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TRUCK-SHOVEL FLEET CYCLE OPTIMISATION USING GPS COLLISION AVOIDANCE SYSTEM

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ABSTRACT: Truck-Shovel operations in surface mines involve high costs. Fleet management systems can provide a tool to improve fleet availability, utilisation and productivity, thereby reducing those costs. However, these systems are expensive to install. Stop-Watch time and motion studies provide a cheaper alternative. They can be undertaken on any segment of the haul cycle to provide accurate timing data, as well as observations on operator performance but are very time consuming and do not provide continuous monitoring of a fleet.

This paper provides an analysis of an alternative option; using a GPS collision avoidance system for truck-shovel fleet cycle optimisation. A case study was undertaken based on an operating mine in South-east Queensland using a commercially available GPS collision avoidance system. The approach was to use the GPS collision avoidance system to collect the truck positioning, speed, and timing data, which is automatically recorded as part of its normal function then to apply this information in a conventional time and motion study. This was combined with production loading data to provide some additional performance indicators. The methodology for using in a truck-shovel fleet cycle optimisation is discussed and the results from the case study are presented. Finally, the applicability of this approach is evaluated.

INTRODUCTION

Truck-shovel cycle optimisations are commonly performed to increase productivity, reduce costs and generally improve the profitability of the mobile assets at a mine. This task is most often performed by a fleet management system. These systems incorporate timing and positioning data, payload data, maintenance information, operator details and other pertinent information. They can perform detailed optimisation analysis with very little input from other systems or operators; however they are very expensive. Stop-watch studies provide a much cheaper alternative to a fleet management analysis. Using a stop-watch, accurate timing data and many field observations can be obtained for little to no upfront cost. However these studies can require extra inputs from other systems and are time consuming. Furthermore, such studies are conducted over a limited field and time of observation, not the full production system.

This paper looks at an alternative option to these two types of optimisation analysis; using a GPS Collision Avoidance System (CAS). These systems provide a data recording function that is used as part of their incident play-back feature. Data includes positioning, timing, speed, heading, number of satellites and alarms. A case-study into the effectiveness of such systems was undertaken at an operating coal mine in south-east Queensland. Presented in this paper are the results of that study, including the methodology and an evaluation of their applicability.

TIME AND MOTION STUDIES

The focus of a time and motion study is to provide feedback on a system's performance by highlighting good and bad practices within the system that can then lead to overall improvements. The process is usually undertaken multiple times during the life of that system to continue the improvement of operational practices.

Methodology overview

Niebel (1988) generally accepted as the father of time and motion studies stated that undertaking a time and motion study should generally follow these steps:

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1. Get the facts;
2. Present the facts;
3. Make an analysis;
4. Develop the ideal method;
5. Present the method;
6. Install the method;
7. Develop a job analysis;
8. Establish time standards; and
9. Follow up the method.

Arzi (1997), who continued on from Niebel's work, compiled a set of steps that was more robust and applicable to this investigation, those being:

1. Selection of project and objectives definition;
2. Definition of measures for evaluating the design in view of the objectives;
3. Determination of the project limitation and freedom of action;
4. Data gathering and presentation;
5. Analysis of the data;
6. Development and presentation of alternative methods;
7. Evaluating alternative methods and selection of the best one;
8. Detailed design and presentation of the selected method;
9. Implementation of the designed methods (work place and method); and
10. Following up the method.

Both of these procedures cover five major components:

1. Definition;
2. Data collection;
3. Data analysis;
4. Evaluation; and
5. Implementation.

Another key component highlighted is the requirement to continually re-evaluate the processes; however this is not an actual step in the time and motion study itself.

CASE STUDY METHODOLOGY

Definition

A time and motion study should be well defined to have clear goals and maintain the focus of the investigation. The investigation undertaken, focused on the haul cycle of a selected fleet of coal trucks at one open cut mine. The haul cycle was broken down into separate tasks:

- Spot time at loader and dump;
- Travel time loaded and empty; and
- Dumping and loading times.

The delays in the cycle were also analysed, where possible. As this was a test case-study to analyse the capabilities of the system, the evaluation of the analysed data was left open, undertaking investigations where data limitations permitted.

Data collection

The data was collected on a fleet of five 136 t off-highway rear dump coal haul trucks. The data covered the period of time between 10:00 am on the 10/06/11and 10:00 am on the 11/06/11, a twenty four hour period including three different shifts. During this time the trucks were operating from two different pits ("southern" and "central" pits) loading coal to the coal bins and ROM stockpile. Payload and maintenance information was also collected to assist in the evaluation step of the study.

Data analysis

The data analysis step is where the time study is undertaken. This is done by calculating the average time to perform a specific task, in this case a section of a haul cycle. This can be done by using the mean or mode of the sample and is called a time standard. Once the time standard for a task has been found, it can be used as a rating factor to highlight good and bad performances which are later evaluated.

For this analysis time standards for each task were calculated using Google Earth to interpret the downloaded file's traces. These standards times were then entered into and analysed using Microsoft© Excel™. The mean, median, mode, standard deviation and range were all found and a histogram plot of the distribution was produced to provide better understanding of the samples.

Evaluation

As outlined in the case-study definition, the scope of the evaluation was left completely open. Many evaluation methods and techniques were explored. Some of these options were ultimately rejected as data limitations prevented them from being viable. Some of those rejected were:

- Availability;
- Productivity; and
- Telemetry analysis.

Those that were used included: utilisation, TKPH analysis; and motion study analysis.

The utilisation, in general, is defined as the percentage of uptime hours that the truck was operating (Paraszczak, 2005). In this case uptime hours would refer to the available hours. The availability and therefore the available hours could not be calculated definitively, but as the maintenance reports indicated no scheduled maintenance or downtime, it was assumed that availability was 100%.

Tonne Kilometres Per Hour (TKPH) is a non-standard unit of measure for the load bearing capacity of a truck tyre (TAM, 2008). It can also be used as a form of productivity indicator when calculated for an entire truck rather than a single tyre. It accounts for not only the payload and time travelled, but also the distance travelled, therefore providing a more accurate result when evaluating loaded travel times over slightly different distances.

A motion study evaluates the different motions that are required to complete a task to identify why a certain task has been performed better or worse than the average. This can be as simple as spotting the differences or as complex as defining why a certain order of motions works better than another. In the case of a haul cycle this would focus on truck positioning and manoeuvring by the operator.

Implementation

The implementation step is undertaken after the analysis and evaluation is complete. It involves setting in place ways to ensure the good practices identified are used and bad ones are eliminated. As this is only a test case-study and the implementation is not impacted upon by the means in which the time and motion is undertaken, this step was not undertaken.

RESULTS

Time standards

The time standards were calculated for each section of the haul cycle as outlined and delays in the system were also highlighted. The time statistics were broken down into an average and optimal case. The optimal case is different in that it had significance or explainable outliers removed from the data set.

The travel time empty readings were split in two; one set for the central pit and one set for the southern pit. The statistics for the central pit are shown in Table 1 and a histogram of the sample is shown in Figure 1. The standard time for both the average and optimum case were identical for the central pit as no outliers were removed. The statistics for the southern pit are shown in Table 2 and a histogram of the optimum sample is shown in Figure 2. Six entries were removed from the optimum case in the southern pit due to the truck either travelling through central pit en-route to the southern pit or taking a detour through other areas of the mine.

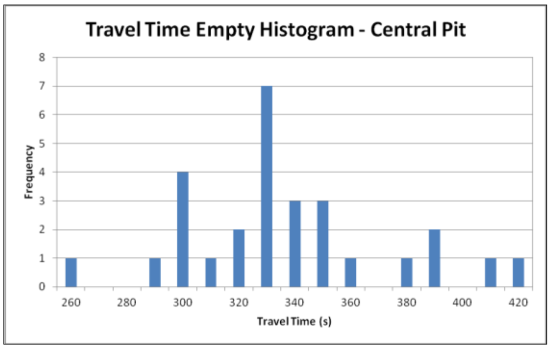

Figure 1 - Histogram of the central pit empty travel times

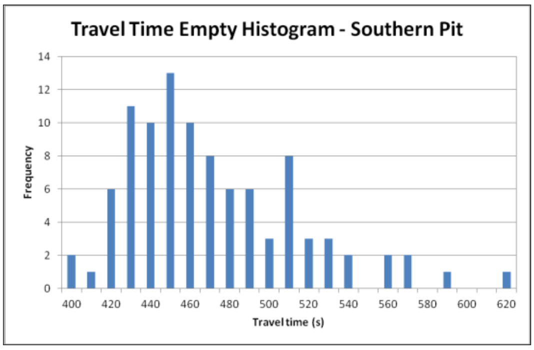

Figure 2 - Histogram of the southern pit empty travel times

Table 1 - Central pit travel time empty standard time statistics

Statistic	Average/Optimum Case (s)
Mean	331.86
Median	330
Mode	330
Standard Deviation	36.15
Range	255 - 420

Table 2 - Southern pit travel time empty standard time statistics

Statistic	Average Case (s)	Optimum Case (s)
Mean	478.70	466.55
Median	461	457
Mode	470	423
Standard Deviation	61.35	42.94
Range	396 - 716	396 - 611

The travel time loaded readings were also split in two. The statistics for the central pit are shown in Table 3 and a histogram of the sample is shown in Figure 3. The standard times for both the average and optimum cases were identical for the central pit as no outliers were removed. The statistics for southern pit are shown in Table 4 and a histogram of the optimum sample is shown in Figure 4. Two entries were removed from the optimum case in the southern pit due to the truck taking a detour through other areas of the mine.

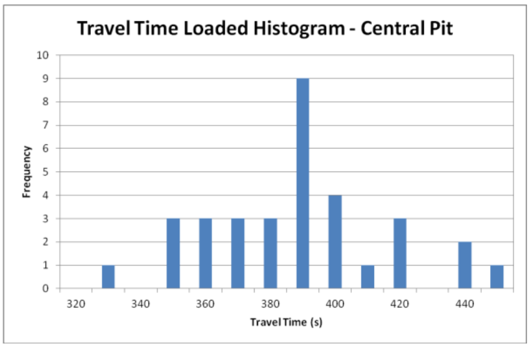

Figure 3 - Histogram of the central pit loaded travel times

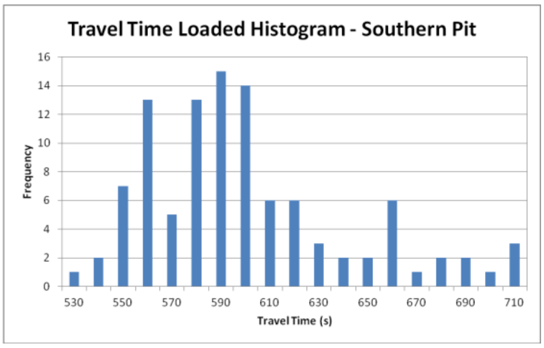

Figure 4 - Histogram of the southern pit loaded travel times

Table 3 - Central pit travel time loaded standard time statistics

Statistic	Average/Optimum Case (s)
Mean	384.57
Median	385
Mode	390
Standard Deviation	28.29
Range	328 - 441

Table 4 - Southern pit travel time loaded standard time statistics

Statistic	Average Case (s)	Optimum Case (s)
Mean	600.08	596.13
Median	589	588
Mode	551	551
Standard Deviation	50.04	41.41
Range	528 - 817	528 - 706

Dumping time refers to both dumping at the ROM stockpile and at the coal bin. The statistics for dumping time are shown in Table 5 and a histogram of the optimum sample is shown in Figure 5. Five entries were removed from the optimum case due to the truck waiting on the coal bin to open before dumping. The waiting and dumping time could not be separated due to the truck being stationary the entire time so the results were removed.

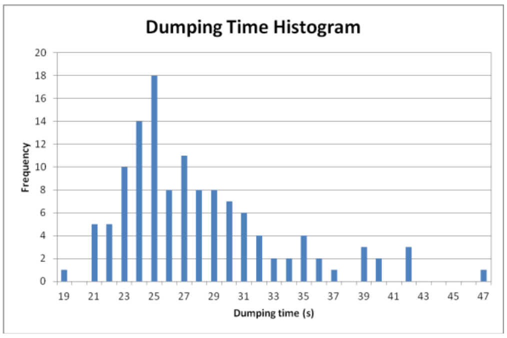

Figure 5 - Histogram of the dumping times

Table 5 - Dumping time standard time statistics

Statistic	Average Case (s)	Optimum Case (s)
Mean	29.78	27.90
Median	27	27
Mode	25	25
Standard Deviation	11.17	5.29
Range	19 - 104	19 - 47

The statistics for loading time are shown in Table 6 and a histogram of the optimum sample is shown in Figure 6. Seven entries were removed from the optimum case: four entries due to the truck being half loaded at one location, then moving and getting completely loaded at another; and three due to an operator change after loading was completed.

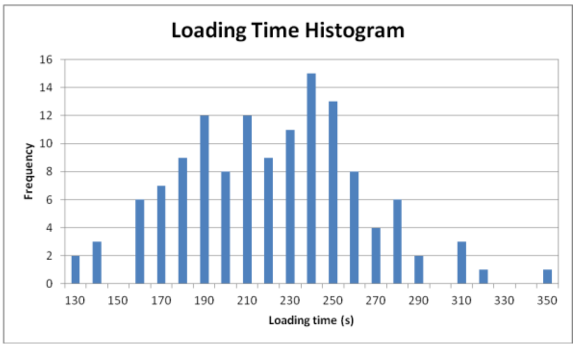

Figure 6 - Histogram of the loading times

Table 6 - Loading time standard time statistics

Statistic	Average Case (s)	Optimum Case (s)
Mean	227.53	216.94
Median	219	219
Mode	243	243
Standard Deviation	108.60	41.7
Range	74 - 1136	127 - 348

The statistics for spot time at loader are shown in Table 7 and a histogram of the optimum sample is shown in Figure 7. Three points were removed from the optimal case. One point was removed due to the truck positioning itself ready to reverse during its queuing time, and the other two points were removed due to pausing several times during reversing waiting for the loader to be in position.

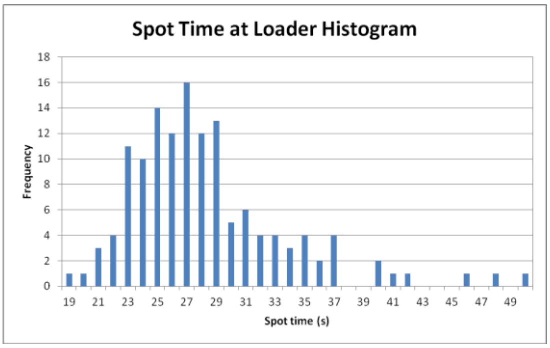

Figure 7 - Histogram of the spot times at loader

Table 7 - Spot time at loader standard time statistics

Statistic	Average Case (s)	Optimum Case (s)
Mean	28.67	28.35
Median	27	27
Mode	27	27
Standard Deviation	6.52	5.38
Range	14 - 58	19-50

The statistics for spot time at dump are shown in Table 8 and a histogram of the sample is shown in Figure 8. This sample set had many outliers removed, 29 in total. Two of these were removed due to multiple attempts to position the truck at the ROM stockpile. The remaining 27 were removed due to the truck waiting for the coal bin to be open/ available for dumping. For this case an attempt was made to separate out the waiting time from the spot time. This proved difficult, however, as when the truck is forced to wait it must come to a stop and then accelerate again. This additional stop adds extra time during spotting through acceleration and deceleration that cannot be calculated by simply removing the stationary time. Consequently these samples were removed.

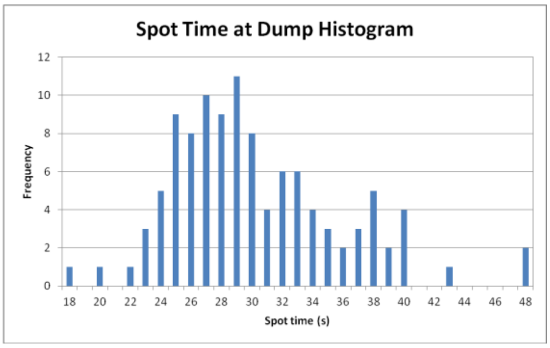

Figure 8 - Histogram of the spot times at dump

Table 8 - Spot time at dump standard time statistics

Statistic	Average Case (s)	Optimum Case (s)
Mean	64.28	30.25
Median	31	29
Mode	29	29
Standard Deviation	86.02	5.52
Range	18-496	18-48

It can be seen in some of the samples that removal of outliers has a significant effect on the mean and standard deviation. In the loading and dumping time samples the standard deviation is halved and in spot time at dump it is reduced by more than 90%. The mean in the spot time at dump sample is also reduced by half. Those outliers that have a significant statistical impact on the time standards would also be contributing to large amounts of lost production time.

The histograms all show a similar distribution pattern; a regular or left skewed bell curve. The left skewed distributions are for those samples that have comparatively lower means (spot and dumping times). This is due to it being difficult to significantly go under the mean, whereas it is quite easy to exceed it. The loading time sample is somewhat different from the others. It is regular in shape but is also slightly bi-modal. This could be due to the loader not using a consistent number of bucket loads to fill each truck.

These results provide the basis for comparison of good and bad results, both within the set and in the future. They also provide a good starting data for planning and scheduling purposes.

Delays

There were two major sources of delays that could be calculated; queue time at loader and parked up time. The statistics for queue times are shown in Table 9 and a histogram of the sample is shown in Figure 9. As these are delays they are all counted in the average case.

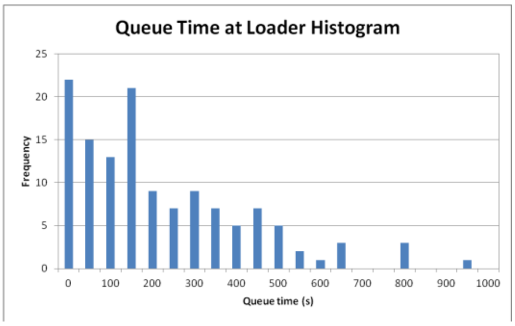

Figure 9 - Histogram of the queue times at loader

Table 9 - Queue time at loader standard time statistics

Statistic	Average Case (s)
Mean	199.12
Median	135
Mode	0
Standard Deviation	198.92
Range	0-936

The spread on this sample is not a bell curve, which is to be expected as most results are zero and cannot go negative. The most significant part of this sample is the mean. At 200 s per cycle this adds a large amount of lost time. In total 7 h and 11 min out of the 120 h of recording time was lost due to queuing, which is just under 6%. This is significant lost production.

A significant amount of parked up time was found throughout the recording period, on all trucks. The causes of these parks are not known but would mostly be caused by shift changes, crib breaks, lack of operator or planned downtime. However, all parked up time was assumed to be caused by operational delays as no maintenance downtime was found. Therefore, it was assumed that availability was 100%. There was a total of 51 h of lost time found due to park ups; this gave a utilisation of 57.5% based on the 120 h of recording. This is quite low and creates a large loss of production. This is however a relatively small sample set for the calculation of utilisation of a fleet and may not be a complete representation of the entire fleet.

Payload analysis

A payload analysis was performed to see what affects, if any, the variation of payload weights would have on loading times and loaded travel times. The payload data was directly compared to the loading times to see if there was a correlation between the two. None was found.

To evaluate the loaded travel times, the average speeds were plotted against payload carried for that trip. The scatter plot is a graphical means of showing the TKPH results whereby the higher results fall higher and to the right on the plot and lower results fall lower and to the left on the plot. It would be expected that if there was a correlation between payload and average speed that in would show up on this plot. The graph of the results can be seen in Figure 10. Also included on the plot is a breakdown of which truck and shift the recording took place and by extension when a different operator was on the machine. The three numeral code refers to a different truck number and the letters A, B and C refer to the first day shift, night shift and second day shift respectively.

The plot shows little to no correlation at all; so the conclusion would be that payload does not affect average speeds and thereby loaded travel times. By including the various operators a different correlation can be identified. The data points for each separate operator are somewhat grouped together indicating that a major factor in the loaded travel time performance may be the operator performance. There are however a number of outliers within sample 312A, 312B and 314B. It was found that these outliers all occurred during or close to shift changes and crib breaks. This could mean a different operator was on the truck for a hot seat change-out giving more weight to the theory that operator performance is a driving factor.

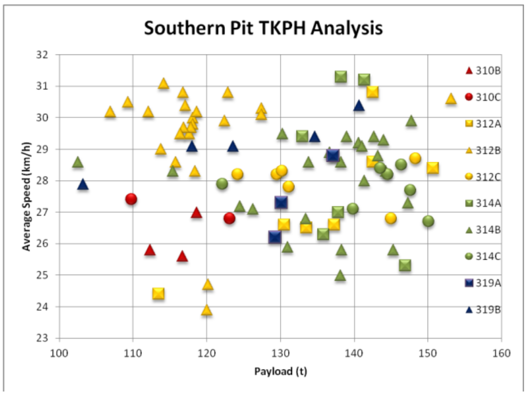

Figure 10 - Southern pit TKPH analysis scatter plot

Motion study

Motion study principles were applied to analyse the method by which operators spotted their trucks at both the loader and dump face. The analysis was first performed on the sample for truck 312 on the night shift as this had the largest sample size. A number of both very good and bad performances were found from the time standard calculations and compared to see if there were any significant differences in the method. Figure 11 shows two such cases at the coal bin and Figure 12 shows three cases from the loading face.

Each blue string represents a different attempt at spotting. The highlighted traces represent some of the best and worst cases from this sample. There were several key differences found between the red and green samples at the coal bin. The first was, the green case travels much closer to the coal bin before reversing than the red case, reducing the distance travelled in reverse. This is faster as the truck travels slower in reverse. The second was that the green case travels along a wider arc when approaching. This may seem like a slower option but on analysis it was found that taking the wider arc is quicker because the truck is able to travel at faster speeds. The third difference can't actually be seen from the snapshots but was evident when replayed at real speed. In the red case the truck remained stationary for a few seconds longer when transitioning from forwards to reverse.

All three of these differences also applied to the cases at the loading face. However there was a fourth difference between the red and green case at the loader face. When the truck reversed in the red case it had to slow and redirect on approach to the loader. This added an additional three seconds, and was the only difference between the red and orange cases at the loader face.

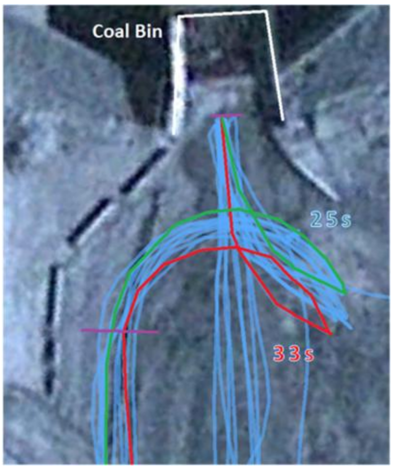

Figure 11 - Spot attempts at the coal bin of truck 312 on night shift

Figure 12 - Spot attempts at the loader of truck 312 on night shift

Case-study performance review

As part of the review of the performance of the GPS CAS, it was compared to other methods of performing time and motion studies.

A stopwatch study is the simplest method of completing a time and motion study. It involves manually collecting timing data with a stopwatch and recording any other observations as they happen, either while on an operating truck or observing from a distance. The CAS had a number of benefits over this method. The biggest advantage is the CAS automatically records data and it records more information than can be obtained from simple field observations. It also removes almost all the time spent in the field. There is one disadvantage in that the collected data needs to be formatted before it can be analysed. However, the added time from this step is less than half the extra time required to collect data from a stopwatch.

From the analysis stage onwards both studies would be the same. Both would require external input for payload information or other telemetry data. The final difference is the price of the two studies. In terms of time cost, the CAS is better, but in terms of upfront costs there is no comparison. A stopwatch could cost around ten dollars whereas a GPS CAS costs hundreds of thousands of dollars. The cost component is somewhat irrelevant as many mines already have CAS's installed for safety reasons, and with the push for ever safer working environments it is likely that systems like these may become mandatory in the near future.

The second comparison is to a Fleet Management System (FMS) study. FMS's include systems like Caterpillar© VIMS and Leica© JigSaw360™. They encompass a large amount of hardware and software specifically designed to monitor and report on many aspects of operation. This gives this type of study an advantage in the amount and type of information that can be collected. They also have the advantage that most data is automatically recorded and reported in a form that can be readily analysed. Compared to the CAS this is a significant time saver. It comes at a cost, however, with these FMS's costing up to tens of millions of dollars depending on fleet sizes.

If costs are an issue and a CAS is already available for use, then in would provide a viable alternative to the time and motion study needs of a mine compared to stopwatch and FMS studies.

CONCLUSIONS

The test case-study produced a number of promising results. Time standards were calculated and distribution plots were produced for each segment of the haul cycle for use in planning purposes. No correlation was found between payloads and loading times, however operator performance was found to be a key driving factor behind the average speed readings for travelling loaded. Finally, four key factors were found to affect the spot times in the case study:

- The radius of curvature of the arc of approach;
- The distance from the dump/loader before reversing;
- The amount of time spent transitioning from forwards to reverse; and
- Maintaining good vision of the dump/loader while reversing to maintain speed in positioning.

On review of the test case-study it was found that the GPS CAS could provide a cheaper but more time consuming alternative to a FMS and would provide a much better all-round alternative than a stopwatch study.

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