An Improved Approach to Production Planning and Equipment Selection in Oil Sands Operations Through Analysis and Simulation of Hauling Activities

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ABSTRACT

This paper presents improvements on established methods for productivity analysis and forecasting, using data from an oil sands mining operation. Initially, in order to reduce the variance in the productivity performance indicators, efforts were made to conduct extensive dispatch data analysis and classification. With variance in the results comparatively reduced, but still high and its source unidentified, a more detailed study of the truck/shovel activities was warranted. A new framework is introduced: code was developed in order to digitize the mine's road networks and subsequently perform a simulation-based estimation of the haul times from specific sources to dump locations. The concept of EFH (Equivalent Flat Haul) is presented and used as a normalizing parameter that accounts for the effects of gradients and changing road conditions on cycle times. The new approach outlined in this paper provides more accurate estimates for long-range production planning and, in turn, equipment requirements forecasting. The main sources of uncertainty are identified and suggestions on possible improvements to the application of this method at other mine sites are given.

1. Introduction

In the current environment of historically low prices in the mining and oil industries, and with ever-increasing regulation, tax regimes and public scrutiny, profit margins for mining companies have dangerously declined - to the point where the economic viability of individual mining operations and, in some cases, entire companies are jeopardized. Making the operations as lean as possible by cutting operating costs and increasing efficiency in every area while achieving production targets has shifted from something that was, perhaps, a means to marginally increase profitability, to something that is now absolutely critical.

Productivity (and in turn, profit margins) are significantly affected by external factors, but some players in the industry also suffer from a lack of development and focus in the area of operational efficiency. It is estimated that there has been an industry-wide decrease in productivity of approximately 30% in the last decade or so (Lala, et al. 2015).

While Lala et al. (2015) have come up with their own metric and KPIs for McKinsey's mining consulting services, most employees with mining engineering training rely on measured production numbers and equipment utilization parameters, which are constantly recorded in their dispatch system, as their key performance indicators (KPIs). Using a combination of parameters in these two areas, planners are able to estimate the future equipment requirements and/or adjust their plans according to their specific situation. This study uses "TPGOH", as the key performance indicator for productivity, which translates to tonnes per gross operating hour. More specifically, it translates to tonnes of productive material fed to the processing plant per gross operating hours in the truck/shovel equipment combination. A much more thorough analysis of this metric is provided after this introductory chapter.

In order to estimate productivity as well as short and long term equipment needs, and to make changes to the mining plan, the mine planning team at the mine developed a simple algorithm which established a relationship between TPGOH and their production plans. The linking parameter between the production plans and the productivity KPI was the distance of the haul from the source location to the dump location, for every individual record. Estimates were generated by fitting a line to this relationship, which resulted in extremely highly variable results. Historical data for 2 years was used to predict TPGOH ranges for the following year and for LOM (life-of-mine) ranges. This study started by investigating this method and conducting in-depth data analysis to improve the estimates. After reaching a plateau in improvements with this method, it became apparent that the source of uncertainty was coming from the characteristics of the operation itself.

Hauling and transport activities in mining are, in a way, the heart of the operation. The main component in the truck/shovel cycle time is the time spent hauling material from a source to its appropriate destination. Cycle time, in turn is one of the main components in the TPGOH metric, with the other being the tonnage. Since the tonnage is almost always fixed at the maximum payload capacity of the haul truck, the only way to affect the productivity is to make changes to the operation that affect the “GOH” component of the metric. These potential improvements are based in short term ongoing operating costs, replacement equipment selection (medium term) as well long term production planning.

The bulk of the existing research tends to focus on one specific area to optimize, whether in finding efficiencies in long term planning, optimizing short-term schedules, developing new technologies or for larger companies, integrating their operations vertically and use their scale to find added synergies. Conversely, the approach presented in this paper is different, since it yields efficiency opportunities both in the short and long ranges, while focusing on a fairly narrow part of the operation: the hauling of material. For an oil sands mine, hauling is even more critical since the overall geometry of the deposits makes them very extensive in area, resulting in comparatively longer haul routes.

This paper is structured chronologically and coincides with the order in which the work was performed for this study. First, the highly unreliable method employed by the mine staff is reviewed in detail, outlining its shortcomings. Then, the objectives set forth before starting this study are presented, followed by explaining its scope and limitations. Subsequently, a thorough explanation of the initial data analysis performed is presented, followed by the novel approach, which implements the use of Equivalent Flat Haul (EFH), simulation and is the main showcase of this study. Results are then displayed and, lastly some conclusions, insights and plans for future work are defined.

2. Problem Definition

2.1. Old Method

As mentioned in the introduction, the old method employed data from the dispatch system in bulk without much filtering or classification. Figure 1 below shows a sample of the data set that was typically used to predict production at different distances between the sources and destinations for variable horizons (short term to LOM).

While the dispatch data contains several years’ worth of production data, only one year is shown. After having retrieved this data, an exponential line of best fit would have been generated. In Figure 1, it can clearly be seen that there is an unreasonable amount of variability, and using a single line of best fit on several hundreds of thousands of data points is an oversimplification of a rather complex system. In addition, estimates were not consistent when varying the years used for the prediction. This motivated the initial stage of data analysis and classification.

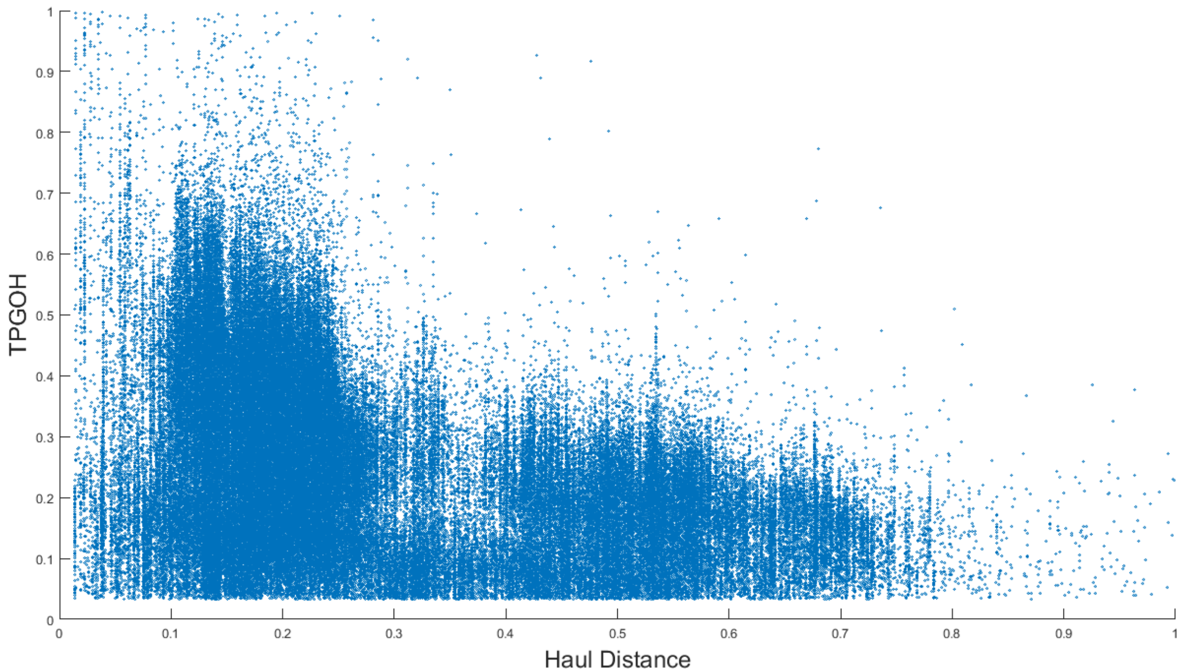

Figure 1. Sample Scatter Plot for Old Method

2.2. Objective

The main objective of this study is to provide planners with a tool, either an improvement of the old method or a new method, that accurately and reliably generates production estimates, so that equipment requirements can be predicted and mining plans can be adjusted accordingly.

In addition, this framework must be able to be used with a modest to reasonable amount of data, be easy to understand, conform to the mine operators' linking method between TPGOH and mine plans via an equipment usage metric (loaded haul distance) and be quick to perform. In addition to providing estimates, it must be able to perform sensitivity analyses and to be flexible, should the characteristics of the operation change. Lastly, the tool should be designed in a way that provides good estimates with basic amounts of data.

2.3. Scope and Limitations

The scope of this study changed since its inception, as it was originally intended to be a data analysis and classification effort, but after identifying the source of unreliability in the estimates, it shifted towards the development of new framework and tools that not only improved on the old method, but replaced it. The framework herein presented, along with the code generated, is applicable not only at this specific mine, but is a useful tool at most other open pit mine sites without much change, especially those that are sensitive to changes in hauling parameters.

There were some pieces of data and information that due to unforeseen reasons were not provided in time for the publication of this paper. This required having to work around some issues that made the overall process of developing this framework longer, but served as valuable lessons from which insights could be shared.

3. Methodology

3.1. Initial Data Analysis and Filtering

The first step in the data analysis effort was to establish realistic caps for the TPGOH metric. These were calculated by looking at cumulative plots which showed where the bulk of the data was, and comparing them to theoretical maximum and minimum values. These were then corroborated with the staff at the mine. Once these caps were in place, most erroneous data, such as zeroes and outliers were removed from further calculations. Subsequently, further data classification took place by filtering the records based on the months indicated in their timestamps, as it was theorized that changes in weather conditions and temperature fluctuations had significant effects on the operations. In addition, the records were classified based on the material type (i.e. ore or waste). These decisions resulted in tangible improvements to the estimates, but took away from the desired simplicity from the staff – effectively shifting from a single line of best fit to several curves. In addition to the previously mentioned filtering by season and material type, the introduction of options in the selection of historical data by year (or years) transformed this into a combinatorial problem. For this specific mine, it was determined that using only the latest (previous) single year of historical production data yielded the best results.

In terms of the key metric, there are 10 individually-recorded fields that go into the calculation of TPGOH, each with their own contribution to the variability of the overall calculation. A breakdown of these fields is given below:

$$TPGOH = \frac{Tonnage}{CycleTime + CycleDelays} \qquad (1)$$

Cycle Time is the sum of the following time items:

- Empty Haul
- Queueing
- Spotting
- Waiting to Spot
- Loading
- Full Haul
- Idling at Dump
- Dumping

After conducting analyses for each of these fields, it was found that a disproportionate amount of the total variability in TPGOH came from the haul times – largely from the full haul time component. This was anticipated, since the other time items relate to activities that are fairly short, constant and mechanized in comparison to the travel of haul trucks in the mine's road network. The tonnage field was also quite constant, nor surprisingly, since trucks are almost always loaded to their maximum payload capacity and it matches a predetermined number of shovel passes.

It is important to note that these analyses were performed by grouping records by their loaded haul distance as a controlling parameter. The fact that abundant variability was present in haul times at fixed distance ranges indicated that the hauling activities and road networks needed a more detailed revision.

3.2. EFH

It was hypothesized that the large variability in haul times was due to factors relating in their entirety to the road network and the hauling equipment. More precisely, the problem could be primarily attributed to one or more of the following: truck operator behavior, safety protocols, characteristics and conditions of the road or heterogeneity in the fleet. Burt and Caccetta (2007) provide very detailed insights into the effects of equipment heterogeneity and the match factor on production and cycle times. At this time, it was assumed that the discrepancies were largely due to the gradients on the roads slowing down or speeding up the truck fleet.

Following through with the study and this hypothesis, the next step was to analyze the road network itself. The staff at the mine did not have a digitized version of their road network, but they did provide a very detailed 3-D file of the topography of the entire mine site, acquired by laser techniques. In addition, they provided several files containing instantaneous velocity and location data from their equipment, acquired via GPS trackers every 30 seconds. It was noted that the elevation coordinate in these records was wrong due to measurement error and lack of calibration. In order to work around that, these data points were then overlain on the detailed topography surface, and the network was digitized by hand, joining the relevant points with lines. Once the network had been finished and had the correct planar coordinates, the lines were then "pressed" onto the topographic surface in order to capture the correct elevation and gradient characteristics of the actual roads at the site. This digital representation of the mine's road network was generated in GEMS, in .dxf format.

In order to try to reduce variability in the calculations, and adhering to the fact that TPGOH was organized by hauling distance, it was necessary to somehow modify the controlling parameter. Equivalent or Effective Flat Haul (EFH) is a parameter that normalizes the distance of a haul by accounting for the changes in elevation in a certain path. EFH, in addition to accounting for the effect of elevation changes on haul times, it provides opportunities to track fuel and energy efficiency in the equipment (Downer EDi et al., 2016). Some companies, such as Newmont, incorporate EFH directly into their key productivity metric by using Tonnes Equivalent Flat Haul per Hour, replacing their previous metric that used kilometres (or simple distance) instead (Newmont, 2014).

This analysis uses a fixed source-destination approach instead of fixed distance intervals, since dispatch systems and availability of equipment make the routes of a single truck and single shift highly variable, and is considered one of the most uncertain aspects of a mining operation (Chaowasakoo et al., 2017).

The way EFH was calculated in this study was by determining a relationship and a factor that would reflect the characteristics of a specific path from a source to a destination. This factor was calculated by performing a simulated estimate of the "actual" travel time of a loaded truck (in this study, CAT 797) using the manufacturer's rim pull data and the roads' gradient characteristics, and then dividing it by the time it would take the loaded truck to travel the same distance without any gradients (a flat haul).

The distance from source to destination would then be multiplied by this adjusting factor, giving EFH. Runge Pty. Ltd. outlines this as one of three possible methods of calculating EFH. The other two require capturing velocity data from different scenarios, and calculating average speeds over certain segments, respectively. Campbell and Hagan (2012) present a case study using the former of the two alternative methods, and they conclude that EFH is a useful metric to account for differences in hauling elevation profiles and also serves as a sensitivity analyzer for road design impact on production.

3.3. MATLAB Code

Code was developed in MATLAB in order to conduct these calculations. The program initially reads the information from the road network (in a .dxf input file), and converts all the nodes into usable information. Segments are created based on the node information, therefore generating from-to lines with specific Euclidean distances and coordinates. The gradients are then calculated for each segment. Junctions and intersections are carefully manipulated as they are vital to the logic of the program.

Since the mine's digital road network was generated by pressing polylines into a topographic surface, several thousands of points (nodes), often within centimetres of each other, were created automatically to capture the features of the roads. In order to simplify the calculations, these are merged into segments of user-defined length, and the details of the gradients are captured by calculating a weighted average from the raw data.

This code features an algorithm that finds the shortest path (distance and time) between user-selected sources and destinations (modeled as nodes), returning the total travel distance and extracts detailed route information from the raw data to another matrix. In this matrix, the rim pull value is calculated by multiplying the effective grade (which is the gradient plus the user-defined rolling resistance) by the weight of the loaded truck at maximum capacity. This is done for every segment of road.

Then, the program queries to the manufacturer's rim pull curve in order to obtain the maximum attainable velocity, which varies based on vehicle weight and effective grade. Since the rim pull data is fed to the code on a discrete, table format, the algorithm linearly interpolates between rim pull values to get a more accurate estimate for velocity. The time for every segment is calculated by using its distance and the velocity. The total travel time is a simple addition of the times of every segment in the route. In order to calculate the EFH adjustment factor, the total travel distance is divided by the velocity attainable by a truck on a flat road, only affected by the rolling resistance. This is an accurate representation of the behavior of the trucks at the mines and is a simulation that is similar to that presented by Bonates (1996).

Some other aspects of this particular operation have been included and reflected in the calculations, such as slowing down at intersections and adjusting the time to account for acceleration and deceleration areas. His factor oscillates at over and under one, depending on the characteristics of the haul; over one if the haul is mostly uphill and under one in the contrary scenario. Lastly, the code then generates a box plots showing the variability of the data, using EFH instead of simple haul distance. Figure 2 displays a flow chart explaining the overall framework of the code.

4. Results

A preliminary calculation, performed prior to developing the code, took an average speed on flat hauls from the velocity records and applied an EFH conversion for every record in the database, irrespective of source/destination individuality. This saw a re-arrangement in the data, generating a decreasing trend in TPGOH with increasing EFH distance, which was not present when using the simple haul distance in the old method, as presented in Figures 3 and 4.

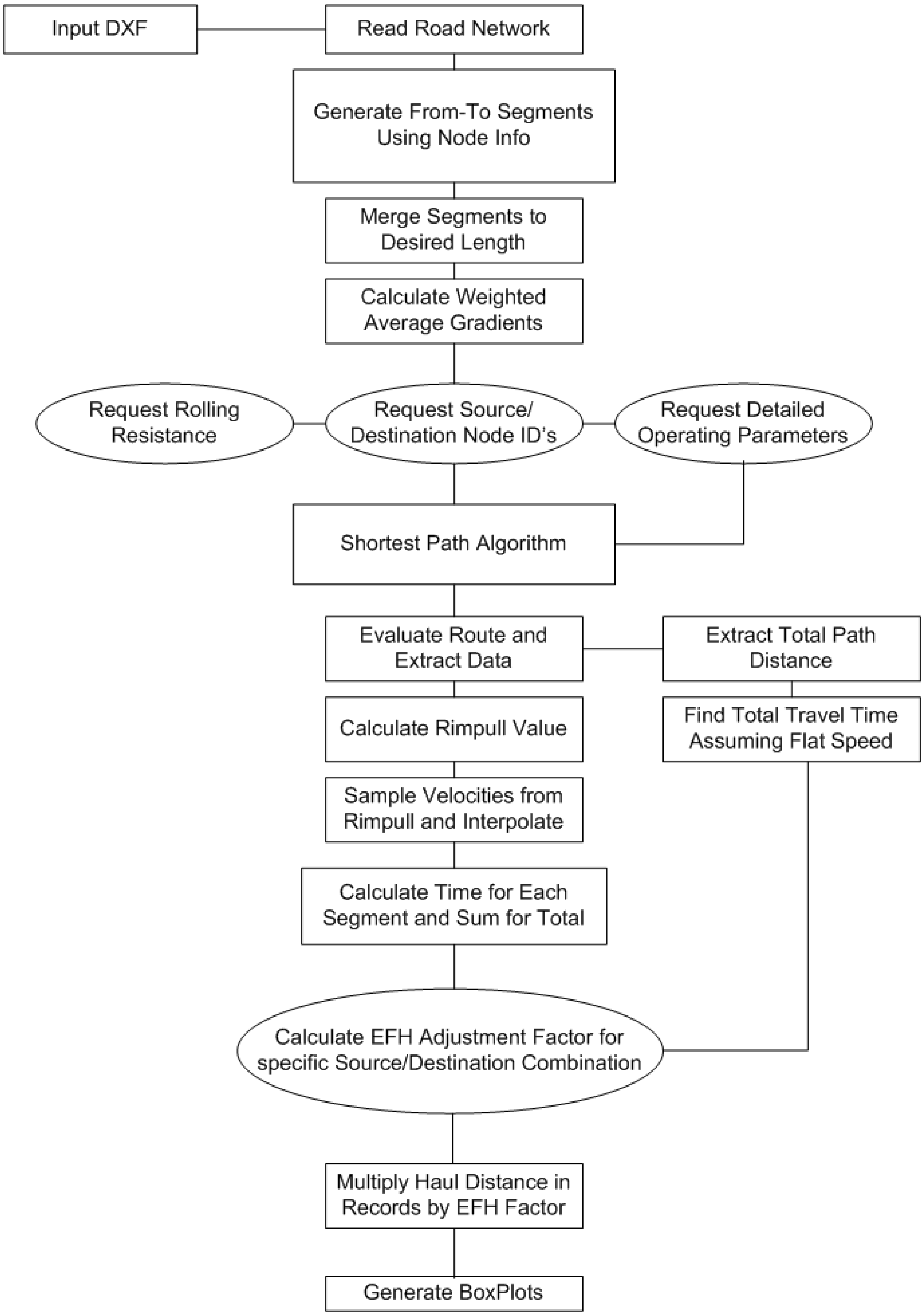

Figure 2: Code Flowchart

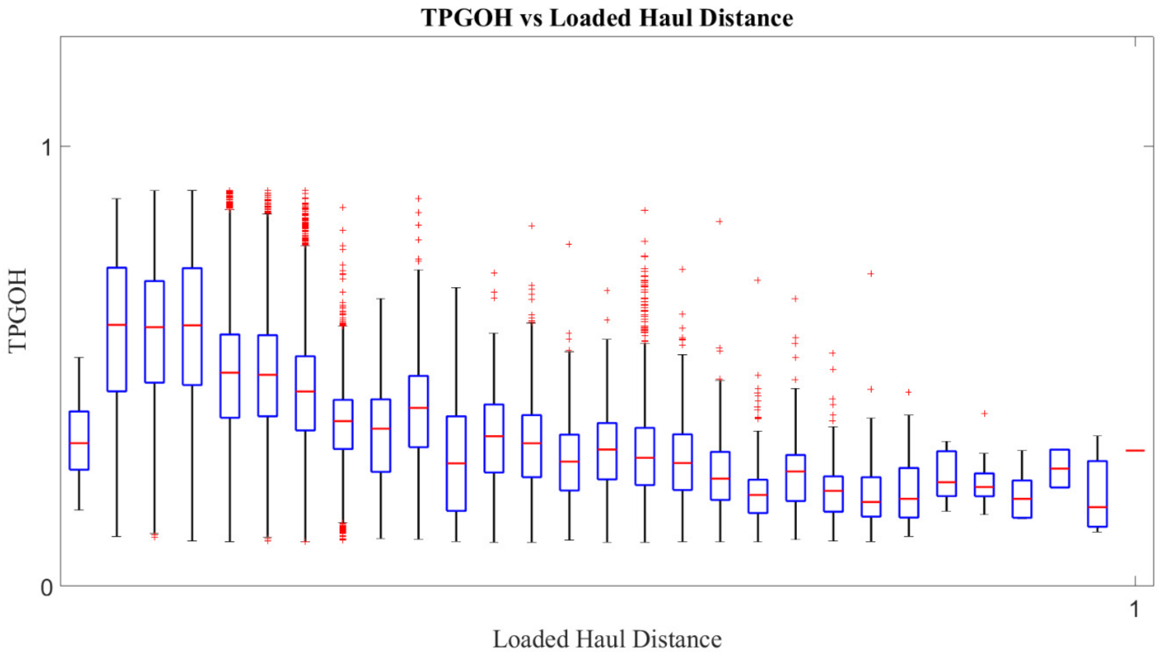

Figure 3: Box Plot Showing Variability of Loaded Haul Distance

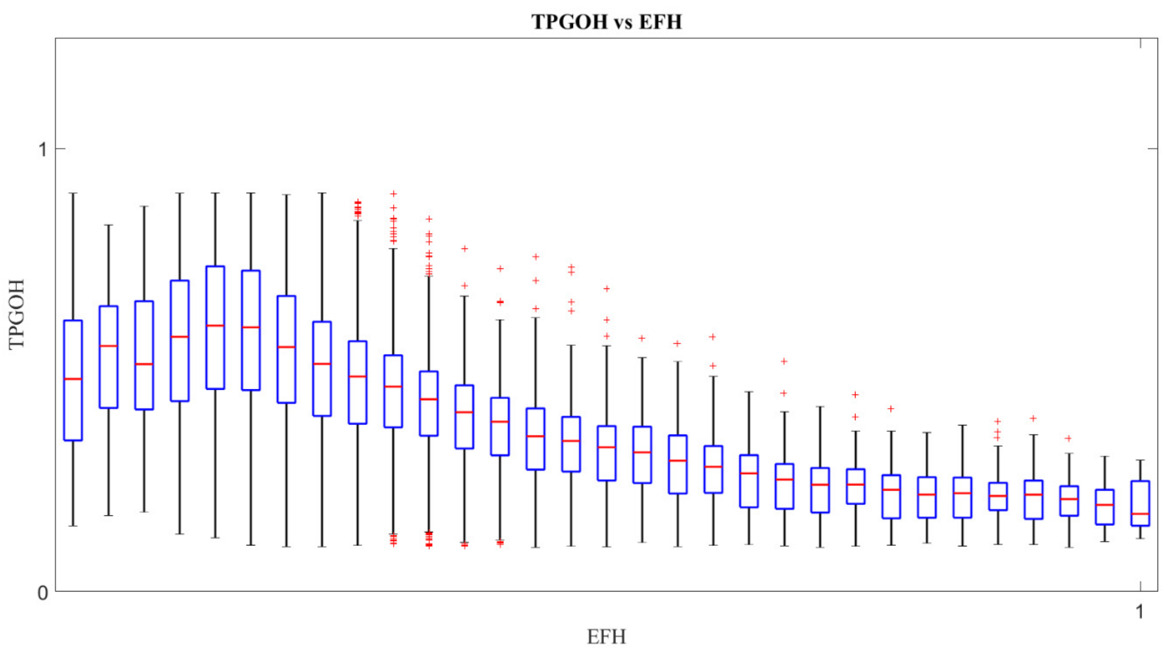

Figure 4: Box Plot Showing Variability of EFH

This gave a preliminary sense that the EFH method rearranges the data in a manner that is logical due to the consideration of gradients and road characteristics on truck performance. The EFH adjustment factor calculated in the code, for a specific source/destination combination, is applied to every historical record in the database (within the same source/destination) and box plots are generated to show a reduction in the variance and display of a downward trend, as shown in figures 5 and 6. An example from a mining polygon source to the processing facility is shown below.

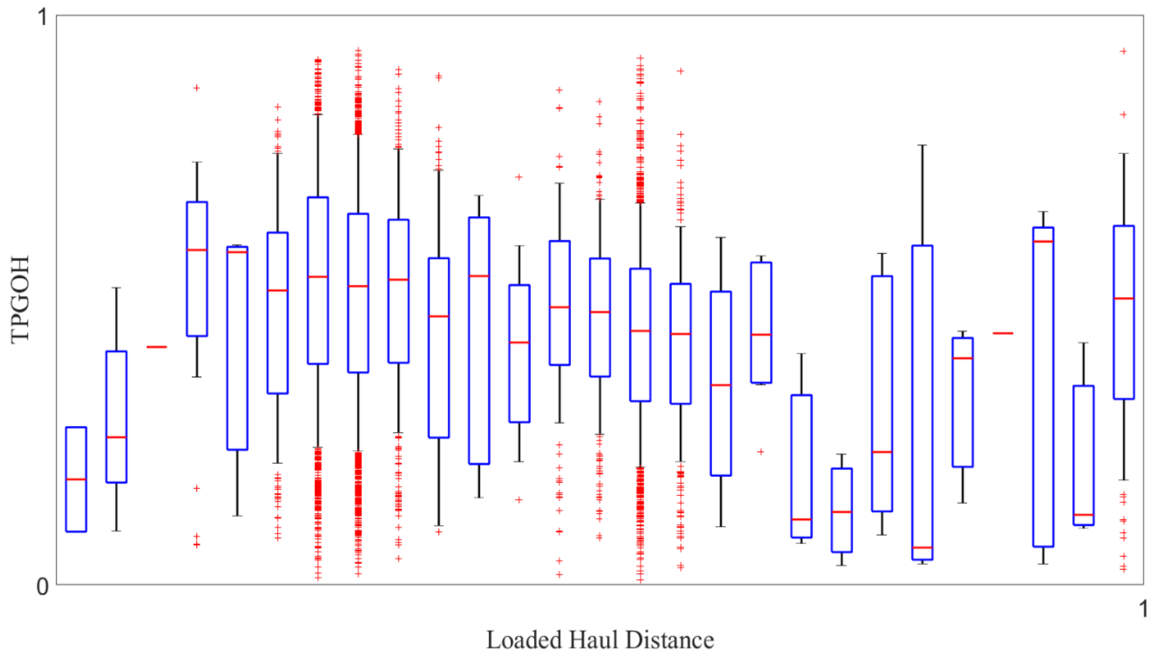

Figure 5: TPGOH vs Loaded Haul Distance for Fixed Source and Destination

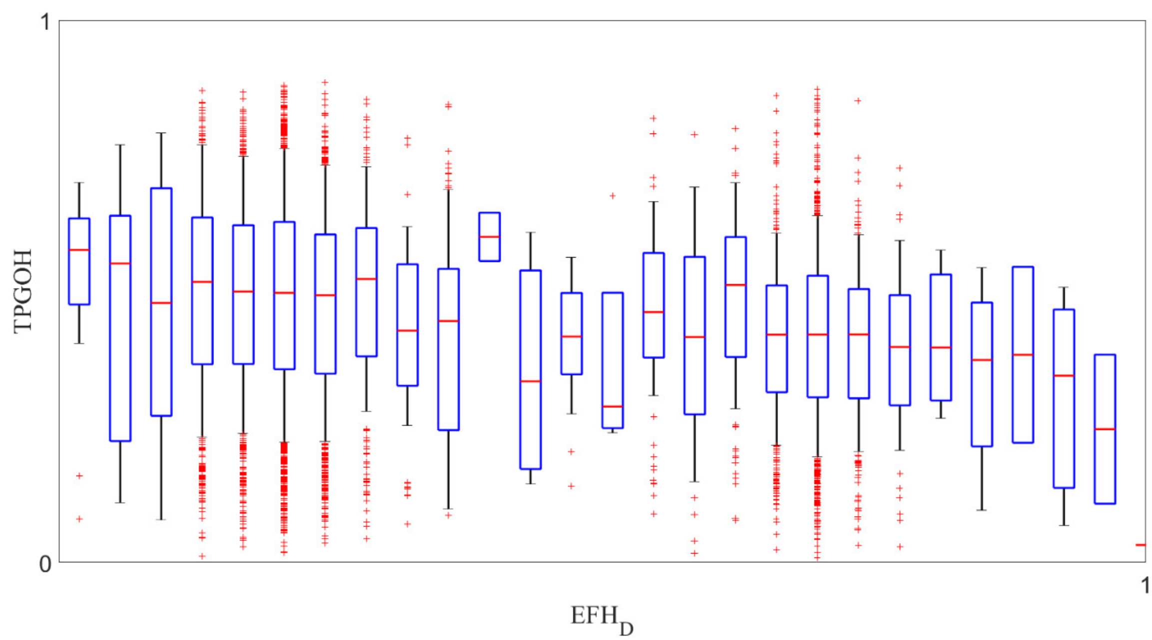

Figure 6: TPGOH vs EFH for Fixed Source and Destination

Even modest improvements to cycle times (in the order of seconds) can add up to very significant changes in equipment utilization per year, especially at large scale operations (Krzyzanowzka, 2007). Variability has been reduced by as much as 20% in some estimates, but is still high, which points to the it not being entirely dependent on the performance of the equipment, but also affected greatly by equipment interactions such as traffic generated by the haul trucks. After consulting with the mine staff, it was revealed that some of the safety rules and regulations imposed on the haul truck operators dictate that speed be reduced drastically in the presence of workers in smaller vehicles and/or on foot.

The effects of these interactions are magnified when considering that mining and development and maintenance of roads happen concurrently, hampering efficiency. In addition, there is variance in distance due to the fact that the size of the mining polygons/faces is quite large, and this prompts the possible introduction of different shortest routes – which cannot be represented in this study without acquiring explicit data provided by the mine staff.

5. Conclusions and Future Work

Throughout the course of this study, the main sources for variability were identified. By developing a tool that accounts for the effects of gradients and road resistance on productivity estimates, the remaining culprit for unreliable calculations is exposed: equipment interaction such as traffic. Further investigation into this area of optimization could be a potential direction for this study. There are, however, many ways to improve on the framework presented in this study. For example, refining the "fine tuning" details of this specific operation and implementing them in the code could yield more accurate results, but requires more data and information.

The next step in this study is replacing the simulation component of the EFH factor by using site-specific velocity records to sample data instead of resorting to rim pull values, which provides the maximum velocity under ideal conditions. This may return more accurate and realistic results. At the time of publishing, the code already has a feature that identifies flat sections of the road, loads velocity records from an external file, fits a distribution and then performs simulation over several realizations to obtain a flat haul velocity value, as opposed to using the manufacturer's recommended maximum speed. Additionally, performing simulation for every component of the TPGOH metric could lead to more accurate estimates.

6. References

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