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Autonomous Monitoring of Hauling Equipment in Earthmoving Operations

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This study has been conducted to explore the feasibility of using Fleet Telematics Systems (FTS) to identify truck hauling cycle-times and optimize trucking power in earthmoving operations. Aftermarket telematics control units and a web-based telematics application were utilized to autonomously monitor and collect cycle-time information on multiple tandem-axel dump trucks. Trucks were monitored during a four-day period of work while performing the same task through the duration of the data collection. The information was then analyzed to determine if inefficiencies in the earthmoving operations could be identified strictly through the collected cycle-time data. The key finding of this study was that information collected through FTS units and applications provided a beneficial understanding of the on-site earthmoving equipment through the data associated with the hauling cycle-times. The authors believe that the telematics technology being introduced to hauling machinery and vehicles provides a low-effort and inexpensive means to autonomously monitor and manage earthmoving operations from anywhere in the world.

Key Words: Earthmoving, Telematics, Automation, Productivity, Efficiency

Introduction

Hauling Operations

Earthwork in the construction industry is heavily dependent upon minimizing cycle times to increase productivity and efficiency. Almost all activities in earth-moving related construction are estimated by using historical data to determine equipment cycle-times. The maximum cycle-times determined for an estimate will help determine, for example, how many cubic yards of soil can be moved per hour. Shorter cycle-times will equate to a higher quantity of material being moved per hour. Construction projects, where material is required to be either imported or exported to or from a site, are driven by the efficiency of material trucks. Trucking times can vary dramatically due to two major variables:

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distance from the project to a borrow or disposal site and the required time to load or unload material. In road construction, earthwork accounts for roughly 25% of total construction costs (Hare, 2011) which does not account for all material hauled to a construction project such as base coarse aggregate, cement or asphalt. More generally, according to Liu, 2013, "Haulage cost typically accounts for around 30% of the total cost of mass earthmoving projects." With such a significant portion of projects being dependent on the haulage of soils and other materials, it is critical that management teams are provided with accurate information for both estimating future projects and managing current projects.

Earthmoving Operations

Monitoring, evaluating and managing earthmoving equipment during construction activities is vital in the completion of a successful project. In an earthmoving operation, all equipment involved in a particular project are interdependent upon each units' effectiveness at completing a task. A simple earthmoving operation (see figure 1) consists of loading, traveling to and from a project location, and placing of material. Each operation is effectively limited by the effectiveness of the speed at which any single task is completed. For this reason, proper equipment allocation is critical to ensure that all operations are being completed with maximum efficiency. Equipment and trucks must be monitored to determine cycle times and efficiency. Archaic means and methods of manually tracking and reporting on project performance is time consuming and limited in the flexibility to make quick changes to projects (Sacks, 2002). The introduction of Fleet Telematics Systems (FTS) into the construction industry may help to solve some of the inefficiencies in manually monitoring and recording field data on earthwork projects. Telematics services can be simply defined as any form of processing and communicating data transferred from an on-board computer information system. Fleet telematics systems are more specifically applied to machinery or automotive machinery. As FTS equipment and web-based applications that allow easy monitoring of telematics data have become more widely available, the ability to remotely monitor every individual piece of earthmoving equipment has become more practical. The goal of this paper is to analyze whether or not GPS logging data from FTS equipment provides enough information to quickly and accurately determine efficiency among multiple trucks hauling material on the same project.

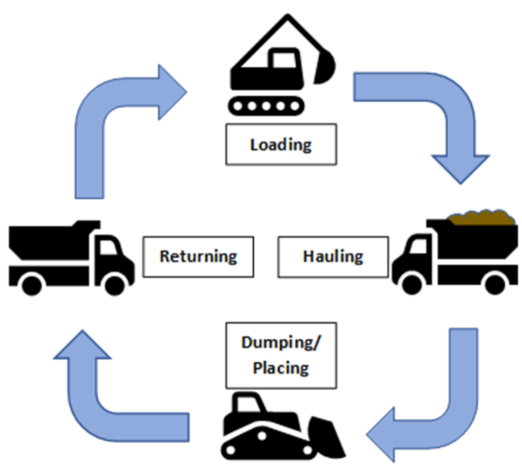

Figure 1. Simple Earth Moving Operation

Background and Related Works

Historically, the simplest and least cost restrictive form of data collection to determine project efficiency and track progress has been through forms of communication between on-site personnel and management personnel. Technological forms of communication such as email and handheld computing have helped to increase the speed in which project information can be communicated from on-site activities to the office management (Omar, 2016). Handheld devices or tablets can be used to track delivered loads by material trucks to or from projects, eliminating the need for paper load counts or tickets. The lag time between collecting this information and presenting it to management for evaluation can still be delayed and not allow for immediate corrective action. Significant lag times between site activities and information transmittal to management have long been identified as a problem that has the potential to be corrected using more automated systems (Sacks, 2002). To decrease the delay between data collection and delivery to management, a handful of studies have been conducted using various technological methods.

One such autonomous monitoring technique used vision-based activity identification to monitor truck and excavator activity during earthmoving operations. Using Tracking-Learning-Detection programming in combination with online learning, trucks and excavators could be identified as differing objects and their activities could also be identified and determined to be “working,” “traveling,” or “idling” (Kim, 2018). This process, while informative, certainly has its drawbacks. For instance, this autonomous monitoring process requires site specific CCTV surveillance which can be a barrier for smaller contractors or contractors with many projects happening simultaneously. Time for analysis of the data and accounting for errors in the imaging identification techniques also create a significant lag between data collection and analysis by management. In the current study, the imagery would also require manual auditing to account for cycle times of each specific truck. The current modeling accounts only for a truck as a single object that is either “working,” “idling,” or “traveling” and does not identify each truck as specific objects that can be autonomously accounted for each cycle of material.

A similar study proposed using Radio Frequency Identification (RFID) tags attached to hauling trucks and reader tags attached to loading machinery to track cycle times for earthmoving operations. This provides a low-cost option to identify cycle times and count completed cycles during the lifespan of hauling activities. When in range of the loading machinery, the RFID tags would identify that it was near the loading equipment and the time for loading the material would begin registering. During travel times, the RFID tag would not be near the reader tag, and thus the travel time would register whenever there was no active reader tag near the RFID located on the truck. Finally, the study used a control sensor to register the time period the dump truck operator began dumping the full load until the completion of dumping the material.. This gives a good breakdown of the four phases of the trucks’ cycles; however, it does not provide accurate measurements for the idle time during loading and dumping of material. Instead, the time spent idling at a dump site or a borrow site is attributed to “travel time” which does not present an accurate representation of the time spent during each phase of the trucks’ cycles (Montaser, 2013).

Current State of Autonomous Spatial Monitoring

As GPS technology becomes more readily available and financially accessible, real time monitoring and reporting of earthmoving activities has become a more feasible form of managing earthmoving operations. The introduction of Fleet Telematics Systems (FTS) has only recently begun to permeate into the construction industry on a significant level. In 2008, the Association of Equipment

Management Professionals (AEMP) cooperated with Caterpillar, Volvo, Komatsu, and John Deere to establish a standardization for telematics data in heavy earthwork equipment. This standardization has allowed all major manufacturers of equipment to provide telematics data such as operating hours, location, fuel consumption and odometer readings to users of FTS equipment and software (Lee, 2018). However, older equipment that was built prior to standardization, can still be equipped with telematics control units that can identify activities such as GPS location, start/stop time, and idle times based on movement provided from the GPS data. This information has proven to be beneficial in monitoring, tracking, evaluating, and forecasting equipment productivity during earthmoving operations. In a case-study performed in 2018, equipment and trucks were equipped with FTS equipment and tracked via the web-based application "VisionLink." Information on location was collected and determined to be in either the excavation, moving, or dumping areas of a project. If trucks moved less than 12 meters during a 30 second interval, that time was "idle-time." If trucks moved greater than 12 meters during a 30 second interval, that time was "working-time" (Lee, 2018). This case-study shows an appropriate utilization of the FTS equipment and applications; however, "working-time" and "idle-time" do not necessarily reflect productivity. Using this model, cycle times are not calculated and thus, even if a truck is considered to be working with no idle-time, they may not be maximizing efficiency. GPS informational modeling has also been used to determine cycle times of individual trucks. In one 2016 study, trucks were monitored via GPS locating. Coordinates of the truck location were collected and then analyzed to determine location. If the coordinates fell within the range of the loading or dump site, time while in these areas were "Loading Time" or "Dumping Time" respectively. Time when the trucks were located outside of these two zones were either "Travel Time" or "Return Time." Data collection for this project occurred with only one truck, although 45 trucks were assigned to the project at the time of data collection. A total of ten cycles were analyzed and recorded with fairly similar results between each cycle (Alshibani, 2016). This study displays the importance of cycle time analysis when managing earthwork operations. Using the collected information, a more accurate prediction of project outcome can be gathered. If the analysis is accurate, the projection on whether the project will be on budget or on schedule can be determined. Adjustments can be taken if estimated cycle-times are not being met or if additional machinery or trucks need to be added to the project to meet schedule goals.

Methodology

This project demonstrates how fleet telematics systems can be utilized to help management teams remotely identify the unknown efficiency of allocated equipment and trucking power on earthmoving construction projects. The purpose of this study is to utilize cycle-time information autonomously collected from telematics control units placed inside hauling trucks on an earthmoving construction project to identify if the performance of the loading equipment, hauling equipment or placing equipment are directly contributing to inefficiencies in the hauling of material from a borrow site to a project location and how the specific project can be optimized through allocation of trucks and equipment.

Fleet Telematics System (FTS)

For this project, data was collected using a telematics control unit, "Zonar V4" and a web-based fleet management application called "Ground Traffic Control (GTC)." Both the hardware installed in the trucks and the web-based application are products of Zonar Systems, Incorporated, a leader in telematics solutions for a variety of industries. The data is collected through the telematics control unit which uses GNSS positioning services and communicates information through built in LTE, 4G cellular radios that can be monitored in near real time from the web-based application. The telematics control units are installed manually inside of the cab of the vehicles with an external GPS antenna attached to the roof of the cab to help provide more accurate information. GPS locating information was collected and logged in real time through the GTC web-based application. Within the application, geofences were created for both the borrow site and the project site. Geofences were manually defined to encompass the working areas within both the borrow site and the project site specifically to minimize the amount of time that would be incorrectly allocated to "travel-time." The web-based application then logged time spent inside of each geofence, as well as the time spent traveling from one geofence location to the next location. The telematics control unit automatically logs information for multiple different reasons: power on, motion start or stop, power off, or a standard log that will occur approximately every 18 seconds if no specific event takes place. This consistent logging of information helps to create significant and accurate locating information. Each unique driver/truck combination is monitored through the entirety of the workday and any discrepancies in cycle time can be clearly identified on both a haul route map visualization as well as the location data. The geofencing also allowed for quick identification of inaccurate GPS data.

Hauling Equipment

The trucks that were utilized for this project included only tandem-axel end dump trucks. All trucks were owned and operated by the same construction organization completing the earthmoving operations for the specific monitored project. All trucks that were equipped with telematics control units that reported accurate information were included in the analysis. Onsite equipment was accounted for, however, telematics locating data was not utilized in the analysis of this project. At the borrow site, a 962G Caterpillar wheel loader was used for the loading of soils being hauled to the project site. At the project site, initially, a D6N Caterpillar dozer was utilized for placing the material and later a D5K Caterpillar dozer was utilized as it provided more maneuverability and quicker placement of the delivered soils.

Project Information

The construction project that was analyzed for this report, consisted of importing and placing approximately 1,500 cubic yards of topsoil material in an area impacted by flood damage. The project took place over the course of five days including four days of hauling material and one day impacted by rain wherein material could not be imported to the site. Operators remained the same through the project duration with one operator loading material and one operator placing the imported material. Driving personnel and trucks utilized for the project remained the same with varying numbers of trucks utilized each day. One equipment change was made on the third day of hauling in order to utilize a more maneuverable piece of equipment and help to speed up the placement process of the imported material. The borrow pit was located approximately 10.21 miles from the project location. Of the total haul distance, approximately 9.21 miles was on public roads and 1.00 miles was on private drives. No off-road hauling was necessary for this project.

Results

On each of the four days, truck cycle-time was audited utilizing the web-based GTC application. Each truck's individual cycle-time information was exported and converted to display components of the cycle including, loading time, travel to and from the jobsite, and dumping time. Specific attention was paid to the dumping time in the cycle process. Each truck was identified by a unique number associated with the vehicles. Individual drivers operating the vehicles were not identified or associated with the trucks. Each day, a varying number of trucks were assigned to the project with the first, second, third and fourth days of hauling consisting of four, six, eight and six trucks hauling, respectively. Unique, discernable events took place on multiple days that could be easily identified through the data collection. On the second day, the operator performing the unloading and placing of the topsoil material spent a period of time in a separate piece of equipment performing an unrelated task. This event contributed to the dramatic increase in time spent dumping and unloading material by the trucks on the project. Also, on days where more trucks were allocated to the project, higher durations for unloading material were detected.

Data Analysis

In this study, all truck units performed the same hauling activity each day. There was no variation in material hauled, locations, or routes taken. Due to the consistency of the activities performed, data was analyzed on a per day basis with all available trucking information combined and utilized for the analysis. Table 1 displays the mean and standard deviations of the combined trucking cycle-time components broken down by loading, travel time to the project, return travel time to the borrow pit, and time spent dumping. Quick analysis of the information displayed in Table 1 shows minimal deviation in the time loading the material into the trucks. There is significant variation in travel time, however. Time spent hauling to and from a project location is influenced by dynamic factors that are out of the control of the construction company. Consequently, a significant deviation in the time it takes to travel to and from a jobsite is expected when traveling on public roads. The significant changes and high deviations in the time it takes to dump or unload materials from the hauling trucks represent an area that is likely affected by factors that are under the control of the hauling organization. Weather conditions remained consistent through the four days of hauling, the earthwork contractor was the only contractor working on the project, and the hauling activity remained consistent throughout the entire duration. Given all these factors, it can be assumed that the earthwork contractor should have complete control of any factors affecting the duration required to dump the material at the project location.

Table 1
Cycle-Time Components Evaluation (Minutes)

	Day 1		Day 2		Day 3		Day 4	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Loading	9.90	3.61	8.68	1.69	8.23	1.86	8.19	1.64
Travel	25.15	5.59	21.43	2.70	21.05	2.97	20.67	3.22
Dumping	10.36	4.57	16.92	27.51	10.81	5.72	10.95	4.82
Return	21.33	2.84	20.01	13.28	19.19	6.71	19.77	4.11

Figures 2 through 5 display statistical process control charts for each of the four hauling days. In these charts, the dumping durations are plotted relative to the time they were delivered. Upper and lower control limits are set with the assumption that the delivery times are within control if the durations fall within 1.5 standard deviations of the mean dumping time. In each of these figures, influencing factors are easily identifiable. It is assumed that if a single duration for delivering materials exceeds 1.5 standard deviations from the mean duration, some special cause has created the variation. This can be noticed most specifically in Figure 3 at the event when the operator at the unloading site switched tasks to haul off some concrete rubble. Additionally, in Figure 4, the time when the dozer was being swapped during the working day can be identified at the first cluster of dumping durations above the upper control limit.

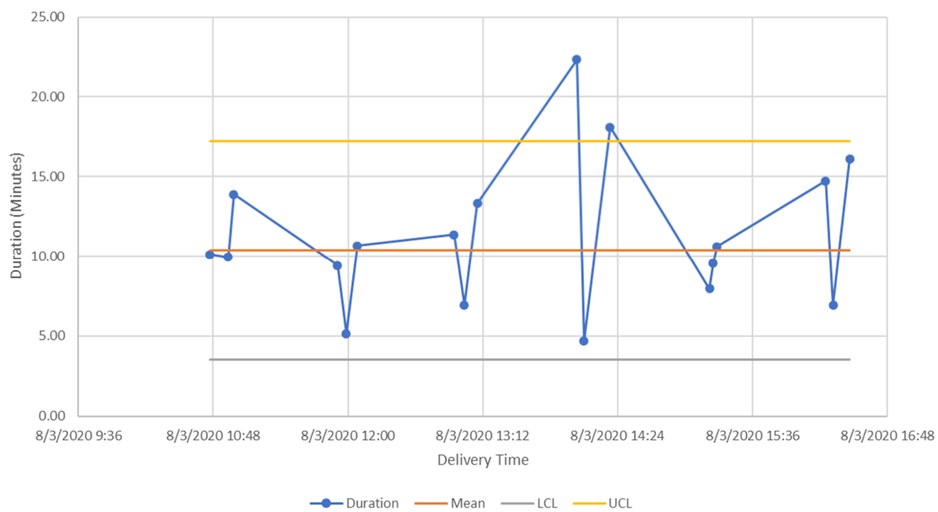

Figure 2. Truck dumping durations and control during the 1st day of data collection

Trends can also be identified utilizing this information. On days 1, 3, and 4, delivery times vary, however, they remain consistent within the mean duration of the project. On day 2, even with the dramatic outlier, there is an upwards trend of durations for dumping material as the day goes on. This could be assumed to be due to the increased number of trucks from the previous day along with the larger, less maneuverable machine being used to place the material.

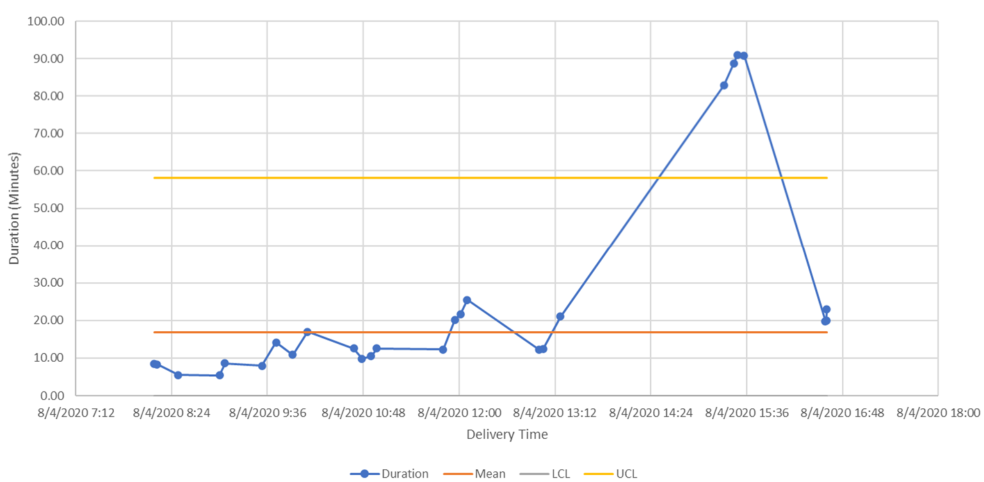

Figure 3. Truck dumping durations and control during the 2nd day of data collection

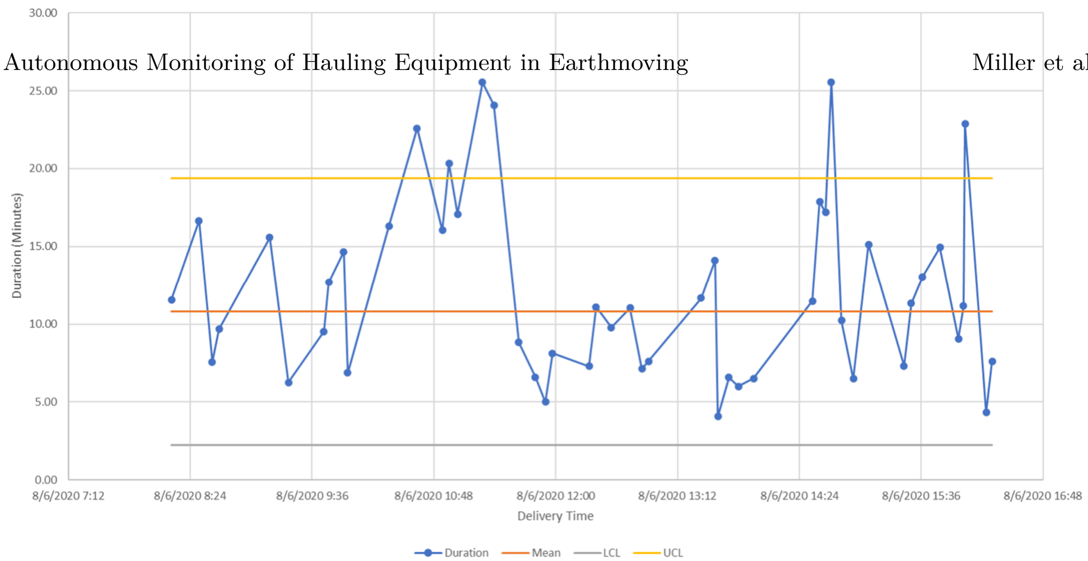

Figure 4. Truck dumping durations and control during the 3rd day of data collection

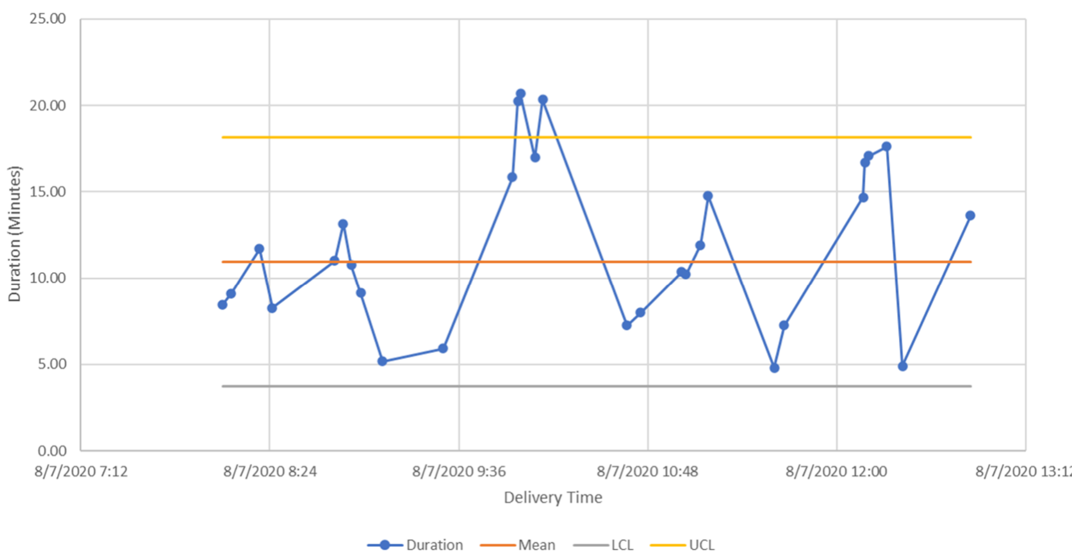

Figure 5. Truck dumping durations and control during the 4th day of data collection

In addition to being able to identify events within a period of time, the gathered information can also be used to identify if machine and trucking allocation has been optimized. Optimization should occur when there is very little deviation in both the loading and dumping durations. Given the very low durations for the loading times throughout the four days, especially days 2 through 4, it can be presumed that the equipment used for loading and the trucks allocated were well optimized. If more trucks are allocated to the project, it can be assumed that the standard deviation would increase. Projects that have too many trucks allocated to them, will likely show an upwards trend in the duration of time to dump the material.

Conclusions and Future Study

The utilization of fleet telematics systems and the GPS functionalities of the hardware and associated web-based applications can provide critical cycle-time information in real time without any need for manual observation of the project activities. The cycle-time data extracted from the technology, can help identify causes of variations in cycle durations as well as determine if equipment and trucking allocation is optimized for a given project. Deviations in specific cycle times is especially insightful as it helps provide an understanding as to whether material is being delivered and/or loaded at a rate that the machines at either end of the cycle can keep pace with. Data can be accessed in real time or used as a historical metric for making management decisions instantaneously or on future projects.

Despite the limitations and the quasi-experimental nature of this study, the results of the telematics data displays some potentially beneficial and unique results that typically require constant manual, impractical, or overly obtuse methods to capture. Utilizing GPS locating data from telematics control units helps to paint a picture of productivity of a hauling operation that management or estimating personnel can use to make critical decisions.

References

Alshibani, Dr Adel. "Productivity Based Method for Forecasting Cost & Time of Earthmoving Operations Using Sampling GPS Data," 2016, 18.

Hare, Warren L., Valentin R. Koch, and Yves Lucet. "Models and Algorithms to Improve Earthwork Operations in Road Design Using Mixed Integer Linear Programming." *European Journal of Operational Research* 215, no. 2 (December 2011): 470–80. https://doi.org/10.1016/j.ejor.2011.06.011.

Kim, Jinwoo, Seokho Chi, and Jongwon Seo. "Interaction Analysis for Vision-Based Activity Identification of Earthmoving Excavators and Dump Trucks." *Automation in Construction* 87 (March 2018): 297–308. https://doi.org/10.1016/j.autcon.2017.12.016.

Lee, Seung Soo, Sang-il Park, and Jongwon Seo. "Utilization Analysis Methodology for Fleet Telematics of Heavy Earthwork Equipment." *Automation in Construction* 92 (August 2018): 59–67. https://doi.org/10.1016/j.autcon.2018.02.035.

Liu, Chang, Ming Lu, and Sam Johnson. "Simulation and Optimization of Temporary Road Network in Mass Earthmoving Projects." In *2013 Winter Simulations Conference (WSC)*, 3181–90. Washington, DC, USA: IEEE, 2013. https://doi.org/10.1109/WSC.2013.6721684.

Montaser, Ali, Ibrahim Bakry, Adel Alshibani, and Osama Moselhi. "Estimating Productivity of Earthmoving Operations Using Spatial Technologies." *Canadian Journal of Civil Engineering* 39, no. 9 (September 2012): 1072–82. https://doi.org/10.1139/l2012-059.

Montaser, Ali, and Osama Moselhi. "Tracking Hauling Trucks for Cut-Fill Earthmoving Operations." Montreal, Canada, 2013. https://doi.org/10.22260/ISARC2013/0089.

Omar, Tarek, and Moncef L. Nehdi. "Data Acquisition Technologies for Construction Progress Tracking." *Automation in Construction* 70 (October 2016): 143–55. https://doi.org/10.1016/j.autcon.2016.06.016.

Sacks, R., R. Navon, A. Shapira, and I. Brodetsky. "Monitoring Construction Equipment for Automated Project Performance Control." Washington, DC, USA, 2002. https://doi.org/10.22260/ISARC2002/0025.