LINE BALANCE AND DRIVE BEARING IN HAULAGE WORK

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Abstract

This paper presents description methods as for both line of balance and drive bearing in a haul work. The line of balance is depicted by coefficient of concordance, which is a ratio of the precedent pitch time to the successive one in a haul work. Pitch time means hours worked per throughput in each work cell. The drive bearing represents appearance and motion in driving. The drive bearing is shown by quantitative indices. These might impact construction efficiency of haul work. In this study, a backhoe and a dump tuck are chosen as examples of construction machinery. The description methods reported in this paper could provide site-manager and supervisors with suitable indices to guide or instruct workers under their control with the objective of increasing construction efficiency and energy-saving.

KEYWORDS: line of balance, pitch time, drive bearing, acceleration.

PURPOSE

We often face capacity- and time-dependent heuristic indices or qualitatively instructions coupled to construction efficiency and energy-saving in a haul work. Regarding the indices and the instructions, it is so time-consuming and embarrassed to collect the data concerned from real haul work field. Therefore it becomes difficult to find differences between the work planned and the work performed. In consequence, it is almost impossible to give operators and drivers quantitative indices and concrete instructions related to construction efficiency and energy-saving.

The purpose of this study is to provide site-manager and supervisors with description methods by which they could make suitable indices and instructions to guide backhoe operators and haul truck drivers with the objective of increasing construction efficiency and energy-saving.

SCHEME

Haul work has work cells for digging, loading, hauling, dumping and land levelling. In this study, a backhoe and a dump tuck are chosen as examples of construction machinery. First, this section presents description methods that could make it easy to quantify line of balance between work cells for loading and hauling. Secondly, are incarnated description methods to make suitable indices that will be capable of representing drive bearing quantitatively.

Line of Balance

Explanatory variables for construction efficiency of loading by backhoe includes average hours worked, average operating hours, average payload, and number of loadings. And then the construction efficiency is explained by dependent variables such as average tonnage hauled, operating ratio and pitch time. Variables of those are derived from the following equations, respectively:

$$OR = AHW \,/\, AOH \,, \tag{1}$$

where "OR" is operating ratio, "AHW" is average hours worked and "AOH" is average hours operated:

$$PT_{bh} = AHW \,/\, ATH \tag{2}$$

where "PT_{bh}" is pitch time by backhoe, and "ATH" is average tonnage hauled that is derived from the equation (3) as shown later.

Explanatory variables for construction efficiency of haul by dump trucks include departure and arrival times, time elapsed for waiting and loading at each work cell, average velocity, average distance hauled, average payload, number of round trips, and round trip time. And then construction efficiency is represented by dependent variables such as average tonnage hauled, ton km per hour, transport efficiency, cycle time and pitch time of dump truck. Dependent variables of these are obtained by the following equations, respectively:

$$ATH = \frac{1}{n}\sum_{i=1}^{n} AP \times NRT_i \ , \tag{3}$$

where “AP” is average payload, “NRT_i” is the ith numeric value of number of round trips for i = 1…n, and “n” is number of dump trucks:

$$TKPH = ATH \times AV \ , \tag{4}$$

where “TKPH” is ton km per hour and “AV” is average velocity, and

$$TE = (ATH \times ADH) / AVR \, , \tag{5}$$

where “TE” is transport efficiency, “ADH” is average distance hauled, and “AVR” is average volume of refuel.

Line of balance is represented by a ratio of the precedent pitch time to the successive one in a project, which has a number of separate but common activities. In fact, however, we often face dynamic imbalance between individual activities over short term such as hours and at most, a few days. Focusing on individual activities, the predecessor constraints the successor, and vice versa. Coefficient of concordance, which is calculated by pitch times, is used for monitoring changes in line of balance. As mentioned before, pitch time means hours worked per throughput in each work cell. And then the coefficient of concordance (CC) of haul work, for example, loading and hauling, is gained as follows:

$$CC = PT_{bh} \, / \, PT_{dt} \ . \tag{6}$$

As the coefficient of concordance is deviated from the numeric value “1”, backhoe operation and dump truck maneuver in a work line of loading and hauling might get less and less efficient due to the fact of waiting for other at the each work cell and the like..

Drive Bearing

Drive bearing represents driver’s behaviour, which might impact construction efficiency and energy-saving regarding haul work. Bad drive bearing for efficiently energy-saving maneuver of haul truck could be shown in terms of changeably speeded driving, sharp speed changes, long lunchtime or long round trip time tendency, driving against the traffic regulation, stray from the designated haul route, and violation of the parking regulation. On the contrary, good drive bearing should have the following characteristics:

- Standard deviation of velocity might be small,

- Maximal numeric value of acceleration might be small,

- Absolute value of minimal deceleration might be small,

- Standard deviation of acceleration and deceleration might be small,

- Acceleration and jerk might have a bell shaped distribution with more or less the same sized tails on each side, respectively,

- Number of changes in acceleration and deceleration might be less, and

- Average of the squared jerks along the travel from a loading spot to the destination might be small.

The characteristics above are explained and found by explanatory variables, which include departure and arrival times, time elapsed for work performed at each work cell, distance travelled, number of round trips, average payload of a dump truck, velocity (travel speed), accelerations, number of changes in acceleration and deceleration, that is to say, mean crossing rate, jerks, trip time (loaded, empty), round trip time, cycle time per day or hour, and driving footprint.

The average payload of a dump truck means average weight of material loaded (in Tons) in a dump truck.

The number of changes in acceleration is represented by mean crossing rate, which is derived from the following equation:

$$mcr = \sum_{i=1}^{n-1} \frac{|\,\mathrm{sgn}(x_i - \bar{x}) - \mathrm{sgn}(x_{i-1} - \bar{x})\,|}{2}, \qquad (7)$$

where "mcr" is mean crossing rate, "x_i" is the ith acceleration or deceleration for i = 1…n, "n" is number of samples, "$\bar{x}$"is the average value, and "sgn" is sgnum function.

The average of the squared jerks is obtained by

$$ASJ = \frac{1}{n}\sum_{i=1}^{n} J_i^{\,2}, \qquad (8)$$

where "ASJ" is average of the squared jerks, "J_i" is the ith jerk for i = 1...n, and "n" is number of samples.

A haulage route from the borrow pit to the destination is divided into several distinct segments considering the road conditions such as width, curvatures, grades, densely close proximity to residential area, etc. Numeric values of the explanatory variables as mentioned above are calculated and summed up regarding the each distinct segment to produce information relevant to haul management. Looking at the information, it could make it possible to make suitable decisions on timely basis and to promptly provide haul truck drivers with relevant instructions.

Data Acquisition

The Global e-Service and the Points on Construction (hereafter refer to as POC) are utilized to gather field data regarding the explanatory variable as mentioned before.

The Global e-Service is a multi-language internet-based back office management system in maintenance and service applications for construction machinery (Nishigaki et al., 2008). The backhoe is equipped with the Global e-Service, which will be able to monitor and control its operational data with a satellite communication system, GPS, and on-board computer.

The POC is a site network tracking system for mobile entities such as construction machines, dump truck, workers, materials, and so on (Nishigaki et al., 2008). It aims to manage a fleet to ensure reliable construction operations at points on and between borrow and land fill areas. The fleet means the complement of construction machines, dump trucks, and workers that are working together.

The POC provides us with event detection system, operator's daily report system, a driver's daily report system, and driving footprint capture system. The event detection system enables us to automatically or easily gather data as for departure and arrival times, time elapsed for work performed at work cell, number of round trips, round trip time, and cycle time per day or hour (Nishigaki, et al., 2010).

Operator's daily report system is a telltale system based on a cellular phone by which operator can submit her/his daily work report to the POC. This report includes information on operator's name, machine ID, work type, work position, work hour, breakdown and standby times, work performed, and so on, in order to find any deviations from the approved operation plan.

Driver's daily report system is also a telltale system based on a cellular phone. It enables driver to submit her/his daily work report of driving log to the POC. This report informs her/his supervisor of driver's name, car number, date, heading, vehicle routing, tonnage hauled, fuel usage, odometer value, and so on, so as to find any deviations from the approved driving plan.

In addition, backhoe operators and haul truck drivers hold cellular phones by which they can send their own daily working reports.

Driving footprint obtained by GPS receiver gives distance hauled, average velocity, maximum acceleration, minimum deceleration, number of changes in acceleration and deceleration, maximum or minimum jerks, trip time (loaded, empty), driving locus. Haul truck rigs GPS receiver that gains its own positions and stores data of its path as it moves.

The data acquisition method as described above would make it easier to gather data as to the explanatory variables related to line of balance and drive bearing.

LESSONS LEARNED

Line of Balance

The data acquisition systems as explained in the previous section have been deployed to a haul work for removal of rocks such as gravel, pebble and boulder being deposited behind a check dam. In this project, approximately 22,000 tones of rocks should be hauled to the destination, which is approximately 9 km away. Six backhoes have been operated at each work cell and twenty dump trucks have maneuvred through the haul road from the loading site to the dumping site in this project. Of these, a backhoe and a haul tuck were chosen as examples that we observe in this study. Figure 1 shows the loading site and the dumping site as the destination.

The operator had to produce her/his daily reports by the operator’s daily report system as previously described.

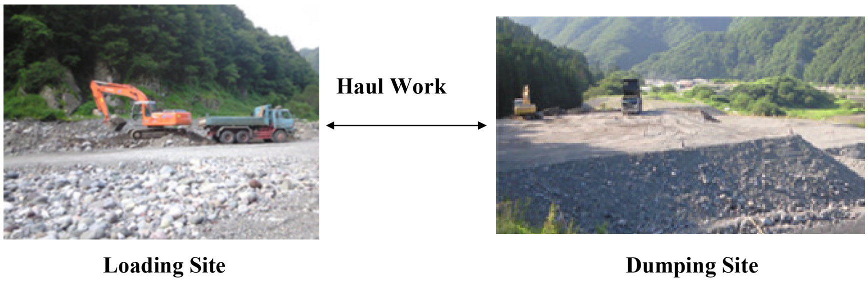

Figure 1: Loading Site and Dumping Site

The Global e-Service daily provided us with administrative information on backhoe operating conditions. Examples of the administrative information include operating conditions, operating hours per day and fuel level, positional information gained by GPS device, scheduled machine maintenance such as periodic maintenance schedule or record, machine operation and maintenance record, and machine servicing log.

Backhoe operation could be characterized by analyzing as-built data that had been obtained by both the POC and the Global e-Service. Figure 2 shows a time series graph of both operating ratio and pitch time as to one of the backhoes being operated in this project.

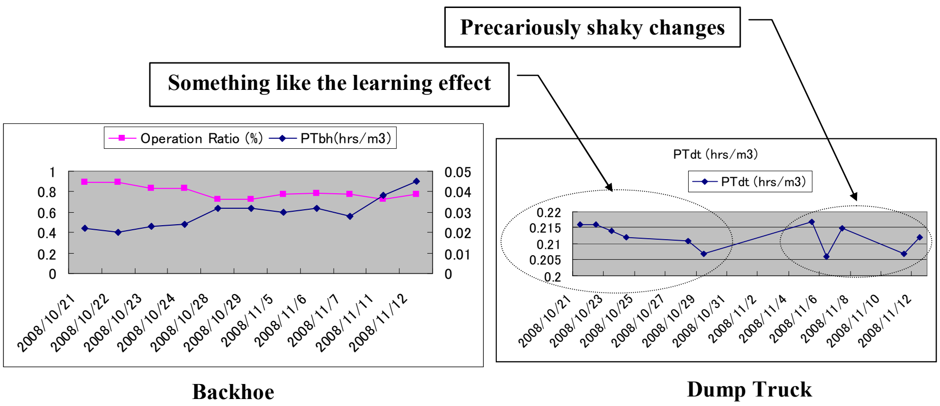

Figure 2: Time Series Graph of both the Operating Ratio and the Pitch Time

It can be seen from Figure 2 that the operating ratio might be inversely proportional to the pitch time. Generally, as a pitch time of an operation might become larger, the operation might get less and less efficient, and then it could be a bottleneck of the work line.

Figure 2 also shows a time series graph of the pitch time as to one of the haul trucks being travelled in this project. It can be seen from Figure 2 that the changes in the pitch time from October 21, 2008 to October 30, 2008 show something like the learning effect as the driver might be familiar with the work environment. On the contrary, we can find precariously shaky changes in the pitch time from November 6, 2008 to November 13, 2008. Since the driver had six days off, it might be conjectured that she/he might be perplexed in something of changes in the work environment.

Unfortunately, we could not depict the line of balance of this work line. Primarily because we have chosen a backhoe and a dump truck as examples that we observed in this case study for viewpoint of cost issues. It could be said, however, that the coefficient of concordance, which is derived from pitch times as to backhoe operation and dump truck maneuvre as shown by the equation (6), would be a numeric metric to show a line of balance of a work line at a point in time

Drive Bearing

Analyzing data regarding the explanatory variables for drive bearing gives the numeric values as follows:

- Departure time into, arrival time, travel time through, minimal or maximal velocity, average velocity, maximal acceleration, minimal deceleration, detection of irregular velocity, mean crossing rate,

- At loading and dumping site, elapsed time on standby and for loading or dumping, and

- Through the haulage route, total tonnage hauled, number of round trips, average trip time, average cycle time.

From January 13, 2010 to January 15, 20120, trial drivings by a car with a GPS receiver have been conducted in order to obtain GPS data. . On the first day, the car ordinarily ran along the designated route as being in compliance with the traffic regulation. On the second day, the car ran strayed from the designated route. Then the driver did not face traffic jam on that day and the driving conditions of this strayed route were very well. In consequence, the driver could easily and stably steer the car. On the last day, the driver roughly steered the car on the designated route.

Figure 3 shows the histograms of acceleration and jerk on the each day. Figure 4 shows transitions of the maximal numeric values of velocity, acceleration and jerk, and the minimal numeric values of deceleration and jerk, and number of changes in acceleration and deceleration. In Figure 4 the maximal numeric values of deceleration and the minimal numeric values of jerk are depicted as the absolute ones.

Looking at Figure 3 and Figure 4, here are described the distinct drive bearings below.

On January 13, 2010

The maximal numeric values of velocity and acceleration, and the minimal numeric value of deceleration might not be extraordinary.

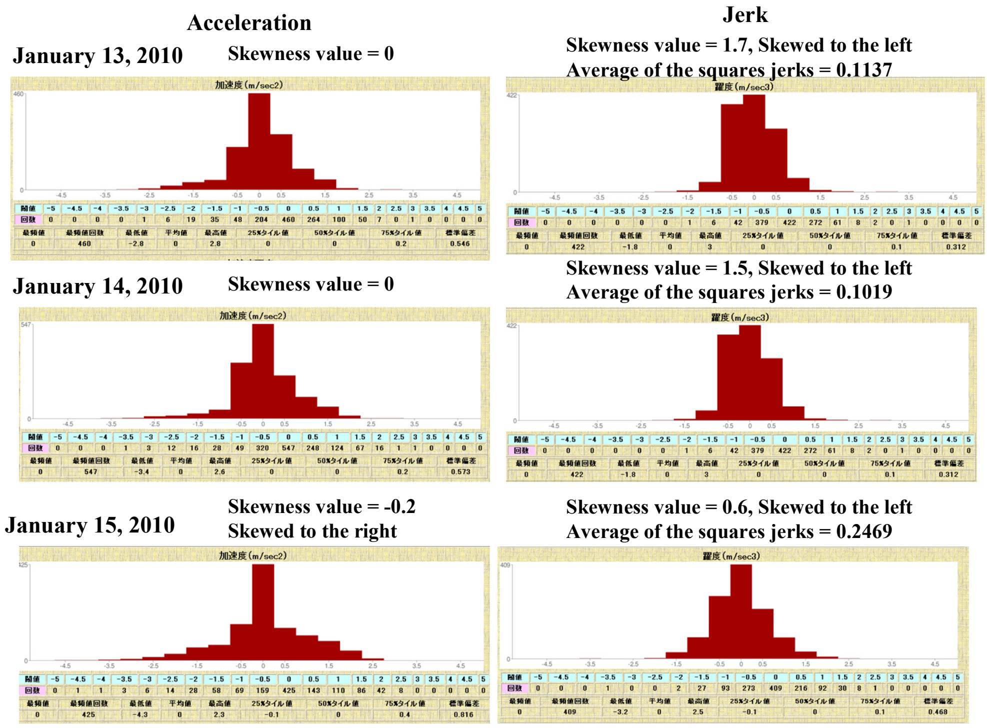

Figure 3: Histograms of Accelerations, Skewness of Acceleration and Jerk on the Each Day

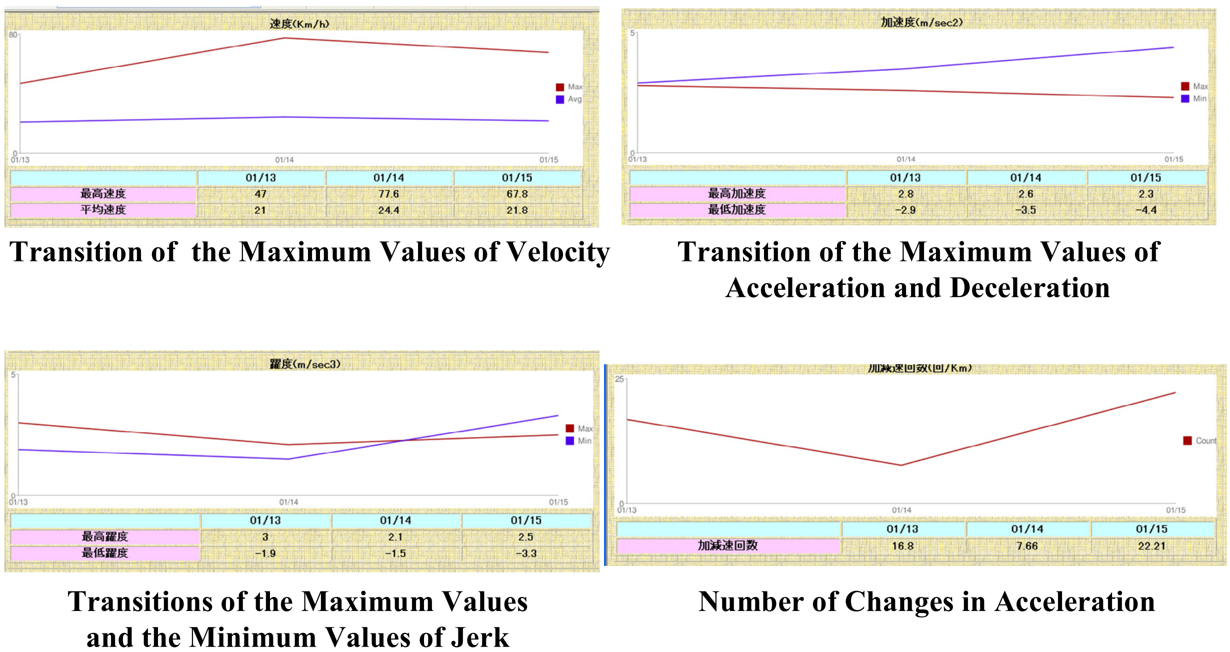

Figure 4: Transition of the Maximum or Minimum Values as to Velocity, Acceleration and Deceleration, and Jerk, and Number of Changes in Acceleration

Especially, the maximal numeric value of acceleration was almost equal to the absolute numeric value of minimum deceleration, but the maximal numeric value of jerk was larger than the absolute numeric value of minimal jerk. The distribution shape of jerk is skewed to the left. In addition, the number of changes in acceleration and deceleration and the average of the squared jerks were comparatively large.

Therefore, it can be conjectured that the driver might be prone to step on the accelerator strong at times, and conversely, to put on the brake short, repeatedly.

On January 14, 2010

The maximal value of velocity was large. The absolute numeric value of minimal deceleration was larger than the maximal numeric value of acceleration. The distribution shape of jerk is skewed to the left.

Moreover, the absolute numeric values of minimal jerks and the number of changes in acceleration and deceleration were smaller than the ones in the other days. The average of the squared jerks is the smallest among the three days.

Consequently, although the driver might to step on the accelerator strong on and off, and conversely, to put on the brake bit by bit, repeatedly, it can be seen that the driver might have stably steered the car under the better driving conditions.

On January 15, 2010

The standard deviation of acceleration was the largest among the three days, and the skewness numeric value was “minus 0.2”, although, on the other days, the skewness numeric value were almost zeros. It is suggested that the driver might be likely to stop urgently and to rush into acceleration frequently.

The absolute numeric value of minimal deceleration was larger than the maximal numeric value of acceleration, and at the same time the absolute numeric value of minimal jerk was larger than the maximal numeric value of jerk. The distribution shape is skewed to the left. The number of changes in acceleration and deceleration was the largest during the three days. The driver might have been likely to put on the brake short at times and to step on the accelerator strong sometimes. Moreover, the average of the squared jerks is the largest among the three days.

Hence it appears that the driving in that day might be the most rude during the three days.

The phenomena as reported in this section properly delineate the conditions of the each trial driving during the three days.

SUMMARY

This paper presents the explanatory and dependent variables as to both line of balance and drive bearing, which could quantitatively explain construction efficiency and temperament of driver’s behaviour very well. The description methods based on the variables of those could provide site-manager and supervisors with suitable indices to guide or instruct workers under their control with the objective of increasing construction efficiency and energy-saving.

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