exit duration and haul time. One form of internal validation performed for the collected data was performing a correlation analysis to ensure a perfect correlation existed between the overall cycle time and the summation of the enter duration, load duration, exit duration and haul time. Furthermore, this analysis ensures that each of the cycle time components (enter duration, load duration, exit duration and haul time) can be evaluated as dependent variables for other regression analysis to identify the impact of more detailed variables on the overall cycle time. The haul duration and enter duration were found to have the highest impact on a dump truck's overall cycle time.

A simple statistical analysis was performed on the collected data to provide insight into the following quantitative analysis. Results of this analysis are presented in Table II. Only measured variables with quantitative values were analyzed.

TABLE II
Statistical Analysis of Select Variables

Variables	Mean	Range	Standard Deviation
Enter duration	6.0 min.	69.3 min.	7.6 min.
Load duration	9.7 min.	57.5 min.	10.4 min.
Exit duration	687.5 min.	26.9 min.	133.2 min.
Haul duration	27.1 min.	992.0 min.	48.1 min.
Enter idle time duration	3.1 min.	53.0 min.	4.8 min.
Enter elevation change	1.6 m.	5.8 m.	12.4 m.
Enter maximum speed	26.2km./hr.	56.6km./hr.	16.3 km./hr.
Enter average speed	21.1km./hr.	40.7km./hr.	8.6 km./hr.
Exit idle time duration	1.4 min.	56.1 min.	3.7 min.
Exit elevation change	5.2 m.	3.9 m.	9.0 m.
Exit maximum speed	28.3km./hr.	49.2km./hr.	21.8km./hr.
Exit average speed	14.4km./hr.	23.8km./hr.	32.4km./hr.
Temperature	14.1 °C	0.6 °C	-12.9 °C
Dew point	6.5 °C	-0.6 °C	-13 °C
Humidity	1.0%	1.1%	0.2%
Visibility	15.2 km.	15.8 km.	2.6 km.
Wind speed	10.3km./hr.	24.1km./hr.	5.1 km./hr.
Construction site duration versus total cycle time	34.7%	80.1%	46.3%

In an attempt to quantify the statistical relationships between the collected data variables and the cycle time components, a processing platform was develop in a commonly-used multi-paradigm numerical computing environment, called Matrix Laboratory (MATLAB). The computing software was selected to perform detailed statistical analysis, but is not required to execute the summarized research. A regression analysis was completed between all potential combinations of the 22 evaluated variables. The platform was developed by writing code to build a linear regression model for the variables. Linear regression was selected after the regression analysis indicated a linear relationship provided the highest potential of correlation when compared to other tested functions. Of these regressions, four plots were found to show the most potential for a correlation. The four plots presented in Figure 5 identify an increasing linear relationship between each of the independent variables of the total cycle time. Regression results indicate that the haul duration is most associated to the linear model. Figure 5 shows the results of each regression analysis. The lack of a correlation between the load duration and cycle time indicates that the overall cycle time is minimally impacted by the load duration.

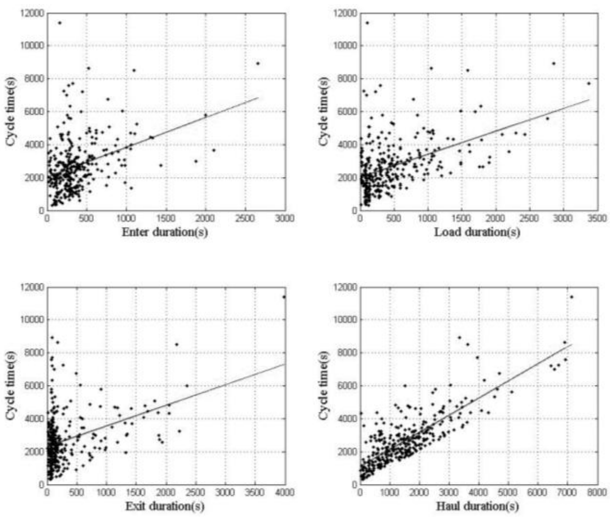

FIGURE V
Linear regression analysis between cycle time components and overall cycle time

It is important to note enter and exit idle time were not included in the cycle time durations presented in Figure 5. Preliminary statistical analysis indicators no identifiable correlation existed between cycle time elements and the overall cycle time when idle time values are included. This is potentially due to the unpredictable nature of idle times. For example, many of the outlying values with extended duration times were due to equipment malfunctions of the excavator.

After verifying that the summation of individual components of the cycle time have a direct impact on the overall cycle time, the next completed step was to identify the contribution of each independent variable on the overall dump truck cycle time.

A.1 Enter Duration Variable Analysis

A stepwise regression analysis identified twelve potential impacting variable on the enter duration. Of these twelve, enter idle time (EnIT), humidity (H) and wind speed (WS) were determined the have the highest impact on the enter duration time. A suggested model for the enter duration (ED) in seconds of a single dump truck is shown in Equation 2. The model is correct on average for all fitted values as shown in Table III.

$$ED = 17.717 + 1.0389(EnIT) + 3.7074(H) - 13.063(WS)$$

Equation 2

TABLE III: Output of Stepwise Regression of Enter Duration

Variable	R-square	F Value	Pr > F
Enter idle time duration	0.5663	408.74	<.0001
Humidity	0.5791	9.46	0.0023
Wind speed	0.5893	7.71	0.0058

The R-square value was implemented to measure how well the individual variables of the enter time duration (shown in Table III) fit the output model. Each R-square value measures the individual variable contribution to the model and how well that value fits with the overall model. These values are obtained by providing a cumulative value of best fit as the model progressed from one variable to three variables. The same regression measurement was used for variables in Equation 3.”

The enter idle time was identified as having an increasing linear relationship with the overall cycle time. As expected, the overall cycle time increases as the frequency and duration of stops for a dump truck increases.

It is important to note that both Equations 2 and 3 have constant values. This represents the culmination of variables found to be insignificant in the model. For example, truck speed was deemed insignificant in the model because the travel distance on the construction site was minimal and only a marginal speed could be obtained by the truth. While speed of the truck wasn’t found to significantly impact the model, some time is required for the truck to travel this distance requiring an initial amount of time on the cycle time.

A.2 Load Duration Variables Analysis

All of the independent variables found to be correlated with the load duration analysis were weather and environmental related. However, the R-Square and F-value indicate these variables are not reliable predictors of the load duration. Therefore, it was determined that load duration is entirely dependent on the functionality and capability of excavation equipment. Because all variables collected were individual properties of the dump truck, the data collected was incapable of explaining the load duration. However, from stepwise regression results, visibility (*V*) and wind direction have a P value less than 0.001 which indicates the weather conditions have an impact on the overall cycle time.

A.3 Exit Duration Variable Analysis

Two evaluated independent variables were determined to impact the exit duration of a dump truck. These variables are exit idle time duration (*ExIT*), visibility and wind speed. Similarly to the enter duration, the idle time was found to have a linear relationship with the exit duration meaning the longer duration and more frequent stops of dump trucks result in longer exit durations. The generated equation from the stepwise regression is shown in *Equation 3*. The R-Square value for this output is minimal indicating it may not necessarily statistically explain all of the Exit Duration (*ED*) variable in seconds. Table IV shows the statistical assessment of output variables of the stepwise regression.

$$ED = 991.21 + 1.2208\,(ExIT) - 72.105(V) - 21.94\,(WS)$$

Equation 3

TABLE IV: Output of Stepwise Regression of Exit Duration

Variable	Model R-square	F Value	Pr > F
Exit idle time duration	0.3263	151.60	<.0001
Visibility	0.3592	15.99	<.0001
Wind speed	0.3699	5.30	0.0220

A.4 Haul Duration Variables Analysis

The stepwise regression output for the haul duration indicated that a significant correlation between the haul duration and all collected data did not exist. The output variables of the regression recorded an insufficient R-Square value to statistically explain the model. Of the output variables from the stepwise regression, most were environmental conditions indicating that more data is required to understand the impact on the haul duration.

IV. Discussion of Results

Results of the data analysis indicate impactful variables to a dump truck’s cycle time as well as many variables that have minimal impact. Additionally, cycle time categories that lack sufficient correlation identify areas where additional research and data collection are needed. Overall, dump truck idle time during both the entrance duration and exit duration proved to be the most influential variable on a dump truck's cycle time of the data collected. A correlation was not identified between idle time and the overall cycle time because of the large range of idle times. For example, a small entrance or exit idle time has little impact on the overall cycle time, but an extended entrance or exit idle time has a significant impact on the dump truck's overall cycle time. Larger dump truck idle times were attributed to equipment malfunctions of the excavator.

Two environmental variables cited to had an impact on the overall dump truck cycle time. The first environmental was the impact of visibility on the dump truck's load duration and exit duration. The second environmental variable was the impact of wind direction of the dump truck's enter duration, load duration and exit duration. Both of these variables suggest environmental factors and haul road conditions have an impact on the overall cycle time of the dump truck.Future research should investigate other variables, such as excavator productivity, to further identify impact variables to the overall construction operation.

The R-square values calculated in both Table 3 and Table 4 are both relatively low for declaration of fitness or correlation. The researchers identified several potential reasons for this including 1) a lack of additional external variables including the excavator productivity data, 2) various skill levels of dump truck operators and excavator operators and 3) external traffic conditions impacting the hauling duration.

V. Conclusion

The cycle time of construction haul equipment can directly impact the overall productivity and resulting success of a construction project. The research objective was to identify and analyze the statistically significant influential variables on a single dump truck's cycle time. It is important to note that the research did not necessarily create a prediction model, but rather scientifically identified impact variables to a dump truck's cycle time. To achieve this objective, GPS technology was deployed on dump trucks in an active construction site setting for location tracking. Data collected from the GPS devices was catalogued and analyzed using linear regression models for each component of the dump truck's cycle time. Variables were categorized based on their specific impact per individual stage of the cycle. Additionally, external environmental variables were included in the regression analysis. The stepwise regression models developed for the dump truck enter and exit duration contained the most significant results. The study revealed that the following four factors have the most impact on a dump truck's enter and exit time: 1) idle time, 2) visibility, 3) wind speed and 4) humidity. These four variables were determined to be the most impactful on the overall dump truck cycle time based on the variables assessed. Construction industry practitioners and researchers can use the primary outcomes of this study in monitoring cycle time systems to enhance and improve construction equipment productivity.

The contribution of this research is the identification and analysis of statistically significant correlations of identified variables with the cycle time of a dump truck. Limitations of this work include minimal variables available for the haul duration and load duration. Additionally, environmental factors were not considered for non-working days. For example, large amounts of rain produced an entire day of delay which was not captured in the regression. Future research could investigate the interaction of excavation equipment with haul equipment and include detailed variables regarding the haul distance.

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