REDUCING HAUL TRUCK FUEL CONSUMPTION IN OPEN PIT MINES

BY STRATEGIC CHANGES TO THE HAULAGE CYCLE

by

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Abstract

The goals of minimizing emissions and lowering operating costs by monitoring and controlling fuel efficiency have been a growing concern in the mining and construction industries. The largest single contributor of energy consumption in an open pit mining operation is haul trucks. At Goldstrike Mine, haul trucks accounted for approximately 67% of fuel used in 2010. By examining haul trucks in their operating environment, strategic changes in critical parts of the truck cycles can result in fuel savings. This project was a subproject of the Mine Traffic Optimization (MTO) project and is funded by MITACS and Barrick Gold Corporation. One objective of the MTO project was to examine how mine traffic affects fuel efficiency.

Certain components of the haulage profile result in inefficient use of fuel, which results in increased operating costs and a larger environmental footprint. Monitoring the trucks in real time allows for the examination of various ways to modify truck’s behaviours in order to improve fuel efficiency. One critical component of the haulage cycle is intersections. An analysis was performed to gain a better understanding of efficient intersection layouts and travel speeds. Cycle time analysis was conducted to ensure that alterations to the haulage cycle would result in minimal impact to the overall productivity of the mine. Modifications to operating practices and simple coding changes to the dispatching program suggest possibilities for potential fuel savings, reduced mechanical degradation, and improved operation efficiency.
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<th>Description</th>
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<tbody>
<tr>
<td>USD</td>
<td>United States Dollar</td>
</tr>
<tr>
<td>MTO</td>
<td>Mine Traffic Optimization Project</td>
</tr>
<tr>
<td>ADVISOR</td>
<td>Advanced Vehicle Simulator</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>SAR</td>
<td>Synthetic Aperture Radar</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial Measurement Unit</td>
</tr>
<tr>
<td>INS</td>
<td>Inertial Navigation System</td>
</tr>
<tr>
<td>SPAN</td>
<td>Synchronized Position Attitude Navigation</td>
</tr>
<tr>
<td>ECM</td>
<td>Electronic Control Module</td>
</tr>
<tr>
<td>DD</td>
<td>Detroit Diesel</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>BMEP</td>
<td>Brake Mean Effective Pressure</td>
</tr>
<tr>
<td>BSFC</td>
<td>Brake Specific Fuel Consumption</td>
</tr>
<tr>
<td>RPM</td>
<td>Rotations per Minute</td>
</tr>
<tr>
<td>Km/h</td>
<td>Kilometers per Hour</td>
</tr>
<tr>
<td>MPH</td>
<td>Miles per Hour</td>
</tr>
<tr>
<td>CDGPS</td>
<td>Common Differential Global Positioning System</td>
</tr>
<tr>
<td>RPM</td>
<td>Rotations Per Minute</td>
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Chapter 1

Introduction

The mining industry is slowly adapting new ideas and changing its practices in order to optimize current equipment usage, increase production and decrease operating costs. The worldwide concern about gas emissions and fuel consumption is forcing many industries, including the mining industry, to monitor and control fuel efficiency in order to lower operating costs [1].

Open pit mining fuel costs are largely affected by trucks haulage activities. Research has found that medium and heavy-duty vehicles in the U.S. account for 26 percent of transportation fuel consumption [2]. At Goldstrike Mine, haul trucks are the largest single contributor to energy consumption which accounts for about 67% of fuel used in 2010 [3]. That same year Goldstrike Mine used over 17 million gallons to fuel equipment. The operating costs for each truck are approximately $335 USD per hour and about 45% of those costs are to supply fuel to the trucks [3]. By examining these numbers it can be concluded that fuel consumption in open pit mining operations account for a large portion of the mine’s operating costs. As fuel prices continue to increase and environmental regulators impose higher fines, operating costs related to fuel consumption become a major concern.

When examining fuel consumption, improvements to engine efficiency could lead to potential improvements in the future, but immediate results can be seen by modifications to driving habits. This project focuses on making immediate, but long term, improvements to existing practices in order to increase fuel efficiency. This can be achieved at relative low cost while maintaining operational efficiency and staying in compliance with Goldstrike Mine safety practices.
1.1 Goldstrike Operation

Goldstrike Mine is located on the Carlin Trend about 60 km northwest of Elko, Nevada, USA [4]. The closest major city is Elko, Nevada, located 60 km southeast from the site. Goldstrike Mine is owned and operated by Barrick Gold Inc and has been in production since 1993. It is Barrick Gold’s largest producing mine and is one of the top five gold producing mines in the world. It has proven and probable reserves of 349,000 kg (12.3 million ounces) of gold at the end of 2012 and is expected to sustain its level of production in upcoming years. The mine consists of one large open pit operation, Betze-Post, and two smaller underground operations, Meikle and Rodeo [4]. All of the operations feed into the same plant for processing of material. For the purpose of this study, focus will be given to the open pit operation and as a result any reference to the Goldstrike Mine in this paper will only refer to the open pit mining operation.

Figure 1: Goldstrike Mine Open Pit Operation
Goldstrike utilizes a conventional truck and shovel operation. The shovels are used to primarily dig and load trucks with either waste or ore material from active mine areas. In order to transport material for processing or waste disposal, large off highway haul trucks are utilized. The fleet consists of five varying sized shovels and 36 trucks. Utilization and availability for the trucks is found to be 76.6% and 87.3% respectively for the testing period [5]. Furthermore, a large array of support vehicles such as dozers, graders, drills and light duty vehicles are used on site to aid in the material extraction [6].

Shifts are twelve hours, day and night, and the operation is only paused for the amount of time required to change equipment operators. On average 272,155 tonnes of material are moved each day [5]. A balance of waste and ore hauling must be achieved in order to maximize production, which is a critical component of any mining operation. By establishing the appropriate ratio between the two hauls, efficient ore extraction can be achieved while waste can be utilized for projects and reclamation. Optimization of cycle time can ensure activities such as queuing, dumping and loading times are minimized and time available for hauling is maximized. Overall by decreasing cycle time and decreasing unnecessary operating expenditures productivity can be increased.
Figure 2: Conventional Open Pit Mining

Truck allocation is done through the mining dispatching system which is used to dispatch trucks to shovels or dump locations. By examining how haul trucks behave on haulage cycles, critical segments of the haulage cycle are examined in detail in order to identify inefficiencies in the current mining model.

1.2 Motivation

With global warming and depleting fuel reserves, the cost of fuel has been increasing steadily over the last decade. According to the recent trends in the price of diesel, the cost has increased consistently over the last 10 years [7]. With the increased world demands, diesel prices are approaching US$4 per gallon,
causing fuel (both diesel and gasoline) to become a significant part of any mining operations operating costs. To illustrate this rising price, Figure 3 illustrates the changes in yearly average diesel prices.

![Average Canada Diesel Prices](image)

**Figure 3: Price of fuel over last three years [8]**

The Environmental Protection Agency (EPA) has in place requirements to decrease emissions from non-road diesel engines. Emission requirements restrict nonmethane hydrocarbons, carbon monoxide, oxides of nitrogen and particulate matter depending on weight and usage [9]. It has been shown that non-road diesel, locomotives and marine engines account for 40% of the total mobile-source inventory of emissions in 1996 and is expected to rise to 70% by 2020 [10]. Furthermore, between 1995 and 2008, the world consumed an additional 300 billion barrels of oil a year. It must be noted that in this period the world has consumed one fourth of all the fuel consumed in human history [11]. With the implementation of new regulations and emissions restrictions, industries such as mining will need to make adjustments to equipment to comply with these new changes. In Canada, action plans have been put out by industry
leaders in order to ensure decreased emissions. One plan is to decrease energy consumption by utilizing technological advancements and continuous improvements [12]. Other companies are putting together individual energy smart programs to decrease as much as three million liters of diesel fuel in a few years [13]. Overall, by decreasing fuel consumption, mines can meet the new emissions restrictions and decrease operating costs without impacting production rates.

1.3 Summary of Contributions

The primary focus of this thesis is to examine how mine traffic affects fuel efficiency. An analysis is performed within normal operating conditions by monitoring the haul trucks fuel consumption and recognition of deficient and critical segments (intersections and dumping) of the mine haulage system. This makes it possible for strategic changes to be made to critical parts of the truck cycle that will lower the amount of fuel consumed.

Segments of the haulage cycle are examined in two different parts: a smaller component and a larger component. The smaller component accounts for the segment of the haulage cycle that takes little time to complete, dumping. The larger component accounts for the segment where the truck spends the largest portion of the haulage cycle, hauling and intersections. Examinations of these components were undertaken and based on work done in the field. Changes are proposed to normal operating conditions in order to increase fuel efficiency. These changes suggest improvements to truck speed, engine usage and path planning. This also establishes benchmarks for cycle times that could further be used to develop more stable forecasting and mine operation planning.
1.4 Thesis Overview

This thesis consists of six chapters. The first chapter is used to introduce the project, the objectives and the goals of this analysis. It will also give an overview of the mine and some of the motivating factors for this study.

The second chapter reviews existing literature on the issue of fuel consumption monitoring and optimization and is split into three sub sections. The first section examines how optimization of fuel economy has been addressed in the past. This section will also focus on explaining how fuel consumption is most commonly monitored. The second section examines mine design and layout in order to elaborate on other impacting factors. The final section examines current path planning practices. Although the literature will focus primarily on the mining industry, literature considering the automotive industry will be examined as well due to the larger amount of information available.

Chapter three focuses on explaining the basic setup of the experiment and provides an in depth look at the equipment used to perform the analysis. An explanation of each component and their purpose is addressed. An introduction to haulage cycles is given in order to give a general understanding of the key components. Finally, since the majority of the work will focus on intersections, the design and road layout is examined.

Chapter four presents the data acquired, and the subsequent analysis of the haulage cycle based on several critical parameters. It begins with an analysis of the smaller component in the haulage cycle and the
impact that change has on improving the overall fuel efficiency. It then examines the relationship between engine speed, acceleration and fuel efficiency.

Chapter five analyzes and expands on the ideas presented in chapter four. A focus will be given to intersection analysis, which is used to understand the layout at Goldstrike and the general approach for this study. An initial analysis of the various intersection behaviours is done to understand the most effective way to approach intersections. It emphasizes intersection management and examines how implementing a management system can lead to more efficient operating conditions. It also presents the primary coding parameters and explains the modelling approach. It develops the ideas by addressing fuel efficiency and implementing real world fuel data. Finally, a cost analysis is done to evaluate the benefit of the system and technology.

Chapter six is a summation of comments regarding the research conducted during this thesis. It evaluates the benefits of this technology and expands on the ideas of industry application. In addition, ideas for future work are presented and discussed in order to consider the methods that could make the current model more effective. Finally it provides some enticement to expand the localized work to the entire open pit mining industry.
Chapter 2

Literature Review

This chapter examines three individual components: fuel consumption, path planning and collision avoidance. First by examining fuel consumption, information is used to understand which parameters have the greatest impact on the amount of fuel used. Path planning practices are researched in order to understand the fundamentals of good mine network management. Lastly, collision avoidance technologies are considered in order to evaluate which practices can be adapted in order to create a safer working environment for equipment.

2.1 Fuel Consumption

Fuel economy is a topic frequently discussed in the transportation and automotive industries. With strict regulations on emissions, automotive manufactures are developing various new technologies in order to meet given standards. The mining industry however has its own regulatory restrictions to meet in this regard. With rising fuel prices operating costs are increasing, and engineering modifications are being made to equipment in order to maintain regulatory restrictions.

Many factors affect fuel economy such as aerodynamics, vehicle mass, rolling resistance, speed and route management. Work done by the Kenworth truck company has shown that each of these factors can affect the fuel consumption of a truck fleet [14]. It is stressed that fuel consumption display is essential in order to make the operator aware of the amount of energy being consumed. It is noted that anywhere between 5
to 15% energy savings can be achieved when the operator is made aware of their energy consumption [15]. In the mining industry fuel economy has long been a factor that has been disregarded. However off road and heavy-duty vehicles have different regulations to follow. It must be noted that heavy-duty vehicles are different from light-duty vehicles in many regards such as size, mass, engine performance and fuel consumption. Despite these differences, the new information provided by the automotive industry should yield similar changes but scaled differently.

Work done in examining driving behaviour was conducted at the University of California [16]. This study showed that there are three primary factors which influence fuel economy; duration, frequency and intensity of the task performed. The study examines driving behaviour on the same road, using the same vehicle but changing the driver. It was shown that although operators drove in a similar fashion the method in which they operated the vehicle resulted in changes in emissions. It was also shown that of the three parameters intensity of the task performed had the greatest impact. Greater intensity can be reflected through increased acceleration or fluctuations in engine speed and have a direct impact on fuel consumption [17]. Further work done by Larry Landman has shown that harder acceleration is directly related to increased emissions and fuel consumption on various light duty vehicles.

The work done at the University of California and by Landman has shown that not only does fuel consumption increase with more intense driving behaviour but so do emissions such as HC, CO and NOx. This relationship between acceleration can be further examined when incorporating stopping [18]. It is shown that emissions and fuel economy are directly affected by the rate of acceleration. Particularly it is found that hard acceleration from a stop has the greatest impact on both fuel consumption and emissions, while deceleration has a much smaller impact. Overall, this helped to show that under controlled
accelerations, factors such as fuel efficiency can be increased but also maintain compliance to emissions regulations in order to decrease environmental impacts.

In order to control fuel consumption many models have been built. Work done at the University of Virginia attempted to model heavy-duty vehicle emissions based on given cycle profiles [19]. By placing vehicles on dynamometers (used to measure torque, force, power or speed by an engine [20]), various cycle profiles simulating real life conditions could be inputted in order to examine impact on fuel consumption. To measure fuel consumption the following equation is used:

$$\text{Fuel Economy [mpg]} = \frac{\text{Average Speed [mph]}}{\text{Fuel Consumption \left[ \frac{\text{gal}}{\text{s}} \right] \times 3600[\text{s/h}]}$$

Although the models do show a relationship between fuel consumption and different driving cycles the testing is performed primarily in a lab environment where simulating real life conditions are difficult. Simulators such as ADVISOR [21] attempt to simulate real life driving conditions using various factors, but due to the large array of input data, the application becomes hard to implement across the industry.

It has been shown that cycle evaluations are the most effective way to model fuel efficiency [19] [22]. By utilizing inputs such as average speed, acceleration and standard deviations, emissions models can be built to correlate these parameters in order to examine impacts on fuel economy. To replicate real world conditions inputs are required from real world operating and the best way to replicate this relationship is with instantaneous data. By utilizing instantaneous speed and acceleration, an attempt is made to predict
fuel consumption and have a good relationship between position tracking and operating parameters [23]. Overall speed, acceleration and GPS data can be used to estimate fuel consumption.

2.2 Path Planning

Path planning is a critical component to the optimization of fuel management for haul trucks. Factors such as the chosen path and the mine traffic can lead to inefficient production rates and increased operating costs. The simplicity of the road network in some small mining operations commonly allows for one path to and from a given shovel. In larger mines, such as Goldstrike, the complexity develops when there are multiple paths to and from a destination. Utilizing technologies such as dispatch to maximize production and efficiency [24] is recommended. Dispatch systems focus on directing trucks to areas in the mine where trucks are required in order to maintain desired production rates. This usually leaves the decision of path planning to the equipment operator, where years of experience and a strong understanding of the mine are the primary factors in determining the best route. These operators usually assume that the quickest route is the best and most efficient route to take in order to get to the final destination [25]. Although the shortest path may be the most effective path, the operators do not have any way of knowing the road conditions ahead of them which is a common cause of mine traffic delays or congestion. A study done at the University of Kwazulu Natal has shown that the shortest route is not necessarily the most fuel-efficient route [26]. It stresses that modifications to path can result in more effective path planning solutions. Overall this can lead to increased production and decreased operating costs. Since fuel efficiency is the single largest contributor to haul truck operating costs, path planning is an important factor to consider optimizing.
In another study, trucks are observed independently in the mine network in order to examine their position in reference to other trucks in the pit [27]. By understanding one truck’s position in relation to other trucks, a better choice can be made in regards to which path and assignment the truck should be given. In certain cases, dispatchers are required to monitor and correct the assignments when necessary [28]. This may mean that trucks are being reassigned to other parts of the mine due to unexpected shovel breakdowns, large amounts of traffic in certain areas, closures or other unforeseen circumstances. However, due to the size of some mining operations, dispatchers aren’t able to respond to all situations. This leads to increased queuing times and inefficient truck allocations overall affecting production and operating costs. By implementing studies such as the one conducted by Arial Arelovich [29], a real time algorithm can be implemented to the allocation process in order to make quicker and more efficient decisions. A real time approach can give the directions to the operator in the cab immediately, resulting in more efficient transmission of information and allowing more fuel efficient approaches to be taken.

One of the most inefficient portions of during the haulage cycle occurs at intersections, where increased traffic leads to trucks stopping or accelerating in order to avoid other vehicles. To minimize this inefficiency, autonomous intersection management work has been done at the University of Texas [30]. In this work, effective autonomous management techniques are tested in order to examine how large amounts of traffic can co-exist in the same intersection without any conflicts. In order to prevent interactions in the intersection a good understanding of the input and output of a specific system must be understood and are usually illustrated by a queuing system.
A queuing system is used to model the input rate of items into a system. Within the system these items are given a service and a depart [31].

This modelling approach can be implemented into intersection management and can be clarified using the Little’s Law. Little’s Law explains that under steady state conditions the average number of items in a system is equal to the average arrival rate of items into the system multiplied by the average time spent in the system [32] [31]. For this given case the throughput of vehicles into an intersection is being studied. Therefore if it is assumed that the system is the intersection and the trucks are the items, Little’s Law can be used as following:

\[ L = \lambda W \]

Where \( L \) = average number of trucks in the intersection, \( \lambda \) = average arrival rate of trucks into the intersection, \( W \) = average time spent in the intersection

By examining work done in the autonomous automotive industry [30] and by implementing Little’s Law it can be found that there are two ways in which increase throughput can be achieved:

1. Increasing the average number of vehicles in the intersection at any given moment
2. Decreasing the average amount of time a vehicles spend in an intersection

Since the mining industry has very strict regulations on safety, having multiple vehicles in a given intersection is prohibited. Therefore the only way to apply Little’s Law effectively, for the scope of this work, is to decrease the average amount of time vehicles spend in an intersection. In order to achieve this
goal work in Chapter 5 will examine how different driving methods have an impact on the time spent in an intersection and determine the most effective approach. Overall maintaining a steady state condition allows good traffic flow throughout intersections.

2.3 Collision Avoidance

Managing trucks to ensure collision avoidance has been examined in both the automotive and mining industry. Stewart Worrall and Eduardo Nebot and their team at the University of Sydney have examined and released several papers in this regard. The focus is on examining position and velocity in order to track vehicles in a mining environment efficiently. Two methods exist for accurate road network construction [33]. The first involves synthetic aperture radar (SAR) or aerial images to create the map. This method is rather limited due to satellite availability, image clarity and weather conditions. The second method involves GPS and gathering vector data. By examining these points, they can be joined together to create a road network.

By creating directional vectors between intersections, distances can be computed, but this approach does not take into consideration the road conditions. In order to address this, GPS is used to both identify vehicle position and generate histograms for sections of the mine [34]. These histograms can be used as a guideline for building the road networks. It is also suggested that GPS refresh rates be given every second in order to ensure accurate results.

In order to construct the road networks, the mine is broken in vertices and edges to determine velocities between specific sections [35]. By implementing a prediction algorithm, an effective approach is created
in order to predict the vehicles velocity as a function of distance. To identify the path taken a state space (S) is created which shows the truck's path taken from beginning to end. By tracking the progress of the truck, examining the average time and velocity of each segment, S can be used to identify the total distance.

Furthermore cluster sets are created for the vehicles path in order to track the vehicles progress in the mine environment using GPS data [36]. This data is then outputted to a display screen in the cab of the truck and shows the truck's location in the mine. The importance of this data is not only to allow trucks to become aware of their position in low visibility conditions but also to display potential for collisions ahead. Overall, this model allows understanding of the mine network in order to identify potential risks.
Chapter 3

Testing Parameters and Equipment

The literature reviews have shown that fuel consumption awareness, path planning and collision avoidance can create a more efficient operating environment. In order to determine potential savings by implementing these improvements within a full scale mining operation, experiments were conducted during the summer of 2011 with the intention of monitoring two key parameters; fuel consumption and engine speed on mining haul trucks. In the following chapter, the general observational methods, data collected and a description of the equipment used are examined.

3.1 Overview

In order to examine how mine traffic affects fuel efficiency, testing is performed at the Goldstrike Mine under real world conditions. 930E Komatsu haul trucks are equipped with monitoring equipment and examined over a six-week testing period.

In order to implement changes and optimize current practices, observed trucks were equipped with monitoring equipment that allowed the recording of the following parameters:

I. Engine speed (rotations per minute (RPM)): Refers to the number of revolutions the engine performed over a minute of operation. This parameter varies depending on the load and driving behaviour.
II. Fuel efficiency (gallon per hour): Refers to the amount of gallons of fuel that are estimated to be burned during an hour of operating under the given condition. This parameter varies depending on load and driving behaviour.

III. Time (s): Refers to the measurement of time required to perform given tasks. This parameter is used to isolate sections of the haulage cycle. Time is also used to synchronize the different equipment.

IV. Global Positioning System (GPS): Refers to the x, y and z coordinates of the truck at any given point in the mine. These points are used to track the truck progress in the mine in order to identify parts of interest, such as intersections and dump locations.

V. Operator experience: Refers to the number of years of experience that the operator has been operating similar pieces of equipment.

In order to examine the fuel inefficiencies in the haulage cycle, dumping and intersections are examined. For the purpose of this study, only controlled variables are examined. Variables such as weather, road conditions, haul truck noise, engine and transmission efficiency are generalized and assumed constant. The focus is to examine components that are controlled with relative ease in order to make modifications to the haul truck’s operation.
3.2 Basic Setup

Testing was performed during the summer of 2011, with most monitoring and data collection being done in the months of June and July. Primary contacts at the mine were the Special Projects Group and Engineering.

In order to monitor haul trucks under real world conditions, haul trucks had to be equipped with monitoring equipment. Equipment installation was done when trucks were scheduled for preventive maintenance at the maintenance truck shop. Trucks with Detroit Diesel engines were chosen for the analysis since the data logger used was only compatible with that engine.

Once trucks were equipped with monitoring equipment they were asked to perform under normal operating conditions. In order to monitor equipment and operating conditions, data acquisition involved physical observations from the inside the cab. Testing was usually completed between 8:00AM and 4:00PM and was paused only for lunch or truck fuelling. Figure 4 below show the general placement of each piece of equipment.
Figure 4: Equipment layout on haul truck
3.3 Equipment

3.3.1 Novatel SPAN-CPT IMU Unit

The inertial measurement unit (IMU) is used to measure linear forces and rotational acceleration in all three axes by utilizing the inertial navigation system (INS). This is performed with the help of three accelerometers and three gyroscopes which measured in three perpendicular axes, x, y, and z. INS took the inputs and calculated position, velocity and elevation. Accelerations are recorded at a frequency of 100 Hz [37].

This piece of equipment is important because it provided insight into the truck’s lateral and vertical movement. It identified critical segments of the haulage profile where greater driving inputs are required to complete the tasks. The IMU was installed in the cab because it allowed easy access to equipment, it was the most feasible area for installation due to operating environment and allowed bolting to metal cab to reflect accurate information about the truck's undertakings.

3.3.2 Global Positioning System (GPS)

The GPS was used to monitor the position of the truck as it moved around the pit. Measurements were done using GPS satellites. To maintain accurate position tracking, good line of sight to at least four satellites must be established. Overall, good access to the satellites is maintained throughout the pit. The GPS data is recorded at a frequency of 1 Hz.
This piece of equipment is central to the study because it allowed for the positions of the trucks to be tracked throughout the mine. The GPS unit was installed on the outside of the cab to ensure strong and clear satellite reception.

### 3.3.3 Synchronized Position Attitude Navigation (SPAN)

The SPAN unit is used to combine the data from the GPS and IMU units. By integrating the two technologies, the data is recorded and stored for future analysis on the SPAN unit [38]. The SPAN unit is placed on the inside of the cab to allow for easy access and to keep it close to the IMU and GPS.

### 3.3.4 NEXIQ USB-Link

The NEXIQ data logger is used in order to extract data from the trucks virtual private network (ECM). The data logger worked in conjunction with the Detroit Diesel (DD) diagnostic software which is monitored on the infield laptop. The data logger extracts information instantaneously from the truck’s internal computer. The data is then transferred to the DD diagnostic software where selected parameters are converted into readable data to be used for analysis. The NEXIQ USB-Link is critical in examining parameters such as engine speed and fuel consumption. The data logger is installed in the cab so that it could access the trucks ECM system. Also, in order to use the diagnostic software a laptop is required to convert the data and is monitored during testing for quick error correction.
### 3.4 Haul Trucks

At Goldstrike Mine, 930E Komatsu haul trucks are used to move material across the mine. These trucks have a 290 tonnes (320 tons) payload and are run continually throughout the day for two 12-hour shifts. They are powered by a Detroit Diesel or Cummings 16 cylinder 2700 hp (2013 kW) engine. These trucks weigh approximately 210 tonnes (232 tons) when empty [39]. For this research, three different haul trucks are equipped with the monitoring equipment and are asked to perform under normal operating conditions. To maintain consistency in the results, only trucks with the engine model number SSDA16V160 are used for testing. All test trucks chassis are approximately 10 years in operation, but due to engine wear, engines were changed or rebuilt between 2007 and 2009. Only trucks that had engines that were rebuilt in the years 2007 to 2009 were used in these tests.

![930E Komatsu Haul Truck](image)

**Figure 5: 930E Komatsu Haul Truck**
3.5 Cycle profile

To understand the haulage profile, the components associated with the hauling process must be examined. A complete haulage cycle would involve a trip from a shovel to a dump and then a return trip from a dump to a shovel. There are several steps that must be completed between the stop at the shovel and the dump; these include spotting, loading, hauling, dumping and queuing. Due to a continuously changing mining environment and shovel relocations, haulage profiles are rarely consistent. In order to accommodate these inconsistencies, sections of the haulage cycle are examined individually.

Figure 6 shows the average waste haulage profile for the Goldstrike Mine during the testing period. The total haulage cycle takes an average of 30.6 minutes. The given percentages show the significance of each factor to the overall haulage profile.

Figure 6: Haulage Profile [40]
The following factors are involved in the haulage profile:

Queuing: Refers to the amount of time a truck spends waiting in order to proceed to their next task. In the haulage cycle queuing occurs most often when the truck is waiting to be loaded by the shovel or when the truck is getting ready to dump their load. Suggestions will be made in order to minimize queuing by modifying practices in other steps of the haulage cycle.

Spotting: Refers to the time required for the truck to position itself under the shovel in order to be loaded. The effectiveness of this part of the cycle will depend on driver’s experience and understanding of the truck. This part of the cycle will not be analysed.

Loading: Refers to the time the truck spends at the shovel being loaded with material. This process varies in duration as a result of the truck size and the shovel bucket size. Overall a bigger shovel bucket can hold a large volume of material which will fill up a truck more quickly. This part of the cycle will not be analysed.

Hauling: Refers to the time the truck spends moving from the shovel to the dump location and vice versa. This is the largest factor of the haulage cycle, accounting for almost 80% of the haulage profile at the Goldstrike Mine. For the purpose of this study, modifications to this part of the cycle are examined. Impacts on fuel efficiency from intersections were evaluated in order to make improvements.

Dumping: Refers to the time the truck spends dumping the load. This process is usually the smallest component to the haulage cycle, accounting for only 3.5% of the haulage profile at the Goldstrike
operation. In this study, modifications to this part of the cycle are examined to determine if modifications to the smaller parts of the haulage profile can have impacts on fuel consumption.

3.6 Understanding Intersections

It is difficult to recognize the high costs associated with factors such as intersections and haul roads because their value is not easily determined [41]. There are many factors that need to be taken into consideration when planning and building an effective intersection. These parameters include, but are not limited to: visibility, length, signage and grade. Previous work provides some guidelines to help develop these intersections [42]. Several of these factors have an impact on fuel efficiency or the effectiveness of equipment to approach these intersections.

3.6.1 Road Quality

The quality of the road results in impacts on fuel efficiency. The vehicle’s ability to overcome the resistance of the road has a direct impact on the amount of force that needs to be generated by the engine in order for the vehicle to move. With poor road quality, more force is required to move the truck and more stress is placed on the equipment resulting in higher operating and maintenance costs [43].
3.6.2 Stopping Time

Stopping times must be evaluated and understood prior to making any intersection designs in order to maintain safety. By evaluating the stopping distance it can be understood how much visibility and what grade is required in order for the equipment to safely and efficiently approach intersections. The Society of Automotive Engineers (SAE) has tested off highway trucks and stopping performance based on weight. Additionally, it has been found that on average, a reaction time of 2.5 seconds is needed between the time the operator realizes the incident and applies enough brake pressure to begin braking [44].

3.6.3 Grade

The grade must be considered because the steeper the grade, the greater the force generated by the engine in order to overcome gravity. The steeper the grade, the higher the impact on the truck’s braking and acceleration abilities which in turn, makes the trucks less versatile. Overall it has been found that a maximum grade of 7% to 9% is considered the optimum for mining applications [45].

3.6.4 Access Points

Access points to intersections should also be taken into consideration because they determine the traffic tolerance for the intersection. This is important to ensure good traffic flow around these highly interactive sections of the haulage cycle. Usually less access points means less interactions between vehicles, which
increases safety and productivity [41]. Figure 7 illustrates the difference between a typical T intersection and a four way intersection.

![Figure 7: T intersection vs. 4 way intersection [41]](image)

The implementation of intersection islands is a good way to direct traffic in the desired directions in order to minimize confusion in the intersection. Intersection islands clearly identify the flow of traffic, allowing vehicles to maintain speed through the intersections. Although used in the mining industry, intersection islands are not utilized at the Goldstrike Mine.
Visibility is another very important factor when considering intersection design. Although visibility does not have a direct influence on fuel efficiency, it does have a major impact on the way the operator operates his or her piece of equipment. With good, clear visibility, haul truck operators are capable of safely entering intersections with minimal modifications to driving speed. Furthermore, good visibility increases the time available for reaction, which is significant when considering the stopping distances for heavy vehicles.

Figure 8 illustrates how curves and crest can impact visibility. These factors must be considered when designing intersections and are best avoided.
Figure 8: Impact of curves and crest [46]
3.6.6 Signage

Signage is another factor that can help increase safety. By implementing proper signage before the intersection, operators have plenty of time to adjust for the upcoming intersection if necessary. Also, lane delineation in the form of guideposts could be implemented to help guide operators properly along roads [41].
Chapter 4

Assumptions and Dumping Analysis

In chapter 4 the relationships between different parameters to ensure consistency in the data gathered from literature and the mining industry is examined. Due to the limited time of data acquisition and equipment availability, an overview of the assumptions will be given. Additionally, an in depth analysis of dumping is examined in order to see the influence on fuel economy.

4.1 Assumptions

Since research in regards to this thesis is conducted at Goldstrike Mine, the available time for data collection was limited. Furthermore only select data acquisition equipment is used for data collection during this period. Due to these constraints the following assumptions are made in order to calculate the final results.

4.1.1 Weight

Trucks are classified as either unloaded or loaded. Although available through the truck’s ECM system, this information is not available at the time of the study even though weight can impact the fuel economy of the trucks [47]. Trucks are assumed to have a loaded weight of 0 tonnes when unloaded and 263 tonnes when loaded. A weight of 263 tonnes (despite 290 tonnes payload) is used because this is the weight the dispatch system uses in order to record truck loads. It is common practice in the industry to never load
trucks at maximum payload in order to decrease mechanical wear and tear and maintenance costs. Since force is a reflection of both mass and acceleration, it must be noted as mass increases more work is needed to be done by the engine in order to generate enough force to maintain acceleration.

4.1.2 Rolling Resistance

Rolling Resistance is known as the force at the axle in the direction of travel required to make a tire roll [48]. Specialized equipment must be used in a mine environment in order to understand the impacts of rolling resistance. Research done by Hall and Moreland at the Michelin Americas Research Corporation in Greenville has found that a 10% decrease in rolling resistance results in a 0.5-1.5% increase in fuel savings depending on tires [49]. In the mine environment, a rolling resistance of 1.2% can be expected for hard and well-maintained haul roads, but a 5% increase in rolling resistance would result in 10% decrease in productivity and 35% increase in production costs [50]. For the purpose of this study, it is assumed that the road quality during the testing period was properly maintained and is a good representation of road conditions in hard rock mining. Rolling resistance is outside the scope of this thesis but should be used to further expand on this study’s results.

4.1.3 Engine and Transmission Efficiency

Although diesel engines have been shown to be 30-35% more efficient than gasoline engines in regards to fuel consumption, engine components and transmissions will account for 62.4% and 5.6% losses in efficiency respectively [51]. Since each engine is assembled manually on site various smaller factors
could result in variations between the different engines regardless if they are the same make and model. These imperfections are taken into account by gathering data from three different trucks, each equipped with the Detroit Diesel SSDA16V160 engine. Overall, these factors are not studied in depth as they hold little bearing on the results of this study.

![Engine Inefficiencies Diagram](image)

**Figure 9: Engine Inefficiencies [51]**

### 4.1.4 Operators

Data is gathered from six different operators with varying years of experience driving mine trucks, as shown in Table 1 below. The data is generalized in order to create a baseline, which can be used for all operators in a mine. It must be noted that driving behaviour varies between the operators. From visual observations made in the field, experienced operators operated trucks in a more controlled matter. Throttle inputs were smoother both during acceleration and deceleration to decrease vehicle wear and tear and ensure less fuel burned. Furthermore tasks performed (e.g. dumping) were performed quickly and
efficiently in comparison with less experienced drivers. Although outside the scope of this thesis, an analysis could be performed to segregate the data based on operator experience over a larger test group to determine if these visual observations can be validated. Once validated experienced driving habits could be examined and used as potential training tools for less experienced drivers. Also driving practices could be examined around intersection and dumping in order to help establish best practices.

Table 1: Operators Years of Experience

<table>
<thead>
<tr>
<th>Operator</th>
<th>Years of Experience (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver 1</td>
<td>0.1</td>
</tr>
<tr>
<td>Driver 2</td>
<td>3.5</td>
</tr>
<tr>
<td>Driver 3</td>
<td>3</td>
</tr>
<tr>
<td>Driver 4</td>
<td>15</td>
</tr>
<tr>
<td>Driver 5</td>
<td>5</td>
</tr>
<tr>
<td>Driver 6</td>
<td>11</td>
</tr>
</tbody>
</table>

4.1.5 Weather Conditions

Data collection was time limited to the summer months where average temperatures vary between 32.2°C and 15°C and average precipitation is 11.7 mm [52]. The work in this thesis could further be expanded to accommodate different weather conditions and seasons.
4.2 Engine Behaviour

Diesel engines are internal combustion engines and utilize chemical energy to produce mechanical energy. A mixture of air and fuel is injected into cylinders and is compressed to initiate combustion. Diesel engines do not use a spark as in conventional gasoline engines to initialize the combustion but instead have high compression ratio engines. Overall this energy is used to create mechanical energy to move the pistons and generate power [53].

The amount of torque produced by the engine from the combustion reaction is known as brake mean effective pressure (BMEP). It can be expressed in the following equation [54]:

\[
\text{BMEP [psi]} = \frac{150.8 \times \tau}{d}
\]

Where \( \tau \): engine torque [lb/ft], \( d \): displacement [cubic inch (ci)]

Overall as more BMEP is generated, there is an increase in engine load. Engine Load is defined as the energy demand exerted on the various vehicle components required to move the vehicle mass along a driving trace [55]. In this case, engine load examines the amount of torque being exerted by the engine in regards to the maximum torque producible by the engine. It can be expressed in the following equation:

\[
\text{Engine Load [%]} = \left( \frac{C\tau}{M\tau} \right) \times 100
\]

Where \( C\tau \): current torque [Nm], \( M\tau \): maximum torque [Nm]
Torque is used to produce power by the engine. Rotational parts power can be expressed in terms of rotational power [56]:

\[ P = \tau \omega \]

Where, \( \tau \): engine torque [Nm], \( \omega \): Angular Velocity (rad/s)

Brake specific fuel consumption (BSFC) examines the relationship between the amount of fuel consumed and the power produced. This relationship can be expressed by the following equation [57]:

\[ \text{BSFC} = \frac{f}{P} \]

Where \( f \): fuel consumed (g/s), \( P \): Power produced (W)

Overall as BSFC increases, more fuel is consumed in order to produce the same amount of power. Two primary conditions can lead to this unfavourable occurrence within the engine. First at low engine speeds, the BSFC is higher because of the amount of time required for the heat transfer between the diesel fuel and the cylinder walls to occur. Diesel engines however do not utilize a throttle, avoiding a throttle restriction at low engine loads due to the vacuum being created from air being drawn through the throttle body. Instead they use a computer to control the amount of fuel injected into the cylinder [58] allowing for more consistent BSFC at lower engine speeds. At higher engine speeds, the amount of friction generated from the moving cylinders reduces the amount of available combustion energy to generate power [57]. Since moving cylinders create friction, with 16 cylinder engines, the amount of friction and heat generated increases with engine speed. In order to ensure good life from the engines, the engine speed on the haul trucks is limited to around 2000RPM.
Overall in order to maintain a balance between power produced and fuel consumed engine speeds should be maintained within a specific range to achieve the best BSFC. Based on the data gathered the following relationship can be shown to illustrate BSFC on the test trucks:

Figure 10: Brake Specific Fuel Consumption (Filtered)

A linear relationship exhibits properties of a good fit between power and fuel consumption, where to generate more power more fuel is required and vice versa. Fuel consumed is a reflection of instantaneous fuel consumed for the truck at one second intervals. Although Detroit Diesel could not disclose the exact method in which fuel data was computed, industry sources have shown that fuel flow is proportional to intake airflow and engine load [59]. Since sensors are installed on various components of the engine, measuring air flow from the intake manifold and measuring torque to achieve engine load can help to determine the fuel efficiency of the truck. Overall this information is stored in the ECM system of the truck. Since data is collected every second the accuracy of the results is a reflection of throttle inputs.
based on a one second average. Data has been filtered in order to eliminate delays or spikes in the data which aren’t reflections of engine behaviour. Filtered is done by finding the median of the line and the determining the upper and lower quartiles pertaining to the data. Once determined the top and bottom quartile are removed in order to eliminate outlying conditions. Furthermore, any data which is incomplete or an error is also filtered and removed from the graph. This filtering method is used for all graphs in the thesis.

Torque data is extracted from the ECM system at one second intervals during testing. Once again Detroit Diesel didn’t disclose how torque is calculated, but from on site communication it is found that a tool such as a torque sensor is used to measure torque on rotational shafts such as a crankshaft. It can be measured both utilizing mechanical or electrical energy depending on the application, but most likely is electric since the Komatsu trucks is a diesel/AC electric trucks [60]. To determine the torque an understanding of the zero load and maximum load of the sensor are understood. By simply measuring the excitation (the force placed on the rotational part) an understanding of the amount of torque required can be determined [61]. Refer to the Table 37 for a typical cycle run and associated torque.

The relationship between engine speed and fuel consumption must be examined in order to further understand the relationship:
Figure 11: Fuel vs Engine Speed (Filtered)

Due to the increased frictional losses in the cylinder as engine speed increases usable energy and power generated from combustion are decreased, therefore, more fuel is required to maintain work. This relationship is shown in the fit between fuel consumption and engine speed. Lower engine speeds result in greater fluctuations since steady state operating conditions are harder to achieve. Fuel rate deviations vary as the engine speed changes because of several factors. Some of these factors include:

1. Truck weight
2. Rolling Resistance
3. Acceleration
4. Driving Behaviour
5. Engine Mechanics
Overall trucks are shown to be the most fuel efficient when operating within a limited range of engine speed. Since varying engine speeds will result in varying power demands from the engine this can result in larger fuel consumption. This information will be considered for future analysis in this thesis.

4.3 Mechanical Wear and Tear

![Engine Load Vs Engine Torque](image)

**Figure 12: Engine Load vs Engine Torque (Filtered)**

Engine Load can be used to measure wear and tear in this analysis. Since all components of the truck are interconnected (engine, transmission, driveshaft, etc.) increased loads on the engine result in increased stress on all mechanical components required to move the truck. Since conditions such as acceleration and driving uphill cause increased engine load and additional stress on the engine, all supporting components
of the truck are stressed in a similar fashion to allow the truck to move. Figure 12 shows that torque and engine load increase proportionally overall resulting in increased wear and tear, but to prove this relationship is beyond the scope the thesis. This relationship should be considered for future parts of the analysis.

4.4 Dumping Analysis

Haul truck dumping is a fundamental component of the haulage cycle. With an average of 19 cycles per shift this results in an average of around 14 000 cycles per year for a single truck [5]. The primary motivation for this analysis is a study done by Modular in regards to dumping practices [62]. The case study states that changes in dumping behaviour could result in annual fuel savings. By modifying the operating engine speed (RPM) for the bed-raising component of the dumping cycle, fuel saving can be made. The data collected showed no impacts on dumping time and the conclusion stated that changing engine speed and dumping practices had no impact on the time.

In order to test this theory for potential fuel saving in a real world scenario, trucks are asked to dump under varying engine speeds (RPM) over the testing period. Each truck’s engine speed (RPM) and fuel consumption (gal/hr) is recorded using the available equipment. However, in order to stay consistent with the Modular case study, data analysis is focused on the most fuel consuming component of the dumping process; raising the bucket.
4.4.1 Understanding Dumping

Haul truck dumping can be broken down into 3 sections: spotting, bed raising and bed lowering. Spotting refers to the time required by the truck to turn around and reposition in order to dump its load. An average time of 17 seconds is needed for trucks to position themselves properly in order to initiate dumping [5]. Raising the bed is the most demanding portion of the dumping process due to the large amount of weight that needs to be lifted by the haul trucks hydraulic system. Finally, lowering the bed involves switching the gear on the truck in order to initiate the action. From gathered data, lowering the bed takes an average of 21 seconds. Overall, raising the bed is examined in further detail.

4.4.1.1 Raising the Bed

Hydraulic systems operate by applying pressure to a fluid to accomplish work. The hydraulic systems on haul trucks are engaged when the operator uses a switch that changes the input from the gas pedal to deliver mechanical power from the crankshaft to a hydraulic pump. The pump converts mechanical power to hydraulic power which is directed to the hydraulic cylinders. The cylinders convert the hydraulic power to mechanical power to push the piston and allow the bed to be raised. This system utilizes hydraulic pressure and fluid flow to ensure smooth operation and can be expressed in a unit known as hydraulic horsepower [63].

\[ HP = \text{GPM} \times \frac{\text{PSI}}{1714} \]

Where HP: Hydraulic Horsepower, GPM: Gallons per minute [fluid flow], PSI: pounds per square inch [hydraulic pressure]
Without sufficient pressure in the system there would be inadequate amounts of force generated to raise the weight of the bed. Furthermore without sufficient flow, systems would be lagging [63]. Overall both flow and pressure are required in order to accomplish work. To examine this relationship in the field the following is found:

**Figure 13: Engine Speed vs Time to Raise Bed**

\[ y = 39189x^{-0.919} \]

\[ R^2 = 0.7311 \]
Fuel consumption pertaining to dumping is calculated by examining the instantaneous fuel consumption during the time raising the bed is performed. Fuel data is recorded at one second intervals. Once raising the bed in complete the fuel rates are averaged over the total time required to perform the action to determine average fuel consumption based on the dumping practices. The same approach is used to determine the average engine speed. Due to the sensitivity of the gas pedal on the trucks, it is very difficult to maintain a steady engine speed and consequently a consistent fuel consumption therefore averaging is required. Overall each data point presented is a reflection of one dump.

Since fuel consumption and engine speed are related, it can be shown that the relationships are similar. Only controllable parameters such as engine speed and fuel consumption are examined for the purpose of this analysis, while parameters such as density, weight and dumping angles are ignored, but could be used

Figure 14: Fuel Consumption vs Time to Raise Bed
to enhance the findings. Data could be validated further with application of throttle regulators and a larger data set.

4.4.2 Operating Point

At Goldstrike Mine performing tasks safely, quickly and efficiently are the main performance evaluation criteria. Therefore to gain a better understanding of the benefits of increasing dumping time to save fuel an analysis of the impact on productivity is done.

The average maximum engine speed for all test trucks is around 2000 RPM and the limit is exceeded slightly due to slight mechanical difference between trucks and engine components. By changing the engine speed, there is an impact on fuel across a large range of engine speeds. When examining all engine speeds, an average engine speed of approximately 1564 RPM is found. Since this engine speed is a good reflection of evaluated engine speeds, it is used for the analysis in the case study. It is found that the average dump time at full throttle (2000 RPM) is 26 seconds and at average (1500 RPM), is 32 seconds. This is a 6 second difference between current operating practices and the new suggested operating range.

4.4.2.1 Cost Savings

The benefits of saving on fuel costs are directly proportional to lowering the engine speed to the newly defined operating range. To find these benefits the savings in fuel from changing the operating engine
speed from 2000 RPM down to around 1500 RPM are examined. A sensitivity analysis is done to see how fuel price would affect the savings.

**Table 2: Savings at different Fuel Prices**

<table>
<thead>
<tr>
<th>Fuel price ($USD/gal)</th>
<th>Saving from operating at average engine speed ($USD/dump)</th>
<th>Saving per truck per year ($USD)</th>
<th>Saving for fleet per year ($USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.38</td>
<td>4,355</td>
<td>156,780</td>
</tr>
<tr>
<td>3</td>
<td>0.57</td>
<td>6,483</td>
<td>233,388</td>
</tr>
<tr>
<td>6</td>
<td>0.94</td>
<td>10,773</td>
<td>387,828</td>
</tr>
</tbody>
</table>

When examining a truck individually a small saving is achieved by modifying the dumping operating point. Since the mining industry involves multiple trucks operating consistently across the year these small individual savings amount into greater savings when considering longer periods of time or the entire operating fleet.

**4.4.3 Dumping Application**

By examining the characteristics of truck operations when dumping at full throttle versus regulated throttle, difficulties in maintaining the engine speed are observed. The engines are so large on these haul trucks that the gas pedals are very sensitive to throttle input changes, therefore maintaining the engine speed around 1500 RPM is much harder than maintaining engine speed at 2000 RPM due to the assistance of a throttle limiter. In order to decrease the deviation of the new operating range, engine speed limiters should be imposed to allow for consistency in the engine speed. A switch can be used to
differentiate between loads that are waste or ore with operators to control the bucket raising with the use of the throttle. Alternatively haul truck operators could be trained to operate in specific ranges of engine speed depending on the material being dumped, but this method would be less efficient and would yield similar deviations as found in the analysis. It has been shown that minimal changes made to a smaller component of the haulage cycle can reduce fuel costs. Although these sections are considered minimal together they account savings of around $230 000 USD at a gas price of $3 USD/gallon.

4.5 Queuing Analysis

In the past studies have been done in order to minimize queuing times [64]. Effective productivity is only achieved if loading equipment is loading trucks in order to increase utilization and decrease idling [65]. Queuing occurs when the truck is waiting to be loaded at the shovel but can also occur when the truck is waiting to dump or when the truck is parked for various reasons. For the purpose of this study we examined the impact on fuel efficiency when the truck is waiting at the shovel.
4.5.1.1 Average Queuing time

The first step in evaluating the queuing process was to determine the frequency of the occurrence and duration. From the data collected it was found that 7.4% of the haulage cycle was spent queuing. [40]. Upon further investigation it was found that the average queuing time was approximately 2 minutes.

It must be noted that queuing occurred more frequently during the beginning of the shift and less as the shift progresses. The reason for this is that as operators prepare for their shift, trucks are usually parked at ready lines (area where trucks can be parked safely for shift change). As the shift begins large numbers of trucks leave from the same location heading in the same direction, overall leading to more trucks at the shovels or dumps than capable of loading by a single shovel. Overall as the shift continues the dispatcher is capable of allocating trucks based on mining priorities and trucks become evenly spaced.

4.5.1.2 Evaluating Queuing

The first analysis is to evaluate the amount of fuel burned per second of queuing. This was done by examining the average fuel consumption for trucks as they queue. The following relationship was found:
The purpose of this study was to evaluate the impact queuing has on the haulage cycle and the amount of fuel that can be saved. A very small saving in fuel can be achieved which is nearly insignificant when examining the overall cycle. By examining queuing we can see that trucks do spend a portion of time queuing, but since trucks require very little energy to queue, it is one of the least fuel consuming parts of the haulage cycle. Time gained in other in other parts of the haulage cycle can result in increased queuing. This means that there is the potential to increase time spent on other segments of the haul cycle without a large impact on fuel costs. By doing this we are potentially saving fuel on the overall haulage cycle. These other factors will be considered in the next chapter but the time flexibility of queuing should be kept into consideration.

### Table 3: Queuing Evaluated Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Engine Speed (RPM)</td>
<td>808.04</td>
</tr>
<tr>
<td>Average Fuel Burned (gal/hr)</td>
<td>3.47</td>
</tr>
<tr>
<td>Average Cycle Time (min)</td>
<td>30.60</td>
</tr>
<tr>
<td>Time Spent Queuing (sec)</td>
<td>135.86</td>
</tr>
<tr>
<td>Fuel Burned Queuing Per Cycle (gal)</td>
<td>0.13</td>
</tr>
<tr>
<td>Average Number of Cycles Per Day</td>
<td>15.70</td>
</tr>
<tr>
<td>Total Cycles Queuing</td>
<td>9.42</td>
</tr>
<tr>
<td>Total Fuels Burned Queuing Per Shift (gal)</td>
<td>1.23</td>
</tr>
<tr>
<td>Total Fuels Burned Queuing Per Truck (gal/year)</td>
<td>899.3592</td>
</tr>
<tr>
<td>Total Fuels Burned Queuing Per Fleet (gal/year)</td>
<td>32376.93</td>
</tr>
</tbody>
</table>
Chapter 5

Intersections

The highest levels of interaction in any automotive road network are intersections, which account for 20.8% of road fatalities in 2009 on US roads [66]. This critical inefficiency in the road network has caused the implementation of many safety precautions, such as stop signs and priority hierarchies to minimize risks when vehicles are approaching intersections. In addition, intersection inefficiencies have a direct impact on production and fuel efficiency as a result of vehicles having to change their driving behaviour to accommodate unexpected intersections events. In order to optimize the mine traffic one of the primary objectives of this project is to examine how intersections would affect fuel efficiency and time required to traverse the intersection. It must be understood that no changes to safety procedures will be made and every suggestion will be in accordance to mine policies.

5.1 The Traffic Priorities

In the mining environment a traffic hierarchy is put in place to identify which vehicles have the right of way with the intention of maximizing safety and maintain production. The hierarchy at the Goldstrike Mine is as follows [67]:

1. Emergency vehicles
2. Loaded haul trucks (Komatsu 930e)
3. Unloaded haul trucks (Komatsu 930e)
4. Support equipment (e.g. Dozers, graders)

5. Light duty vehicles (e.g. Half ton trucks)

For the purpose of this study the focus is given to examining loaded and unloaded haul trucks. By following the hierarchy, loaded trucks have precedence when approaching an intersection at the same time as unloaded haul trucks. It is also assumed that all equipment below haul trucks on the hierarchy would stay in compliance with safety regulations and would yield to the heavy haulers. Emergency vehicles in the pit are a very rare occurrence and will not be accounted for in the paper.

5.2 Intersection Overview

To gain a better understanding of interactions at intersections the intersections at Goldstrike Mine are visually observed from the lookout tower over eight days for four hour segments. On average, 20% of all haul truck intersection passes at busy intersections resulted in some sort of interaction between heavy hauling equipment. This amounts to an average of 12.56 interactions for one truck per shift. This translates to approximately 427 interactions across the entire truck fleet per shift. A greater numbers of interactions involved haul trucks and other mine equipment but these interactions will be ignored in order to stay in accordance to the mine traffic hierarchy.

Variations between the way operators approach, enter and leave intersections are evident especially when intersections are empty and when the intersection has major activity. When operators have good visibility of the intersection and a good understanding of the other mine equipment in operation, visual
observations showed a decrease in variations of behaviours. However when other haul trucks are present or close to the intersections haul truck operators will perform one of the following actions while staying in accordance with the mine traffic hierarchy:

1. Maintain truck speed upon approaching and entering intersection (pass through)
2. Accelerating the truck either before or during the intersection (accelerate)
3. Slow or stop the truck upon approaching the intersection then accelerating from low speed or rest when entering and leaving intersection (stop and go)

These three driving approaches will be referenced for the remainder of this paper.

5.3 Speed limits

Speed limits in the mine for heavy haulage equipment are in place to ensure safety and long operating life. The overall speed limit at the mine is 48 km/h (30 mph) in ideal conditions. Certain scenarios in the mine result in driving conditions that require the overall mine speed limit to be adjusted. Refer to Table 4 for the speed limit depending on a given scenario:

Table 4: Mine Speed Limits

<table>
<thead>
<tr>
<th>Condition</th>
<th>Speed limit km/h (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loaded truck on 0% grade</td>
<td>48 (30)</td>
</tr>
<tr>
<td>Loaded truck going uphill on grade</td>
<td>No limit*</td>
</tr>
<tr>
<td>Loaded truck going downhill on grade</td>
<td>18 (11)</td>
</tr>
</tbody>
</table>
Unloaded truck on 0% grade | 48 (30)
Unloaded truck going uphill on grade | No limit*
Unloaded truck going downhill on grade | 32 (20)

*In these conditions the trucks cannot achieve the overall mine speed limit of 48km/h (30mph)

Furthermore the truck supplier Komatsu has issued safe driving speeds based on grades. The following chart (Figure 15) can be found in all truck cabins:

![Figure 15: Truck Grade Speeds](image)
Certain intersections have stop and yield signs. The speed limit for the intersection after approaching one of these signs is 5 mph. These signs are not changed during testing to ensure compliance with safety standards within the mine.

5.4 Intersection Analysis

5.4.1 Sorting

Data has been organized based on variables of interest. The following classification has been followed in this paper:

1. Intersections: Depending on the haulage route taken by the test trucks data is collected for each intersection independently.
2. Trucks: Since loaded and unloaded trucks behave differently, data identifies if trucks are loaded or unloaded.

Sorting the data in these parameters allows the examination of truck speed, intersection approach and other constraints. Having a good understanding of these variables will allow further analysis to determine how they interact with each other.
5.4.2 Initial Analysis

In order to understand the most effective way to approach intersections, data on 292 runs is gathered and examined. Some data is removed because certain runs had incomplete information mostly due to losing connection to satellites in certain portions of the mine. Out of the 292 runs, 275 runs are found to be a good reflection of truck driving approaches to intersections. Refer to Figure 40 and Figure 41 in Appendix B for the amount of runs that are gathered for both unloaded and loaded trucks.

To illustrate the difference between pass through and stop and go refer to the following figure:
By examining the behaviour of the engine speed and examining the spacing between the GPS dot traces of the truck, differentiation between stop and go and pass through can be distinguished. Pass through commonly requires less time for the truck to traverse the intersection, has less variation on the engine speed and a consistent spacing between the dot traces. Stop and go however exhibits opposite characteristics. These classifications are used to determine how much of the time is spent completing which driving habit when traversing the intersection.

5.4.3 Unloaded trucks

Each of the intersections had distinct characteristics which are reflected in the data. Overall Figure 17 and Figure 18 illustrate the percentage of runs that are found to approach the intersection in one of the three driving approaches.

![Figure 17: Unloaded Haul Truck Downhill Scenarios](image)

**Figure 17: Unloaded Haul Truck Downhill Scenarios**
5.4.4 Loaded trucks

Since weight plays a key role in a haul truck’s performance loaded trucks are analyzed separately. Once again trucks are categorized based on the three given driving scenarios:
Figure 19: Loaded Haul Truck Downhill Scenarios

Figure 20: Loaded Haul Truck Uphill Scenarios
5.4.5 Initial Summary

Since interactions between trucks occur 20% of the time, it is observed from the data that trucks passing through the intersections is the most common occurrence. From observations made in field, trucks did not always maintain speed when entering intersections. This most commonly occurred when trucks are trying to build momentum to get up steep grades or when trucks had braked excessively moving downhill and would accelerate in order to bring truck speeds closer to maximum. In order to understand these two primary changes which cannot be quantified in the scope of this thesis, drivers are asked to explain these driving behaviours. First, truck drivers explained the importance of cycle times and that every second is worth profit to the organization. Second, years of experience and repetition of the same task have resulted in practices that make the truck behave more predictably (such as momentum building when going uphill to reduce wear and tear). These answers have been directly correlated to drivers with greater years of experience as they had a greater understanding of the importance of cycle time and minimized wear and tear on equipment [25].

No data was collected for acceleration of loaded trucks moving uphill, because loaded trucks are moving at a very low speed as a result of the increased load and are usually moving at full throttle when on incline grades. Also, when trucks are moving on downhill slopes they are usually constrained by speed limits, therefore it is observed that once there is a decrease in grade, trucks accelerate with the help of gravity to gain speed and get closer to the speed limit.

Trucks are observed to stop or slow down most commonly when encountering other vehicles in the intersection. These occurrences are observed to both increase the cycle time, as well as increase the
amount of fuel burned by the truck. It must be understood that because Goldstrike is a large mine the option of paths that can be taken is much larger than the typical open pit operation. The same analysis can be performed in a smaller mine with less road network flexibility to examine if smaller mines yield increased amounts of intersection interactions.

Finally the majority of the data gathered is downhill data for unloaded trucks and uphill data for loaded trucks. This reflects the contours of the mine since the active shovel pits are located at the bottom of the pit. Since loaded trucks are usually hauling uphill, the time required to reaccelerate the truck because of stopping or slowing down is increased. This creates a large strain on mechanical components of the truck as well as increased fuel costs.

5.5 Impact on Time

One of the first parameters evaluated is the amount of time required for trucks to traverse intersections. Data is compiled individually for all intersections and is combined to yield the following results.

Table 5: Unloaded Haul Truck Times

<table>
<thead>
<tr>
<th>Downhill</th>
<th>Average Time (s)</th>
<th>Standard Deviation</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass-through</td>
<td>10.97</td>
<td>0.65</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Average Time (s)</td>
<td>Standard Deviation</td>
<td>Difference</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------</td>
<td>--------------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Uphill</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass-through</td>
<td>16.69</td>
<td>1.64</td>
<td>0.00</td>
</tr>
<tr>
<td>Accelerating</td>
<td>17.00</td>
<td>9.11</td>
<td>0.31</td>
</tr>
<tr>
<td>Slow/Stop</td>
<td>*24.42</td>
<td>10.26</td>
<td>7.73</td>
</tr>
</tbody>
</table>

**Table 6: Loaded Haul Truck Times**

<table>
<thead>
<tr>
<th></th>
<th>Average Time (s)</th>
<th>Standard Deviation</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downhill</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass-through</td>
<td>14.38</td>
<td>2.46</td>
<td>0.00</td>
</tr>
<tr>
<td>Accelerating</td>
<td>14.11</td>
<td>6.09</td>
<td>-0.26</td>
</tr>
<tr>
<td>Slow/Stop</td>
<td>*24.43</td>
<td>14.93</td>
<td>10.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Average Time (s)</th>
<th>Standard Deviation</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uphill</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass-through</td>
<td>16.99</td>
<td>3.27</td>
<td>2.62</td>
</tr>
<tr>
<td>Accelerating</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Slow/Stop</td>
<td>*25.87</td>
<td>14.93</td>
<td>11.49</td>
</tr>
</tbody>
</table>
* Note “slow/stop” speeds can deviate from the times shown and are dependent on the severity of the intersection interaction.

It is observed that “pass-through” is the most effective method to go through an intersection. It has the lowest amount of deviation (lowest standard deviation) and has the lowest time required to traverse the intersection. As shown earlier in this thesis, achieving steady state conditions result in the best BSFC for the trucks overall lowering mechanical degradation.

“Acceleration” results in minimal savings on time, but at the expense of other parameters. Firstly, the data is collected from only three trucks in the fleet. When considering the entire fleet that has differences in mechanical components and assembly, the small saving in time could prove to be negligible. Secondly, the most common occurrence is that trucks are using a combination of deceleration and acceleration which is quantified by the standard deviations in overall times. This continuous change results in variations in engine load, overall impacting mechanical stress on components of the truck and has greater impacts on fuel consumption (as shown on the next section).

The slowing or stopping of the trucks results in increased time needed to traverse the intersection and is creating conditions that can lead to potential incidents. This results in impacts on fuel consumption, safety and production rates.
5.6 Impact on Fuel

In order to understand the impact of fuel between loaded and unloaded trucks the two parameters are examined independently for individual trucks and for the entire fleet. Based on the Goldstrike data [40] and the geographic location of the site a fixed gallon price of $3 USD/gallon is used for evaluation. A cost comparison between the three driving behaviours can be determined.

Table 7: Loaded Truck Costs

<table>
<thead>
<tr>
<th></th>
<th>Fuel Burned (gal/hr)</th>
<th>Fuel Burned (gal/sec)</th>
<th>Gallons/Truck</th>
<th>Extra Gallons per truck</th>
<th>Fleet gallons per day (gal)</th>
<th>Gallons per Year</th>
<th>Extra Cost ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downhill</td>
<td>Pass-thru</td>
<td>30.29</td>
<td>0.01</td>
<td>0.12</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Accelerating</td>
<td>53.05</td>
<td>0.01</td>
<td>0.21</td>
<td>0.09</td>
<td>52.61</td>
<td>19204</td>
</tr>
<tr>
<td></td>
<td>Slow/Stop</td>
<td>67.46</td>
<td>0.02</td>
<td>0.46</td>
<td>0.34</td>
<td>203.70</td>
<td>74351</td>
</tr>
<tr>
<td>Uphill</td>
<td>Pass-thru</td>
<td>112.14</td>
<td>0.03</td>
<td>0.53</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Slow/Stop</td>
<td>115.88</td>
<td>0.03</td>
<td>0.83</td>
<td>0.30</td>
<td>183.41</td>
<td>66944</td>
</tr>
</tbody>
</table>

Table 8: Unloaded Truck Costs

<table>
<thead>
<tr>
<th></th>
<th>Fuel Burned (gal/hr)</th>
<th>Fuel Burned (gal/sec)</th>
<th>Gallons/Truck</th>
<th>Extra Gallons per truck</th>
<th>Fleet gallons per day (gal)</th>
<th>Gallons per Year</th>
<th>Extra Cost ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downhill</td>
<td>Pass-thru</td>
<td>7.48</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Accelerating</td>
<td>24.71</td>
<td>0.01</td>
<td>0.07</td>
<td>0.05</td>
<td>28.72</td>
<td>10483</td>
</tr>
<tr>
<td></td>
<td>Slow/Stop</td>
<td>35.07</td>
<td>0.01</td>
<td>0.17</td>
<td>0.14</td>
<td>87.55</td>
<td>31955</td>
</tr>
<tr>
<td>Uphill</td>
<td>Pass-thru</td>
<td>20.44</td>
<td>0.01</td>
<td>0.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Accelerating</td>
<td>67.35</td>
<td>0.02</td>
<td>0.32</td>
<td>0.22</td>
<td>135.05</td>
<td>49293</td>
</tr>
<tr>
<td></td>
<td>Slow/Stop</td>
<td>70.91</td>
<td>0.02</td>
<td>0.48</td>
<td>0.39</td>
<td>233.55</td>
<td>85247</td>
</tr>
</tbody>
</table>
Overall changes in truck speed result in more fuel consumption. Trucks that can maintain a steady state condition can result in the most predictable amount of fuel burned and the lowest operating costs. By examining Table 7 and Table 8 it is observed that interactions in intersections will result in increased fuel costs. Implementing a monitoring system that can control the trucks changes in speed, modifications can be made to improve fuel consumption, wear and tear and cycle times. Furthermore, by decreasing high-risk interactions between equipment at intersections, a safer working environment will be created but the cost savings will be small.

5.6.1 Purposed Plan Forward

It is observed from the initial analysis that changes in truck speed and engine speeds have a direct correlation to fuel consumption. In order to quantify this analysis, a function has been built to control fuel inefficiencies around intersections.

The ideal scenario is to have trucks move freely through intersections with no interactions allowing operators to maintain a consistent speed and, overall, achieve a steady state operating condition. Therefore by monitoring truck parameters as they approach and leave the intersection, truck behaviour is examined to determine what parameters have the greatest impact on fuel. The rest of this chapter will address the following questions:

1. How does truck entrance speed impact fuel consumption?
2. How does the layout of the intersection affect fuel consumption?
3. What parameters can be given to the operator in order to approach intersections in a fuel-efficient matter but avoid haul traffic interaction?

4. Does this analysis justify the application of automated technology in haul trucks?

5.7 Intersection Analysis

Since the mine is a very dynamic environment, testing is conducted at well-defined intersections. Four intersections are chosen based on the following parameters:

1. Active intersections: To ensure the intersection is being utilized for the duration of testing for consistent data gathering.

2. High traffic environments: To ensure conditions are present which can lead to interactions at the intersections.

3. Points of entry: To examine how several points of entry can have impacts to truck behaviours around intersections.

4. Visibility: To ensure safe conditions and good reaction time for the truck drivers around intersections

Each intersection is examined in further detail. Refer to Figure 21 and Figure 22 for locations of the intersections:
Figure 21: Intersection Layout Goldstrike Mine 1

Figure 22: Intersection Layout Goldstrike Mine 2
5.7.1.1 Intersection 1

This intersection is located in the northeast corner of the pit. It is a four-way intersection with traffic flow moving in all directions. In order to control traffic flow and maximize safety two stop signs are present at this intersection for northbound and southbound traffic. The north path leads to a shovel loading location and the east path leads to the exit of the pit and the refueling station for the trucks. The west path is an alternate access path to the shovel pits in the south. This path is not used during the given testing period because cycle times increased as a result of the longer distance to the shovel pits.

Figure 23: Intersection 1 (Green Intersection)

5.7.1.2 Intersection 2

This intersection is located in the eastern part of the pit. It is a three-way intersection with traffic flow in all directions. This intersection has a one-way direction path entering from the west side, but incorporates a stop sign for safety purposes. This intersection is highly active since the east path leads to two of the
primary in-pit waste dumps and one of the major in-pit lay-downs for the pit. The south path leads to most of the active shovel pits.

Figure 24: Intersection 2 (Red intersection)

5.7.1.3 Intersection 3

This intersection is a three way intersection with traffic moving in all directions. There are no traffic signs present at this intersection. The south path leads to a newly established in-pit dump location while the east to west paths are main access paths in and out of the pit. The west path leads to the active shovel locations while the east path gives access to the northern in-pit dump locations.
5.7.1.4 Intersection 4

This intersection is a three-way intersection with traffic flow in all directions. No traffic signs are present at this intersection. The north and west path are the main access paths to the active shovel pits. The east path gives access to the in-pit dumps. This is one of the most active intersections in the pit since most haul traffic had to pass through this intersection at least once during their cycle runs.
Figure 26: Intersection4 (Yellow Intersection)

5.7.2 Modelling

For data analysis a high level computing language program called MATLAB® is used to create an interactive environment for computation visualization and programming [68]. This software program is used for data analysis, function definition and model creation for illustration.

Several functions are constructed and used in conjunction with the main script to produce the final results in this report. Raw data is converted into .mat files that could be used for analysis in MATLAB®. Figure 27 outlined the process flow stream for the code. All components of the code can be found in Appendix C.
Before any analytical work can begin a good understanding of the mine network must be outlined and illustrated. In order to perform this work a light duty mine vehicle was equipped with a GPS unit on the roof and was driven throughout the mine.
The vehicle was driven at relatively low speeds when haulage traffic was minimal in order to ensure good results and safe operating conditions. It was driven along the sides of the road and through the middle of the road. Each road was driven three times to ensure good data acquisition for future analytical work. Shovel pits and dump locations were avoided due to the large amount of heavy haulage equipment present in the areas.
Each run was extracted from the GPS unit and stored into separate .mat files. The data was given in latitude and longitude associated with each point. The best runs were chosen and compiled into a map outlying the pit called combinedmap (see Appendix C).

![X-Y View of Data]

Figure 29: Pit Layout

5.7.4 Circles and Polygons

To evaluate each intersection individually, circles/polygons are built around each of the intersections to create an operation environment in which to perform the analysis. In order to define the circles/polygons a
corresponding script is built that can be found in Appendix C. The scripts are based on the script utilized in work done by Andrew Chapman [69] but modified for the following application.

The function is structured to allow the user to select the center of the circle based on a defined map or to manually input a longitude and latitude point to represent the center. Furthermore since circle size will affect the results the user has the flexibility to define the radius of the circle in meters (the code will manage the conversion to longitude and latitude distances) in order to focus on specific ranges of interest.

Figure 30 illustrates a typical region around an intersection:

![Figure 30: Circle region around intersection](image)
As can be seen from Figure 30, two circles have been defined around the intersection. The blue circle is used to encompass the area where the paths come together and is used to define the entrance and exit location of the intersection. Due to safety considerations only one truck should be present in the intersection region at any given time in order to avoid possible conflict between equipment. Therefore for the remainder of this paper the blue circle will be referred to as the intersection zone and will only be permitted to have one truck inside its boundaries at any given time.
The yellow zone defines the closest region around the intersection for the given paths. For the purpose of this thesis, the yellow zone will be referred to as the change zone. The change zone is an area that may see varying level of haul truck activity at any given part of the day. This region will be the primary focus of this paper since it is the area in which haul trucks will be analyzed and the behaviour modified in order to increase intersection efficiency and result in fuel savings. For the base analysis, the change zone has been chosen to encompass a region 200 m away from the intersection entrances to ensure good braking distances, reactions times and reasonable data size for processing.

The study is further expanded by examining polygons, which are built manually to encompass an area around the intersection. The intersection zone is created by identifying the entrances to the intersection and then using the polygon to encompass this region. It was checked with the circle intersection zone to ensure consistency between the analyses.

The change zone is defined by examining the truck path and determining where 200 m from the entrance of the intersection occurred along the path. Once this is defined for all the paths entering the intersection, a polygon is built within these limits. This ensures that path for the analysis of the change zone is 200 m.
5.8 The Code Elements

5.8.1 Distance Evaluation

The applicable .mat files from the GPS unit stored information for the trucks location in longitudinal and latitudinal coordinates and gave elevations above sea level. For the purpose of this thesis the behaviour of the trucks between coordinates is analyzed. In order to perform this analysis, distances between points must be converted from longitude and latitude to measurable units such as meters. In order to achieve distances in meters the Carlson model is used [70].

A function called DistGPS [71] is used and modified for this application. Due to the location of Goldstrike the code is built using measurements in both metric and imperial. For the purpose of this thesis measurements are presented in meters.

5.8.2 Truck Behaviour

Since the way trucks behave during their haulage cycles directly impacts fuel consumption, this analysis had to be modelled for intersections. Each trucks distance, speed and time in relation to intersections are examined in further detail. To understand how the trucks behaved a function called tracktruck is built to examine each of these variables.
By using DistGPS to convert all the latitudinal and longitudinal points to meters, by taking the sum based on the data points, the total distances to the circles/polygons of interest could be determined. In the case of this analysis the primary points of interest is the distances to the entrance and exit of the intersections.

Speed is the most versatile parameter in this analysis and is therefore used as a given input rather than being calculated. When the main script is run an input is asked for the trucks current speed. For the simplicity of this thesis this value can be inputted manually. Future work can consider adapting a real time velocity analysis which could be extracted from the trucks ECM. The input is asked in miles per hour due to the geographic location of the research site. In the function tracktruck, the velocity input is converted to meters/second to stay consistent with the rest of the analysis.

Time is calculated by rearranging the variables in the following relationship:

\[ v = \frac{\Delta d}{\Delta t} \]

Where \( v \): velocity [m/s] \( d \): distance [m], \( t \): time [s]

Time is important for the distance to the entrance of the intersection and to the exit of the intersection because it showed the impacts on cycle times.
5.8.3 Priority Definition and Speed Change

A priority system using the mine traffic hierarchy is modelled in order to differentiate between loaded and unloaded haul trucks. In order to define this relationship a function called Truckpriority is built. A numerical system is used as followed:

Table 9: Numeric System for Truck Allocation

<table>
<thead>
<tr>
<th>Loaded Truck</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unloaded Truck</td>
<td>0</td>
</tr>
</tbody>
</table>

In order to give the right of way to one truck the lower priority truck must be slowed down in order to give the right of way to the higher priority truck. When the main script is run, an evaluation is performed first to determine which truck has the higher priority. Once this is determined, based on the current location and speeds of the two trucks the time required for the trucks to reach the entrance and exit of the intersection is determined. If it is found that the two trucks will be in the intersection at the same time, the time for the higher priority truck to reach the exit of the intersection is recorded. This time is then used to adjust the time required for the lower priority truck to enter the intersection to ensure only one truck is present in the intersection at any given time. Consequently this results in a velocity change to the lower priority truck which is displayed with the new suggested velocity for the truck. If however the priorities of the two trucks are found to be the same, then the truck closest to the intersection is given higher priority and the same process is repeated.
The reason for this speed change is to ensure minimal impact on the lower priority truck. By minimal modification to the times in order to ensure only one truck in the intersection, a smaller change in speed is required by the lower priority truck. Second, the higher priority truck is unaffected therefore eliminating situations where both trucks slow down around intersections to determine which truck has the right of way. Overall this translates to the smallest impact on cycle times, mechanical wear and tear (since in most cases adjustments are made to unloaded trucks) and fuel consumption as will be presented in the following subchapters.

5.8.4 Main Script

In order to examine the interactions between two haul trucks at a given intersection a main script called drive_code_truck is compiled. The first step in the script is to load the .mat files of interest; trucks GPS data and haul roads. Since the equipment used allowed for data analysis of only one truck at a time, in order to examine the relationship between two trucks at a given intersection two separate .mat files are loaded in conjunction. Each individual .mat file is used as a representative of individual trucks behaviour in the analysis.

The script uses the circle/polygon data in order to begin defining the regions surrounding an intersection. By incorporating the trucks path into the defined circles/polygons, analysis of the truck's behaviour through the intersection being studied can begin.

In order to differentiate the data in each section, the code script is structured to examine the times and distances applicable to the circle regions. For simplicities sake, analysis is always begun at the first point
found to enter the change zone and all data falling outside the circles/polygons is ignored. By adjusting the circle sizes and distances from the intersections, distance can be evaluated in conjunction with time.

5.8.5 Analysis Layout

The following steps are used to achieve the given results:

1. Data is sorted to appropriate intersections
2. For each intersection run that yielded a good reflection of route trajectory and engine behaviours are chosen.
3. Data has been run with truck 1 and truck 2 driving at various speeds. The speeds chosen are 8 (5), 16 (10), 24 (15), 32 (20), 40 (25), and 48 (30) km/h (mph). By controlling velocity, the impact of different speeds can be found.
4. Data has been analyzed for circle/polygon sizes at equal distances from the intersection.
5. Data has been gathered and sorted according to three priority systems:
   a. Truck 1 being loaded therefore having priority 1 and truck 2 being unloaded therefore having priority 2.
   b. Truck 2 being loaded therefore having priority 1 and truck 1 being unloaded therefore having priority 2.
   c. Assumes both trucks are either unloaded or loaded, therefore having equal priorities.
5.9 Intersection Paths

The following outlines the paths that are evaluated in each intersection:

5.9.1 Yellow Intersections

The majority of the interactions found in the analysis happened in this intersection. The most common paths taken for this intersection are from east to west because this is the access to the major shovel pits and dumps during the time of study. For this intersection paths are chosen that reflect the large variation in time spent in the intersection. This is done to examine the behaviour of trucks spending prolonged periods of time in intersections. Truck 1 traversed from west to east and truck 2 traversed from east to north.

Figure 32: Circle Outline of Yellow Intersection Paths
5.9.2 Blue Intersection

Since this intersection is fairly new, variation in paths are not available. The paths chosen for this intersection is the most commonly found interactions present at this intersection. Truck 1 traverses a path from west to south and truck 2 traversed a path from east to west.
Figure 34: Circle Outline of Blue Intersection Paths

Figure 35: Polygon Outline of Blue Intersection Paths
5.9.3 Red Intersection

This intersection is one of the most active intersections in the mine and has trucks travelling in all directions. In order to understand how different paths affect cycle times, two paths heading in the same direction are chosen for analysis. Truck 1 traverses a path from east to north and truck 2 traversed a path from south to north.

![Figure 36: Circle Outline of Red Intersection Paths](image)

Figure 36: Circle Outline of Red Intersection Paths
5.9.4 Green Intersection

The primary paths taken are from north to south. Since these paths would yield no interactions between the trucks, a path that utilizes the eastern part of the intersection is chosen since this is the primary access to the fuel bay. When mining activities are focused in the northern path of the pit several interactions are observed in this given part of the intersection. In order to gain a good understanding of this relationship truck 1 traversed a path from north to south while truck 2 traverses a path from south to west.
Figure 38: Circle Outline of Green Intersection Paths

Figure 39: Polygon Outline of Green Intersection Paths
5.10 Interaction Frequency

The frequency analysis is aimed to examine the number of interactions that take place in the intersection zone. The scenario evaluated is to have truck speed for one truck fixed and the truck speed of the second truck varied. The analysis was performed by fixing speed for the initial truck and examining the amount of interactions that are present when the second truck increased its speed from 8 (5) to 48 (30) km/h (mph) in increments of 8 (5) km/h (mph).

Table 10: Frequency of Interactions in Yellow Intersection

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Priority Truck 1</td>
<td>Priority Truck 2</td>
<td>Equal Priority</td>
</tr>
<tr>
<td>8 (5)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16 (10)</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>24 (15)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>32 (20)</td>
<td>3</td>
<td>2</td>
<td>2</td>
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<tr>
<td>40 (25)</td>
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<td>3</td>
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<td>48 (30)</td>
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<td>3</td>
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<tr>
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</tr>
</tbody>
</table>
### Table 11: Frequency of Interactions in Blue Intersection

<table>
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<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Priority Truck 1</td>
<td>Priority Truck 2</td>
<td>Equal Priority</td>
</tr>
<tr>
<td>8 (5)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16 (10)</td>
<td>1</td>
<td>1</td>
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<td>32 (20)</td>
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<td>40 (25)</td>
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<td>48 (30)</td>
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### Table 12: Frequency of Interactions in Red Intersection

<table>
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<th>Circle</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Priority Truck 2</td>
<td>Equal Priority</td>
</tr>
<tr>
<td>8 (5)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16 (10)</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>24 (15)</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>32 (20)</td>
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<tr>
<td>40 (25)</td>
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<td>48 (30)</td>
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<td>2</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
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<td><strong>10</strong></td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>
As can be seen from Tables 10-13, the number of interactions is relatively equal regardless of truck priorities. This is expected behavior because the code is structured to always give one truck the right of way by slowing down the second truck. Overall the variation in interactions across the varying speeds is consistent in all intersections. The lesser amount of interactions happened at lower speeds and an increased number are present as the truck speeds increase. The majority of interactions are present when the speeds of two trucks are found to be closer to each other. Finally, the variation between intersection paths and time trucks spend in the intersections is the primary reason for changes between the different numbers of interactions.

It must be noted that from observations gathered in the field it is found that certain interactions create confusion amongst truck operators resulting in both trucks slowing down or stopping. This is a very realistic occurrence in the mine. By varying the truck speeds greatly between the two trucks it is found that very few interactions took place regardless of the time spent in the intersection. It is observed that large deviations between truck speeds will create situations where interactions can be avoided.
By examining the interactions, polygons yield a decreased amount of interactions at nearly every intersection. The reason this occurs is because the paths the trucks take in the change zone is more consistent with polygons. Since polygons examine 200 m along the truck path changes in time spent in the zone are minimal since deviations from the path are decreased. However with circles, the path followed in the change zone can vary from each truck since the path is not considered. This can result in trucks travelling more than 200 m in the change zone to reach the intersection. Overall, this results in increased time in the change zone and overall increased interactions.

This analysis is performed to identify the conditions that will yield the highest probability of interactions. By implementing modifications to the cycles these interactions can be completely avoided creating much safer conditions around intersections.

5.11 Impact on Cycle Time and Velocity

Since conditions that cause interactions at intersections are observed at the mine site, the impact on cycle times must be examined. This analysis is performed by fixing the speed of the initial truck and then examining the additional time required to pass through the intersection as the other truck varied its speed from 5 mph to 30 mph in increments of 5 mph. The times are then averaged at each speed segment of the first truck to find an average change across all interactions at that given speed. Once this is achieved a standard deviation is evaluated across all speeds to understand how lower versus higher speeds impact time.
Table 14: Yellow Intersection Times Change (s) and Standard Deviations

<table>
<thead>
<tr>
<th>Time</th>
<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of Initial Truck km/h (mph)</td>
<td>Priority Truck 1</td>
<td>Priority Truck 2</td>
<td>Equal Priority</td>
</tr>
<tr>
<td>8 (5)</td>
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<tr>
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Table 15: Yellow Intersection Speed Change (mph) and Standard Deviation

<table>
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<th>Difference</th>
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<tbody>
<tr>
<td>Speed of Initial Truck km/h (mph)</td>
<td>Priority Truck 1</td>
<td>Priority Truck 2</td>
<td>Equal Priority</td>
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<td>St. Dev</td>
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Table 16: Blue Intersection Times (s) and Standard Deviations

<table>
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<th>Speed of Initial Truck km/h (mph)</th>
<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
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<tbody>
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<td>Priority Truck 1</td>
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<td></td>
</tr>
<tr>
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<tr>
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Table 17: Blue Intersection Speed Change (mph) and Standard Deviation

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<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
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<tbody>
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<td>Priority Truck 1</td>
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<td></td>
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<tr>
<td>Priority Truck 2</td>
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<tr>
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</table>

Table 18: Red Intersection Times Change (s) and Standard Deviations

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<th>Time</th>
<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of Initial Truck km/h (mph)</td>
<td>Priority Truck 1</td>
<td>Priority Truck 2</td>
<td>Equal Priority</td>
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<tr>
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<td>3.63</td>
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Table 19: Red Intersection Speed Change (mph) and Standard Deviation

<table>
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<th>Polygon</th>
<th>Circle</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of Initial Truck km/h (mph)</td>
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<td>Priority Truck 2</td>
<td>Equal Priority</td>
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<td>0.16</td>
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Table 20: Green Intersection Times Change (s) and Standard Deviations

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<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of Initial Truck km/h (mph)</td>
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<td>Priority Truck 2</td>
<td>Equal Priority</td>
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Table 21: Green Intersection Speed Change (mph) and Standard Deviation

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<th>Difference</th>
</tr>
</thead>
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<td>Equal Priority</td>
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<td>0.31</td>
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<td>1.01</td>
<td>0.95</td>
<td>0.73</td>
</tr>
</tbody>
</table>

By examining the cycle data from the four intersections, the first observation that can be made is that there are greater impacts on the time it takes a truck to traverse an intersection when they are at a lower speed. By examining the speed changes, it is found that as speed increases the change required to accommodate the higher priority truck increases. This shows that impacts to cycle times on slow moving truck are greater than faster moving trucks since the time required to accommodate the truck in the
intersection results in increased time in the change zone. In addition, slow moving trucks usually are travelling uphill or under load and impacts on mechanical wear and tear are amplified when changes to truck speed occur. Second, since the change in velocity increases with speed, the mechanical wear and tear on equipment increases. Overall a sensitive balance is required to limit mechanical wear and tear, but maintain good cycle time conditions.

Priority definitions have made certain distinctions from when two trucks of equal importance approach the same intersection. When both trucks are shown to have the same priority the truck closest to the intersection is given priority and the truck further away has its velocity modified to accommodate the first truck. By applying this approach the impact on cycle time is decreased because the change to velocity is smaller to allow the first truck to traverse the intersection. A similar finding can be found when examining changes in speed. Also, standard deviation between the different truck speeds is found to be generally lower when equal priority conditions are present. By having a smaller change in velocity the impact on fuel is decreased since trucks are not required to decelerate and reaccelerate to accommodate the change. As shown in previous relationships by comparing engine speed and fuel the largest saving to fuel can be achieved when steady state conditions are maintained.

When comparing polygons and circles data shows that smaller changes to time are observed by utilizing polygons. This is true since the deviations along the path is much smaller in comparison to circles where the road network is not defined and the distance travelled can vary depending on how the truck choses to travers the change zone. In addition, changes in velocity are smaller with polygons in comparison to circles. This is possible since the road network is defined with polygons. Also, mechanical stress on components is minimized since the load on the engine fluctuates less to accommodate the changes.
In Tables 14 to 21, the cells in green show the savings that can result when this technology is implemented compared to current practices when stop and go conditions occur (orange shows when implementing will not be beneficial). When examining the real life operating conditions of the mine, it is found that most truck interactions can result in an improvement in regards to average time savings when compared to stop and go traffic approaches. Furthermore the mechanical wear and tear from moving equipment having to decelerate and reaccelerate can result in avoidable damage to brakes, engines, transmissions and suspension systems.

5.11.1 Conclusion for Cycle Time and Change in Speed

Due to the variation of intersection layouts and truck paths each intersection impacts to cycle time and speed are shown. First, the red intersection had traffic flowing in one direction which, overall results in a lower variation in speed changes regardless of priority. The other three intersections are observed to have a greater deviation once priority is introduced due to the variation in time and distance one of the two trucks spent in the intersection zone. Secondly, low speed changes are observed to have the largest influence on time and interactions due to the vehicles low speed. In addition, high speed changes result in minimal time impacts but increased influence on change in speed leading to larger effects on mechanical wear and tear. This observation shows that applying this modification could be beneficial but an ideal operating range must be maintained to achieve a good balance between the two parameters. Measuring variables such as weight, rolling resistance and grade could be used as a next step for further expansion on the finding in this thesis. Overall it is recommended that implementing this simple modification can yield improvements regardless of truck speed and intersection layout.
Polygons have been shown to be a more effective method of intersection planning since the road network is defined. This results in decreased interactions, cycle time and change in speed impacts. Circles have increased variation when the road network meanders in the change zone. This results in trucks spending longer times in the change zone and impacting the lower priority truck. Circles would be most applicable around intersections that have straight paths. In the end, both circles and polygons can yield improvements over current mine practices.

**5.12 Impact of Circle Changes**

Previous results are achieved with fixed distances from the intersection. In order to understand how the size of the change zone impacts the results, four scenarios are run with the yellow intersection. Only polygons are analyzed since they yielded better results in comparison to circles. The relationships found in examining the yellow intersection are very similar to the results found when examined all the other intersections, but are scaled differently due to the layouts of each intersection. For simplicity only the results from the yellow intersection are presented in this thesis.

**5.12.1 Big Circle**

The big circle is used to examine the impact of doubling the change zone to 400 m from the entrance of the intersection.
Table 22: Yellow intersection big circle velocity

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>0.13</td>
<td>0.31</td>
<td>0.13</td>
</tr>
<tr>
<td>16 (10)</td>
<td>1.33</td>
<td>0.63</td>
<td>0.25</td>
</tr>
<tr>
<td>24 (15)</td>
<td>1.58</td>
<td>0.99</td>
<td>0.45</td>
</tr>
<tr>
<td>32 (20)</td>
<td>3.99</td>
<td>1.6</td>
<td>0.88</td>
</tr>
<tr>
<td>40 (25)</td>
<td>2.07</td>
<td>2.21</td>
<td>1.31</td>
</tr>
<tr>
<td>48 (30)</td>
<td>0.74</td>
<td>2.97</td>
<td>1.89</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.64</strong></td>
<td><strong>1.45</strong></td>
<td><strong>0.82</strong></td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td><strong>1.33</strong></td>
<td><strong>1.01</strong></td>
<td><strong>0.68</strong></td>
</tr>
</tbody>
</table>

Table 23: Time for Big Circle

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>5.19</td>
<td>10.73</td>
<td>3.34</td>
</tr>
<tr>
<td>16 (10)</td>
<td>10.01</td>
<td>5.37</td>
<td>1.67</td>
</tr>
<tr>
<td>24 (15)</td>
<td>5.87</td>
<td>3.84</td>
<td>1.58</td>
</tr>
<tr>
<td>32 (20)</td>
<td>7.78</td>
<td>3.81</td>
<td>1.96</td>
</tr>
<tr>
<td>40 (25)</td>
<td>3.04</td>
<td>3.36</td>
<td>1.88</td>
</tr>
<tr>
<td>48 (30)</td>
<td>0.89</td>
<td>3.19</td>
<td>1.95</td>
</tr>
</tbody>
</table>
5.12.2 Small Circle

The small circle is used to examine the impact of decreasing the change zone to 50 m from the entrance of the intersection.

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>15.6</td>
<td>2.3</td>
<td>0.72</td>
</tr>
<tr>
<td>16 (10)</td>
<td>13.7</td>
<td>11.53</td>
<td>2.88</td>
</tr>
<tr>
<td>24 (15)</td>
<td>11.93</td>
<td>15.76</td>
<td>6.23</td>
</tr>
<tr>
<td>32 (20)</td>
<td>10.35</td>
<td>15.15</td>
<td>16.03</td>
</tr>
<tr>
<td>40 (25)</td>
<td>8.77</td>
<td>14.57</td>
<td>11.3</td>
</tr>
<tr>
<td>48 (30)</td>
<td>7.41</td>
<td>13.99</td>
<td>12.52</td>
</tr>
<tr>
<td>Average</td>
<td><strong>11.29</strong></td>
<td><strong>12.21</strong></td>
<td><strong>8.28</strong></td>
</tr>
</tbody>
</table>

| Standard Deviation                | 3.07             | 5.07             | 5.96           |
Table 25: Time for small circle

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>30.69</td>
<td>24.28</td>
<td>4.49</td>
</tr>
<tr>
<td>16 (10)</td>
<td>12.53</td>
<td>29.71</td>
<td>8.27</td>
</tr>
<tr>
<td>24 (15)</td>
<td>6.76</td>
<td>22.79</td>
<td>9.22</td>
</tr>
<tr>
<td>32 (20)</td>
<td>4.24</td>
<td>16.14</td>
<td>7.77</td>
</tr>
<tr>
<td>40 (25)</td>
<td>2.72</td>
<td>12.15</td>
<td>7.48</td>
</tr>
<tr>
<td>48 (30)</td>
<td>1.85</td>
<td>9.49</td>
<td>7.08</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>9.80</strong></td>
<td><strong>19.09</strong></td>
<td><strong>7.39</strong></td>
</tr>
<tr>
<td><strong>St. Dev</strong></td>
<td><strong>10.93</strong></td>
<td><strong>7.78</strong></td>
<td><strong>1.60</strong></td>
</tr>
</tbody>
</table>

5.12.3 East Circle

The east circle is used to examine the impact of having the truck coming from the east at 300 m from the intersection entrance and the second truck coming from the south at 100 m from the intersection.

Table 26: Yellow intersection east circle velocity

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>1.42</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 27: Time for east circle

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>7.28</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16 (10)</td>
<td>5.62</td>
<td>6.84</td>
<td>2.05</td>
</tr>
<tr>
<td>24 (15)</td>
<td>0.73</td>
<td>1.94</td>
<td>1.94</td>
</tr>
<tr>
<td>32 (20)</td>
<td>0</td>
<td>3.42</td>
<td>1.03</td>
</tr>
<tr>
<td>40 (25)</td>
<td>0</td>
<td>5.21</td>
<td>2.00</td>
</tr>
<tr>
<td>48 (30)</td>
<td>0</td>
<td>3.25</td>
<td>1.65</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2.27</strong></td>
<td><strong>3.44</strong></td>
<td><strong>1.45</strong></td>
</tr>
<tr>
<td><strong>St. Dev</strong></td>
<td><strong>3.29</strong></td>
<td><strong>2.40</strong></td>
<td><strong>0.80</strong></td>
</tr>
</tbody>
</table>
5.12.4 South Circle

The south circle is used to examine the impact of having the truck coming from the south at 300 m from the intersection entrance and the second truck coming from the east at 100 m from the intersection.

Table 28: Yellow intersection south circle velocity

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>0</td>
<td>4.84</td>
<td>2.5</td>
</tr>
<tr>
<td>16 (10)</td>
<td>0.47</td>
<td>7.91</td>
<td>7.9</td>
</tr>
<tr>
<td>24 (15)</td>
<td>1.41</td>
<td>4.52</td>
<td>4.51</td>
</tr>
<tr>
<td>32 (20)</td>
<td>2.82</td>
<td>2.06</td>
<td>2.06</td>
</tr>
<tr>
<td>40 (25)</td>
<td>4.78</td>
<td>0.56</td>
<td>0.56</td>
</tr>
<tr>
<td>48 (30)</td>
<td>6.74</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td><strong>2.70</strong></td>
<td><strong>3.32</strong></td>
<td><strong>2.92</strong></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td><strong>2.63</strong></td>
<td><strong>3.00</strong></td>
<td><strong>2.91</strong></td>
</tr>
</tbody>
</table>
### Table 29: Time for south circle

<table>
<thead>
<tr>
<th>Speed of Initial Truck km/h (mph)</th>
<th>Priority Truck 1</th>
<th>Priority Truck 2</th>
<th>Equal Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>0</td>
<td>28.55</td>
<td>17.88</td>
</tr>
<tr>
<td>16 (10)</td>
<td>5.92</td>
<td>15.28</td>
<td>15.42</td>
</tr>
<tr>
<td>24 (15)</td>
<td>7.14</td>
<td>5.3</td>
<td>5.30</td>
</tr>
<tr>
<td>32 (20)</td>
<td>7.36</td>
<td>1.69</td>
<td>1.69</td>
</tr>
<tr>
<td>40 (25)</td>
<td>7.64</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>48 (30)</td>
<td>6.91</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>5.83</strong></td>
<td><strong>8.53</strong></td>
<td><strong>6.77</strong></td>
</tr>
<tr>
<td><strong>St. Dev</strong></td>
<td><strong>2.92</strong></td>
<td><strong>11.34</strong></td>
<td><strong>7.92</strong></td>
</tr>
</tbody>
</table>

By adjusting the size several variations in time and speed are observed between the polygons. First, the big polygon requires a very low change in speed from the lower priority truck in order to accommodate the higher priority truck. This results in very low changes in speed. The standard deviation reflects very small changes between the different travel speeds of the two trucks. The small polygon does not allow the flexibility of distance in order to accommodate speed changes and therefore changes in speed and time are much larger to accommodate the second truck. This polygon is a very close representation of the current conditions where trucks are forced to slow down or stop at intersections to accommodate the second truck. Although the large polygon does have the smallest impact on speed, it does encompass a very large region of the road network. This could lead to issues in and data overload and acquisition if applied to a
real life scenario. However, the small circle would be very easy to implement and manage but would yield very large impacts on fuel consumption and potential mechanical degradation due to the large change in speed required to accommodate the changes.

By adjusting the distance of the trucks from the intersection the amount of time in the intersection zone has a greater impact on the changes in speed and cycle time. Since certain trucks spend a larger amount of time in the intersection, the amount of interactions between the trucks is variable because speeds required to create an interaction must be within a specific range.

### 5.13 Dynamic Case

To understand the impact of applying this technology the dynamic case is examined. The yellow intersection is chosen for analysis. Initial vehicle speeds are chosen based on field observations and accelerometer data in an attempt to replicate real world conditions. The algorithm is run every second to examine impacts on the trucks.
When the initial interaction is detected the lower priority truck is required to slow down to accommodate the first truck. In this specific case due to the proximity to the intersection a larger change in speed is required by the second truck. As the second truck lowers its speed closer to the suggested speed and the algorithm is run the variation between the current speed and the suggested speed for the lower priority truck decreases. By maintaining a speed closer to the suggested speed, as the higher priority trucks speed varies, the changes required by the second truck to accommodate the first are minimal or non-existent.
5.13.2 Priority Truck 2

Table 31: Dynamic Case Equal Priority

In the case where both trucks are equal priority the truck further from the intersection changes its speed to accommodate the other truck since it will enter in intersection first. In the scenario presented the first truck slows down greatly which consequently, under the conditions analyzed, allows the second truck to reach the intersection first, switching the priority and forcing the first truck to slow down further. Overall since truck 2’s route through the intersection is longer, the change in speed is greater for truck 1 in order to accommodate the second truck. Once again changes in speed decrease as the lower priority truck maintains a speed closer to the suggested speed despite speed fluctuations with the higher priority truck.

Overall as trucks are presented the new suggested speeds, by attempting to maintain the new speed changes in speed by the higher priority truck are less influential to the lower priority truck. Depending on
the proximity to the intersection as trucks get closer the change in speed required increases to accommodate the higher priority truck but can be avoided if lower priorities trucks attempt to adjust speed well in advance. Overall by adapting this technology, trucks changes in speed are decreased gradually to ensure trucks are not stopping at intersection or decelerating from much larger speeds to accommodate higher priority trucks.

The dynamic model is presented to provide direction for improvement which could be implemented by expanding on the finding in this thesis. Instead of using the static algorithm as presented, a real time algorithm can be created which will update at pre set time intervals. Since savings have been shown by tracking trucks through intersections, the real time algorithm can be used to considered multiple input variables (trucks) and examine how various real world conditions impact fuel consumption around intersections. Overall this is outside the scope of this thesis.

5.14 Impact on Operating Costs

5.14.1 Fuel Costs

The majority of interactions result in modifications to unloaded trucks and the savings are found when loaded trucks pass through the intersections unaffected. It must be understood that loaded trucks can interact at intersections, but these interactions are rare since trucks in most cases are hauling in the same direction. For the fleet, unloaded and loaded interactions fuel savings between $95,864 USD/year and $223,052 USD/year respectively for downhill and unloaded and loaded fuel savings between $255,740 USD/year and $200,832 USD/year respectively for uphill runs. Although the savings do appear to be at
odds with the current traffic hierarchy, it must be understood that the data available for interactions involving a loaded truck to slow down were rare compared to unloaded trucks and as a result the numbers presented are a reflections of the data compiled during the testing period. Savings can be quantified in greater detail with a larger data set and are recommended for future analysis pertaining to this thesis. Since no equipment is available for measuring mechanical wear and tear, there is no quantifiable method to measure the amount of cost savings. However, additional work performed by the engine in order to acceleration and deceleration could potentially lead to avoidable maintenance costs and increased equipment life. Overall cost savings associated with mechanical degradations and are outside the scope of this thesis.

Table 32: Fuel Cost Saving with Modification

<table>
<thead>
<tr>
<th>Savings ($/year)</th>
<th>Unloaded</th>
<th>Loaded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>95,864</td>
<td>200,832</td>
</tr>
<tr>
<td>Max</td>
<td>255,740</td>
<td>223,052</td>
</tr>
</tbody>
</table>

5.15 Ideal Operating Range

The final part of the analysis involves examining the optimal operating range for trucks regardless of intersection layout. At low speeds it is observed that trucks have the greatest impact on cycle time, but as speed is increased the impact to cycle time decreased. At low speeds minimal changes to truck speed is required to yield to the higher priority truck in the intersection, but at higher speeds a much larger change
takes place resulting in potentially increases mechanical wear and tear. With this understanding of the relationship, cycle times are examined in conjunction with changes in speed across all the tested velocities to determine if a range can be determined. This range isolates BSFC to find the potential ideal speed for trucks to travel throughout the mine in order to minimize impact to cycle time and mechanical wear and tear on equipment.

Table 33: Ideal Speed (mph) between Cycle Time and Change in Speed

<table>
<thead>
<tr>
<th></th>
<th>Yellow</th>
<th></th>
<th>Blue</th>
<th></th>
<th>Red</th>
<th></th>
<th>Green</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Circle</td>
<td>Polygon</td>
<td>Circle</td>
<td>Polygon</td>
<td>Circle</td>
<td>Polygon</td>
<td>Circle</td>
<td>Polygon</td>
</tr>
<tr>
<td>13.25</td>
<td>15.5</td>
<td></td>
<td>14.00</td>
<td>19.25</td>
<td>12.5</td>
<td>17.00</td>
<td>13.00</td>
<td>20.00</td>
</tr>
<tr>
<td>18.25</td>
<td>20.00</td>
<td></td>
<td>14.50</td>
<td>16.75</td>
<td>22.00</td>
<td>19.50</td>
<td>13.50</td>
<td>17.50</td>
</tr>
<tr>
<td>19.00</td>
<td>19.50</td>
<td></td>
<td>15.00</td>
<td>12.50</td>
<td>21.00</td>
<td>19.25</td>
<td>12.50</td>
<td>16.50</td>
</tr>
</tbody>
</table>

Table 33 presents the intersect points for cycle time and change in speed (Figures can be found in Appendix B). From the data gathered it is found that when trucks travel between 19 (12) and 32 (20) km/h (mph), a balanced impact between cycle time and change in speed is observed. This range also yields the greatest BSFC for the trucks and is the ideal range to maintain truck speed during steady state conditions, when no changes to the truck speed is required. The red intersection is observed to have a very close relationship between the intersection points since the directional flow of traffic is identical resulting in the least amount of change to accommodate the higher priority truck. Increased impact on the ideal range is caused by one truck spending a larger portion of the time in the intersections. Furthermore, by having a good understanding of where the largest impacts on time or speed are located, these parameters can be used as planning parameters. Trucks can have speeds adjusted in order to either maintain good cycle times or minimize potential mechanical degradation due to changes in speed. A quantified analysis of
wear and tear should be performed in order to quantify the benefits of the parameter. Overall to achieve a balance between the two parameters the follow range of speed should be maintained throughout the mine.

5.16 Implementing Intersection Improvements

Various methods of application exist for these technological improvements such as implementing beacon technology around the site to identify regions of interest. Active beacon technology, as is used in the marine and aero industry can be implemented because of its high reliability, accurate positioning information and high sampling rates [72]. In addition, research with advancements in pseudolites (transmitters) has shown flexibility with integration of CDGPS navigation systems for increased reliability and real-time data collection [73]. Although beacons are available in laser, infrared and ultrasonic transducers [72] utilizing a simple triangulation based method is sufficient for this application.

Implementation of this technology does pose some challenges in a mining environment. First mines are very dynamic and the layouts change often. This makes implementing stationary beacons difficult since they will have to be moved often in order to accommodate the mine progress. Second, mining environments are harsh operating environments because activities often take place in isolated parts of the world. Equipment at mines must be very robust if they are to operate in this environment. Beacons and transmitters need to be placed areas that protect them from mining activities if this type of technology is going to be implemented on site. Since this technology would be new to the site, installation costs would be high because all of the equipment would need to be acquired, installed and calibrated at one time. Furthermore, these components are fragile, and costs of repairs and replacements would add to operating costs. Finally because transmitters require good visibility to beacons this might be hard to achieve since
the mining environment has many berms and walls which need to be considered when determining clear paths of trajectory.

An alternative application method is directly implemented into the current dispatch system. Since the dispatch system has all the roads and intersections within the mine updated, by taking the algorithm presented in this thesis the information can be integrated directly into the dispatch algorithm. Furthermore Modular uses waypoint beacons that could be utilized for application of this technology. This would enable the easy definition of intersections and can be changed easily to accommodate the dynamic environment of the mine. Since the dispatcher can monitor mine activities in real time, this improvement can be directly integrated into daily practices. Finally a simple output to the trucks on board dispatch computers can show the drivers new suggested travel speed. The frequency of outputs to the drivers can be in conjunction with the mines current refresh rate in order to increase intersection efficiencies.
Chapter 6

Summary and Conclusions

The primary objective of this thesis is to determine which parts of the haulage cycle present opportunities for fuel savings. The haulage cycle was examined to determine the potential for how inefficiencies in the cycle could be fixed and to result in reduced fuel consumption.

6.1 Dumping

Over the course of this study, savings were found in the dumping portion of the haulage cycle, which accounts for 3.5% of the overall cycle. First, it must be noted that as fuel prices are increased, the amount of savings generated by changing the operating engine speed at dumping become greater. Second, the literature review that inspired this work was validated, showing that savings can be achieved in trucks on a larger scale. Lastly, it is shown that time is a factor and is impacted slightly as engine speed is decreased, unlike the conclusion of the literature review.

By changing the engine speed, fuel savings can be achieved. It must be understood that by lowering the engine speed, six seconds are added to every dump. Overall, this results in approximately 94 seconds lost on the overall 12-hour period. Inefficiencies are present in the overall hauling cycle, and small changes in time become negligible when compared with the time lost as a result of inefficiencies in other parts of the haulage cycle. Queuing, for example, results in time lost and the additional time spent dumping can potentially be regained during this portion of the haulage cycle. Since, the entire haulage cycle is
interconnected, modifying one part of the haulage cycle might help to improve other parts of the cycle. Overall, by modifying such a small component of the haulage cycle a minimal saving of nearly $6,500 USD saving per year per truck was estimated, which amounts to 8,328 liters (2,200 gallons) of fuel conserved.

6.2 Intersections

The largest part of the haulage cycle occurs when trucks are moving across the mine network, either empty or loaded (78.9% of haulage cycle). It is shown that implementation of the algorithm presented in this thesis could reduce interactions at intersections, potentially decreasing wear and tear on equipment and increasing fuel efficiencies. This could help to create safer, cost effective and more fuel efficient intersections. Furthermore the development of a dynamic speed allocation algorithm could be used to provide direction for future work and help understand in further detail how real world conditions impact intersections.

6.3 Environmental Savings

Apart from savings in fuel consumption and decreases in operating costs, environmental benefits can be achieved by implementing these technologies. Every gallon of diesel has been found to release 10,180 g of CO₂ into the environment [74]. For dumping, it is found that by implementing these small modifications, savings of 22,000 kg of CO₂ per year are achievable. Avoidable stop and go interactions can account for up to 281,419 (74,351) to 253,383 (66,944) liters (gallons) of additional fuel burned per
year for loaded fleet and between 120,950 (31,955) to 322,660 (85,247) liters (gallons) for unloaded fleet. The environmental impact translates to large amounts of avoidable CO₂ released into the environment each year.

Table 34: CO₂ released each year due to avoidable intersection interactions

<table>
<thead>
<tr>
<th>Additional CO₂ released (kg of CO₂)</th>
<th>Unloaded</th>
<th>Loaded</th>
</tr>
</thead>
<tbody>
<tr>
<td>min</td>
<td>325,299</td>
<td>681,489</td>
</tr>
<tr>
<td>max</td>
<td>867,813</td>
<td>756,890</td>
</tr>
</tbody>
</table>

### 6.4 Summary of Contributions

This thesis makes the following main contributions and conclusions

- Data was collected on site at the Barrick Goldstrike operation. These data were acquired by equipping multiple haul trucks with sensors and logging data over an extended period of time, during normal mine operations.

- A dumping analysis was performed to see what effect changing the speed of dumping would have on fuel efficiency. Minimal savings from modifying dumping practices can be achieved, amounting to estimate savings of about $6,500 USD in fuel costs, 8,000 liters of fuel conserved and 22,000 kg of CO₂ not released into the environment per truck per year. However, the additional time required to save on fuel may not be worth the potential cycle time it would take to achieve these savings.
• A technique for altering the behaviour of trucks near intersections was proposed. Altering the behaviour of trucks approaching intersections could result in savings of about 95,000 to 250,000 in fuel costs, 30,000 to 85,000 liters of fuel conserved and 325,000 to 867,813kg CO\textsubscript{2} not released into the environment for the fleet. However, these savings may not be sufficient to warrant possible changes to productivity.

• A semi-static approach dynamically changing vehicle speeds near intersections was presented, to show how application of a real time algorithm might expand on the findings of this thesis. Future work is required to develop a fully dynamic algorithm for coordinating multiple vehicles at intersections to optimize fuel consumption.

• Ideal operating truck speeds between 19-32 km/h were found to have the smallest impact on change in speed and cycle times.

6.5 Recommendations

6.5.1 Dumping Recommendations

In order to properly implement this study, several factors must be considered. First, factors such as material weight, density and angle of dumping should be examined and not averaged as was done in this study. This will allow for a more accurate reflection of the fuel savings when dumping. Second, a time relocation study should be done to determine if additional time for dumping could be recovered when queuing. This could result in relocation of time from dumping to queuing in order to save costs. Finally, implementation of equipment such as engine speed limiters should be considered and cost benefit analysis
performed. Implementation of the dumping modification could result in savings in any operating mining environment but would seem to be greatly beneficial in younger operations where the savings can be spread over more years. Overall, small changes such as these could result in fuel cost savings and lower haul truck emissions without complicated implementations.

6.5.2 Intersection Recommendations

To properly implement the intersection improvements further research must be conducted to build upon the findings presented in this thesis. First, due to time constraints and equipment availability, data is gathered from one truck as it traversed throughout the mine. The amount of data gathered could be increased with the use of multiple trucks, overall resulting in a greater diversity in findings. Secondly, due to the ability to gather data from one truck, intersection interactions are created through the algorithm to understand truck behaviours at intersections. Although all the data is from real life results, the findings might yield more realistic behaviours if interactions are observed and captured in field versus application through algorithms. Third, applying a dynamic algorithm to data gathered from multiple trucks would help further illustrate how real world conditions impact intersections. Finally, in addition to heavy hauler interactions further interactions have been observed to occur with smaller pieces of equipment. In many cases the traffic hierarchy is obeyed but certain conditions cause heavy haulers to yield to smaller traffic. As a next step, the data can be expanded to include smaller traffic by applying the same principals. Since smaller equipment is lower on the traffic hierarchy it would always yield to heavy haulers and application would be a good tool for traffic management across the pit to ensure minimal equipment interactions.
Several factors are not considered in this thesis that could change the amount of savings found by this research. Parameters such as rolling resistance, weight, engine efficiencies, and weather can impact the truck’s behaviour around the mine. By factoring these parameters into the findings from this thesis, more accurate savings in regards to fuel efficiency could be achieved. One factor that could play a key role in vehicle behaviour around intersections is grade. Due to deficiencies in the present data, grade is a difficult factor to consider in this analysis. By having smaller grades around intersections, trucks can accelerate and decelerate easier in order to accommodate any changes in the intersections. As a next step, grade should be considered to evaluate its impacts on intersections.

Finally, the results are applicable not only to the Goldstrike Mine but any mining environment that has intersection inefficiency. As the circles/polygons can be modified for any intersection, the analysis can be conducted to examine what savings can be achieved with its application.

6.6 Closing Remarks

Since open pit mining creates a very dynamic environment, interactions between haulage equipment is a reoccurring event. Dispatching systems attempt to manage an entire operation with several haul trucks and shovels but with large operations, especially mines such a Goldstrike, where several input variables are present, imperfections in the management system arise. Although many studies have been done in the automotive industry which attempt to improve imperfections in intersection management, fewer studies have been conducted with a large scale mining operations. Furthermore, dumping components of the haulage cycle have been conducted in similar fashions in the industry for a long time and very little work pertaining to its improvement has been conducted with effective evidence of operating costs savings. The
Data gathered in this study can be used to potential help develop improvement in the mining industry in automation implication, road network definition and planning, dispatch system improvements and advancements, minimizing queuing for unloaded trucks and safety improvements for open pit mining operations. As the mining industry continues to strive in developing efficient mining operations with increased safety and decreased environmental impacts many opportunities presented in this thesis can help create improvements.
Bibliography


[71] Ramin Shamshiri, *Distance between GPS points*, Matlab Central, 2011.
## Appendix A

### Table 35: Operating Parameters [40]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average grade (oz/ton)</td>
<td>0.12 (0.035 to 0.8)</td>
</tr>
<tr>
<td>Truck Fleet</td>
<td>36</td>
</tr>
<tr>
<td>Total trucks used for testing</td>
<td>3</td>
</tr>
<tr>
<td>Average tons in loaded truck (tonnes)</td>
<td>268</td>
</tr>
<tr>
<td>Shift length (hrs)</td>
<td>12</td>
</tr>
<tr>
<td>Average operating cost ($/hr)</td>
<td>335</td>
</tr>
<tr>
<td>Cost/gallon ($/gal)</td>
<td>3</td>
</tr>
<tr>
<td>Total Runs Analyzed</td>
<td>275</td>
</tr>
<tr>
<td>Average number of cycles</td>
<td>15.7</td>
</tr>
</tbody>
</table>
Table 36: Parameters of Dumping Process

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full throttle engine speed (RPM)</td>
<td>2000</td>
</tr>
<tr>
<td>Average engine speed (RPM)</td>
<td>1564</td>
</tr>
<tr>
<td>Time to dump at full throttle (s)</td>
<td>26</td>
</tr>
<tr>
<td>Time to dump at average engine speed (s)</td>
<td>32</td>
</tr>
</tbody>
</table>
Table 37: Cycle Run Torque Variation
Appendix B

Figure 40: Total Runs Unloaded

Figure 41: Total Runs Loaded
Figure 42: Ideal Operating Range Yellow Intersection Polygon
Figure 43: Ideal Operating Range Yellow Intersection Circle

Figure 44: Ideal Operating Range Blue Intersection Polygon
Figure 45: Ideal Operating Range Blue Intersection Circle

Figure 46: Ideal Operating Range Red Intersection Polygon
Figure 47: Ideal Operating Range Red Intersection Circle

Figure 48: Ideal Operating Range Green Intersection Polygon
Figure 49: Ideal Operating Range Green Intersection Circle

**Figure and Graph Clarification**

Figure 10

Power calculated by multiplying torque (Nm) which was recorded from the ECM system by the angular velocity (rad/s). To calculate angular velocity engine speed (RPM) which is recorded from the truck ECM is converted to rotations per second then multiplied by $2\pi$ to get rad/s. Fuel Consumed is recorded from the ECM system and converted to g/s.

**Table 2**

Calculated by examining the new fuel consumption (gal./hr) based on changing the dumping time from 26 seconds to 32 seconds. Once done fuel consumption is determined for gal/s and then the 6 second difference is used to determine the addition saving in regards to gallons from switching the operating range. This is then multiplied by the fuel prices to determined $/dump saved.

**Table10-13**

Examine all the interactions which occur across the various speeds for both trucks. For the initial trucks speed, based on the priority of the trucks, the amount of interactions are recorded. The difference between circle and polygon is shown for comparison.
Table 14-29
Examine all the time and velocity changes which occur across the various speeds for both trucks. For the initial trucks speed, based on the priority of the trucks, the amount of changes pertaining to those criteria are recorded and averaged. The difference between circle and polygon is shown for comparison. Green defines time savings in regards to current practices while orange presents conditions where a time loss occurs.

Table 32
Displays the maximum and minimum fuel savings recorded through the document in regards to modifying intersection practices to accommodate the algorithm presented.

Table 33
Examines graphs 42-49 and displays the intersection points where trucks are likely to see a balance between required changes in speed and the smallest impact on time.

Table 34
Presents the total amount of addition of CO₂ burned based on total gallons of diesel fuel burned by comparing current practices to the potential savings from apply the modifications presented in this document.

Figure 42-49
Examine the speed and times recorded in tables 14-21 and graphs then versus the speed of the initial truck. This is done for both polygons and circles to determine the intersection points between time and speed in order to determine the point at which trucks are likely to see a balance between required changes in speed due to interactions and the smallest impact on time.
Appendix C

Combinedmap

% combinedmap.m - Used for plotting the mine network

% User loads the appropriate .mat files for desired section
% of mine. Files are combined and plotted for visual reference.

clear all;

% load .mat files that are relevant to mine network

hold all

load('truck03.mat');
load('truck04.mat');
load('truck05.mat');
load('truck06.mat');
load('truck07.mat');

% Combines into x and y data for easy plotting

x = [ G_long03; G_long04; G_long05; G_long06; G_long07];
y = [G_lat03; G_lat04; G_lat05; G_lat06; G_lat07];

% Plots the mine network

plot(x,y,'g-');
axis equal;

title('Mine Layout')
xlabel('Longitude')
ylabel('Latitude')

Circles
% Circles.m - Used to Define Circles around intersections

% All data analysis will be conducted within the circles. User is given %option to manually choose or input coordinates for the center of the %circle. User has option to create several circles. Once complete %naming convention is used to store circles for use in later parts of %analysis. Circles are used in the driver_code_truck (circle) main %script

close all;
clear all;

nsp = 1; % defines the one point which will be used for the center of the intersection

% Use combinedmap.m to load in mine network. Allows used to have visual %reference while choosing circle location.

f = fullfile('C:', 'Users', 'combinedmap.m');
run(f);
disp('Chose the appropriate intersection of interest for evaluation: [enter to close]');
disp('');
disp('Select an intersection of interest and define the center of the circle');

for i = 1 : 2 %input number of nodes
disp(' ');

% User is given the option to manually input the center of the
% intersection or to choose a point based on the map

% Manual select option

man = input('Enter (m) for manual point definition or enter (p) for point selection: ', 's');

if man == 'm';
    xc = input('please give longitude coordinate of interest:');
    yc = input('Please give latitude coordinate of interest:');

% Point select option

elseif man == 'p';
    disp('Zoom to the desired intersection and press SPACEBAR to define the circle:');
    zoom on;
    waitfor(gcf,'CurrentCharacter');
    [xc,yc] = ginput;
else
    nsplits = i;
    break
end

% User has flexibility to define the circle radius in meters

disp(' * * * * *Define Circle Radius* * * * *');
radius = input('Radius of the circle in (m):');
r = radius*0.00000628;
N = 256;
theta = (0:N)*2*pi/N;
xc = r*cos(theta) + xc;
yc = r*sin(theta) + yc;
patch(xc, yc, 'y');

% Naming convention for drawn circle

str = sprintf('Give circle %d a name. (No spaces)', i, 1);
disp(str);

% Labeling option

splitname(i, 1) = {input('Name: ', 's')};
pause(1);

text(x(1), y(1), splitname(i, 1));
z = [x' y'];

% Separate variable definition. Allows user to draw additions circle(s) %as needed

str1 = ['circ_' num2str(i) '=' z];
eval(str1);
leave = input('
Continue? Y/N [Y]: ', 's');
if isempty(leave) || leave == 'Y' || leave == 'y'
else
nsplits = i;
break
end
% reset zoom

zoom out;
end

reply = input('Are the circles you defined satisfactory? Y/N [Y]: ', 's');
if isempty(reply) || reply == 'y' || reply == 'Y'
disp(' ');

% Allows the naming of the new defined circle(s)

filename = input('Describe the circle (ex. yellow, red, green, blue, etc.): ', 's');
foldername = [datestr(now,1), ',', filename, '_circles'];
filename = [filename, '_circles'];
timestamp = datestr(now);

% Used to define path to where file will be stored

mkdir('C:\Users', filename);
runfolder = fullfile('C:', 'Users', filename);
f = fullfile(runfolder, filename);
save(f, 'circ_*', '*split*', 'timestamp', 'runfolder');
disp(' ');
disp4 = sprintf('circle saved to %s.mat.', filename);
disp(disp4)
return;

% If user replies ‘N’, the program is restarted- useful for mistake

elseif reply == 'N' || 'n'
disp('Try again!');
disp(' '); disp(' '); CIRCLES; end

Polygons

% POLYGONS.m - Used to define polygons

% All data analysis will be conducted within polygons
% User is given option to manually choose the layout of the polygon. %User has option to create several polygons. Once complete naming %convention is used to store polygons for use in later parts of %analysis. Polygons are used in the driver_code_truck (polygon) main %script

close all;
clear all;

% Enter desired number of points for the polygon

nsp = 4;

f = fullfile('C:', 'Users', 'combinedmap.m'); run(f);
disp('Click on vertices to define desired polygon: [enter to close]'); disp(' '); disp(' ');
% allow zooming before polygon definition for more accurate polygon
% boundary definition
disp('');
disp('Zoom to desired area of interest, press SPACEBAR to begin polygon definition:');
zoom on;
waitfor(gcf, 'CurrentCharacter');

[x,y] = ginput;
patch(x,y,'y');

% allow user to label each polygon
splitname(i,1) = {input('Name: ', 's')};
pause(1);

text(x(1), y(1), splitname(i,1));
z = [x y];

% Separate variable definition. Allows user to draw additions %polygon(s) as needed

str1 = ['poly_' num2str(i) '=' z];
eval(str1);
leave = input('Continue? Y/N [Y]: ', 's');
if isempty(leave) || leave == 'Y' || leave == 'y'
  else
    nsplits = i;
    break
  end

% reset zoom
zoom out;
end
reply = input('Are you satisfied with your exclusion zones? Y/N [Y]: ', 's');
if isempty(reply) || reply == 'y' || reply == 'Y'
disp(' ');

% Allows the naming of the new defined polygon(s)
filename = input('Describe the polygon (i.e. Yellow, Blue, Red, Green etc.): ', 's');
foldername = [datestr(now,1), ', ',filename, ' polygons'];
filename = [filename, '_polygons'];
timestamp = datestr(now);

% Used to define path to where file will be stored
mkdir('C:\Users', filename);
runfolder = fullfile('C:\', 'Users', filename);
f = fullfile(runfolder, filename);
save(f, 'poly_*', '*split*', 'timestamp', 'runfolder');
disp(' ');
disp(' ');
disp4 = sprintf('polygon data saved to %s.mat.', filename);
disp(disp4)
return;

% If user replies ‘N’, the program is restarted- useful for mistake
elseif reply == 'N' || 'n'
disp('Try again!');
disp(' ');
return;
DistGPS

%DistGPS.m - Converts distance between latitude and longitude points into meters and feet.
%Loads pre-defined point from main script (driver_code_truck). Loaded points are converted and used for future calculations in tracktruck.

function distance_m = DistGPS( longy, laty)
clc;
format long       % Switch to long format decimal display

% Gets number of data points and store in rows

[rows,cols]=size(laty);

for IN3 =1;

% Initialize vectors and set all cells to zeros

angle1 = zeros(rows,1);
angle2 = zeros(rows,1);
r1 = zeros(rows,1);
r2 = zeros(rows,1);
xy1= zeros(rows,1);
xy2= zeros(rows,1);
xy3= zeros(rows,1);
xy4= zeros(rows,1);
X= zeros(rows,1);
Y= zeros(rows,1);
distance_m=zeros(rows,1);
distance_ft=zeros(rows,1);

% Constant definition

maj_const=6378137;   %Major axis constant
min_const=6356752.3142;  %Minor axis constant
h=334.9;   %Elevation

% computes for all points in given range

for i=1:rows
    if i+1 <= rows

        % True angle determination (atan=ArcTan)
        angle1(i,1)=(atan((min_const^2)/(maj_const^2)*tan(laty(i,1)*pi()/180)))*180/pi();
        angle2(i,1)=(atan((min_const^2)/(maj_const^2)*tan(laty(i+1,1)*pi()/180)))*180/pi();

        % Radius calculation for the two points
        r1(i,1)=(1/((cos(angle1(i,1)*pi()/180))^2/maj_const^2+(sin(angle1(i,1)*pi()/180))^2/min_const^2))^0.5+h;
        r2(i,1)=(1/((cos(angle2(i,1)*pi()/180))^2/maj_const^2+(sin(angle2(i,1)*pi()/180))^2/min_const^2))^0.5+h;

        % X-Y earth coordinates
        xy1(i,1)=r1(i,1)*cos(angle1(i,1)*pi()/180);
        xy2(i,1)=r2(i,1)*cos(angle2(i,1)*pi()/180);
        xy3(i,1)=r1(i,1)*sin(angle1(i,1)*pi()/180);
xy4(i,1)=r2(i,1)*sin(angle2(i,1)*pi()/180);

X(i,1)=((xy1(i,1)-xy2(i,1))^2+(xy3(i,1)-xy4(i,1))^2)^0.5;  % X coordinate
Y(i,1)=2*pi()*(((xy1(i,1)+xy2(i,1))/2))/360)*((longy(i,1)-(longy(i+1,1))));  % Y coordinate

format short   % Switch to short format

% shows distance in units of interest

% Distance Meter
    distance_m(i,1)=((X(i,1))^2+(Y(i,1))^2)^0.5;
% Distance feet
    distance_ft(i,1)= distance_m(i,1)*3.28084;
end
end
end

% Displays distance in meters or feet based on user requirements

display('.........Distance (m).........');
distance_m;
%display('.........Distance (ft)...........')
%distance_ft

tracktruck1

%tracktruck1.m - Used to determine distance, time and velocity of %trucks entering intersection zone as defined by circle/polygon(s).
%Loads converted measurements from DistGPS and determined total distances for change and intersection zones. Once defined time and velocity are calculated and used in main script (driver_code_truck). This is repeated for both truck involved.

function [dist, dist2, time1, time2, totaldist, totaltime, velocity, dist02, dist202, time102, time202, totaldist02, totaltime02, velocity2] = tracktruck1(lon, lat, lon2, lat2, velmph, longy, laty, longy2, laty2, velmph2)

% Run latitude and longitude points of interest in DistGPS to determine total distance traversed for first truck to the intersection

distance_m = DistGPS(lon, lat);

% finds the sum of total distance

dist = sum(distance_m);

% converts inputted velocity from mph to m/s

velocity = velmph/2.23694;

% computes time based on give inputs

time1 = dist/velocity;

% Run latitude and longitude points of interest in DistGPS to determine total distance traversed for first truck through the intersection

distance_m1 = DistGPS(lon2, lat2);

% finds the sum of total distance
dist2 = sum(distance_m1);

% computes time based on give inputs

time2 = dist2/velocity;

% defines total time and distance from start point to exit of intersection for first truck

totaldist= dist + dist2;
totaltime= time1 + time2;

% Run latitude and longitude points of interest in DistGPS to determine
% total distance traversed for second truck to the intersection

distance_m02 = DistGPS( longy, laty);

% finds the sum of total distance

dist02=sum(distance_m02);

% converts inputted velocity from mph to m/s

velocity2= velmph2/2.23694;

% computes time based on give inputs

time102=dist02/velocity2;

% Run latitude and longitude points of interest in DistGPS to determine
% total distance traversed for second truck through the intersection
distance_m102 = DistGPS(longy2, laty2);

% finds the sum of total distance

dist202 = sum(distance_m102);

% computes time based on give inputs

time202 = dist202/velocity2;

% defines total time and distance from start point to exit of intersection for second truck

totaldist02 = dist02 + dist202;
totaltime02 = time102 + time202;

end

Truckpriority

% Truckpriority.m Evaluate conditions to find when interactions between two trucks in the intersection zone will occur.

% Based on truck priority definition, the function evaluates which truck has higher priority and gives that truck the right of way. The lower priority truck has its speed changed in order to ensure only one truck exists in the intersection zone. If only one truck is present in the intersection zone to being with, no modifications to either trucks speed are done.

function [velocityn2, velocityn1] = Truckpriority(truck1, truck2, time1, time102, totaltime, totaltime02, velocity, velocity2, dist, dist02)
This function allows the priority to be given to the appropriate truck when approaching intersections.

Loaded trucks have a priority of 1
Unloaded trucks have a priority of 0

Used to identify any changes of velocity

\[
\text{velocity}_{n1} = \text{velocity};
\]

\[
\text{velocity}_{n2} = \text{velocity}_2;
\]

For scenario where truck 1 is loaded

\[
\text{if } \text{truck1} > \text{truck2};
\]

\[
\text{if } \text{time1}_0 < \text{time1} && \text{time1} < \text{totaltime0}_2;
\]

\[
\text{disp(} \text{* * * * *Potential Intersection Interaction1* * * * *)};
\]

\[
\text{velocity}_{n2} = \text{dist0}_2/\text{totaltime};
\]

\[
\text{return};
\]

\[
\text{elseif } \text{time1} < \text{time1}_0 && \text{time1}_0 < \text{totaltime};
\]

\[
\text{disp(} \text{* * * * *Potential Intersection Interaction1.1* * * * *)};
\]

\[
\text{velocity}_{n2} = \text{dist0}_2/\text{totaltime};
\]

\[
\text{return};
\]

\[
\text{else } \text{when no interaction is found}
\]

\[
\text{fprintf(} \text{* * * * *No Intersection Interaction* * * * \n});
\]

\[
\text{return};
\]
%for scenario where truck 2 is loaded

if truck2 > truck1;
    % determines if condition is present which will result in both trucks being in the intersection zone at the same time. If yes the appropriate truck is required to change its driving speed.

if time102 < time1 && time1 < totaltime02;
    disp(' * * * * *Potential Intersection Interaction2* * * * *');
    velocyn1 = dist/totaltime02;
    return;
elseif time1 < time102 && time102 < totaltime;
    disp(' * * * * *Potential Intersection Interaction2.1* * * * *');
    velocyn1 = dist/totaltime02;
    return;
else % when no interaction is found
    fprintf(' * * * * No Intersection Interaction* * * * *\n');
    return;

    end

end

%for scenario where both trucks are unloaded or loaded (equal priority)

if truck2 == truck1;
%determines if condition is present which will result in both trucks being in the intersection zone at the same time. If yes the appropriate truck is required to change its driving speed.

if time1<time102 && time1<totaltime02;

disp(' *** Potential Intersection Interaction ***');

velocity1 = dist/totaltime02;

return;

elseif time1<time102 && time1<totaltime02;

disp(' *** Potential Intersection Interaction 3.1 ***');

velocityn2 = dist02/totaltime;

return;
else %when no interactions are found

fprintf(' *** No Intersection Interaction ***
');

return;
end

driver_code_truck (circle)

%driver_code_truck.m - Used to compute new idea velocity for trucks in order to avoid interactions in the intersection and have minimal impact on fuel consumption and change in speed
% Appropriate .mat file are loaded to analyze specific haul truck GPS traces and the mine network. User then chooses the most applicable circle(s) file to identify his intersection of interest. User can define specific portion of GPS dot traces in order to examine runs individually. The user is given the option to define truck priorities and the script will then determine which points fall within the defined circle and use them in tracktruck and truckpriority to determine if any changes to current speed are required. Finally the script will output the new parameters of interest and plot the circles and path taken.

clear all;

% Used to differentiate time of interest for Truck 1 based on given .mat file

load July24.2_G.mat
hour_truck1 = hour;
minute_truck1 = minute;
second_truck1 = second;
lat_truck1 = G_lat;
long_truck1 = G_long;

clear hour minute second G_lat G_long;

% Used to differentiate time of interest for Truck 2 based on given .mat file

load July21.3_G.mat
hour_truck2 = hour;
minute_truck2 = minute;
second_truck2 = second;
lat_truck2 = G_lat;
long_truck2 = G_long;
clear hour minute second G_lat G_long;

% max time sample = 3600

% loads the road network

load('truck03.mat');
load('truck04.mat');
load('truck05.mat');
load('truck06.mat');
load('truck07.mat');

% Splits the latitude and longitude into x and y vectors.

x = [ G_long03; G_long04; G_long05; G_long06; G_long07];
y = [G_lat03; G_lat04; G_lat05; G_lat06; G_lat07];
w = [x y];

% Allows used to choose pre-defined circle

disp(' * * * * *CIRCLE FILE SELECTION* * * * *');
cirnametemp = input('Enter circle filename to be processed: ', 's');
circlename = [cirnametemp, '_circles.mat'];

% load chosen circle

f = fullfile('C:', 'Users', circlename);
load(f);
disp(' * * * DATA FILE SELECTION* * * *');
exst = exist('runfiles','var');
if exst == 1
    filetemp = char(runfiles(i));
    load(filetemp);
end

% For First truck

% loads a GPS truck data file

% allows focus on specific part of run to force interaction analysis

hold all

tStart = find((hour_truck1==11)&(minute_truck1==41)&(second_truck1==57));
tEnd = find((hour_truck1==11)&(minute_truck1==42)&(second_truck1==14));

% defines new lat and lon which focuses in given range

lon = long_truck1(tStart:tEnd);
lat = lat_truck1(tStart:tEnd);

% checks if in circle

for w = 1 : nsplits
    clearvars counttemp;
    str1 = ['circ_1' ' ;'];
    str11 = ['circ_2' ' ;'];
eval(str1);
    IN = inpolygon(lon, lat, circ_1(:,1), circ_1(:,2));
IN2 = inpolygon(lon, lat, circ_2(:,1), circ_2(:,2));
IN3 = IN+IN2;
end

% used to store specific part of the run
b3= [IN3 lat lon];

% Examines part of run up to intersection
i1 = find(b3==1,1,'first');
i2 = find(b3(i1:end)==1,1,'first');
u1 = b3(i1:i1+i2-2,1);
u2 = b3(i1:i1+i2-2,2);
u3 = b3(i1:i1+i2-2,3);

%Outputs latitude and longitude associated with change zone
longy= u3;
laty= u2;

% Examines part of run in intersection
i3 = find(b3==2,1,'first');
i4 = find(b3(i3:end)==2,1,'first');
y1 = b3(i3:i3+i4-2,1);
y2 = b3(i3:i3+i4-2,2);
y3 = b3(i3:i3+i4-2,3);

%Outputs latitude and longitude associated with intersection zone
longy2 = y3;
laty2 = y2;

% For Second Truck

% loads a GPS truck data file
% allows focus on specific part of run to force interaction analysis

hold all
tStart2 = find((hour_truck2==11)&(minute_truck2==33)&(second_truck2==02));
tEnd2 = find((hour_truck2==11)&(minute_truck2==33)&(second_truck2==31));

% defines new lat and lon which focuses in given range

lon2 = long_truck2(tStart2:tEnd2);
lat2 = lat_truck2(tStart2:tEnd2);

% checks if in circle

for w = 1 : nsplits
    clearvars counttemp;
    str1 = ['circ_1' ' '];
    str11 = ['circ_2' ' '];
    eval(str1);
    IN02 = inpolygon(lon2, lat2, circ_1(:,1), circ_1(:,2));
    IN202 = inpolygon(lon2, lat2, circ_2(:,1), circ_2(:,2));
    %str2 = ['split(:,' num2str(w) ')= IN*w;'];
    %eval(str2);
    IN302 = IN02+IN202;
end
% used to store part of the run

b302= [IN302 lat2 lon2];

% Examines part up of run up to intersection

j1 = find(b302==1,1,'first');
j2 = find(b302(j1:end)==1,1,'first');
utt1 = b302(j1:j1+j2-2,1);
utt2 = b302(j1:j1+j2-2,2);
utt3 = b302(j1:j1+j2-2,3);

%Outputs latitude and longitude associated with change zone

longy02= utt3;
laty02= utt2;

% Examines part in intersection

j3 = find(b302==2,1,'first');
j4 = find(b302(j3:end)==2,1,'first');
ytt1 = b302(j3:j3+j4-2,1);
ytt2 = b302(j3:j3+j4-2,2);
ytt3 = b302(j3:j3+j4-2,3);

%Outputs latitude and longitude associated with intersection zone

longy202 = ytt3;
laty202 = ytt2;

%used to define if truck 1 is loaded or unloaded
disp(’* * * * *Truck Priority Definition* * * * *’);
truck1 = input(’Define if truck 1 is Loaded (1) or unloaded (0) ’);

%used to define truck 1 speed

disp(’* * * * *Vehicle Speed Definition* * * * *’);
velmph = input(’Input truck 1 speed in mph ’);

%used to define if truck 2 is loaded or unloaded

disp(’* * * * *Truck Priority Definition* * * * *’);
truck2 = input(’Define if truck 2 is Loaded (1) or unloaded (0) ’);

%used to define truck 2 speed

disp(’* * * * *Vehicle Speed Definition* * * * *’);
velmph2 = input(’Input truck 2 speed in mph ’);

%outputs new velocities

% can be enabled to show all parameters of interest
[dist, dist2, time1, time2, totaldist, totaltime, velocity, dist02, dist202, time102, time202, totaldist02, totaltime02, velocity2] = tracktruck1(longy, laty, longy2, laty2, velmph, longy02, laty02, longy202, laty202, velmph2)

%velocityn2 is new velocity for truck 2
%velocityn1 is new velocity for truck 1
[velocityn2, velocityn1] = Truckpriority(truck1, truck2, time1, time102, totaltime, totaltime02, velocity, velocity2, dist, dist02)

% Can be enables to show new times in intersection
inttimen2 = (dist02/velocityn2);
inttimen1 = (dist/velocityn1);

% Plotting the graphs

% axis definitions
axis equal;
title('X-Y View of Data')
set(gca, 'XDir', 'normal')
xlabel('Longitude')
ylabel('Latitude')

% illustrating the intersection circles

% used to show change zone
verts = [circ_2];
faces = [1:257];

p = patch('Faces', faces, 'Vertices', verts, 'FaceColor', 'y');
hold on

% used to show intersection zone
verts = [circ_1];
faces = [1:257];

p = patch(Faces', faces, Vertices', verts, FaceColor', 'b');

% plots the paths taken
hold on;
% path of first truck in red
plot(longy, laty, 'r*');
plot(longy2, laty2, 'r*');
% path of second truck in green
plot(longy202, laty202, 'g*');
plot(longy02, laty02, 'g*');
hold on;

driver_code_truck1 (polygon)
%driver_code_truck.m - Used to compute new idea velocity for trucks in
%order to avoid interactions in the intersection and have minimal %impact on fuel consumption and
change in speed

% Appropriate .mat file are loaded to analyze specific haul truck GPS %traces and the mine network. User
then chooses the most applicable %polygon(s) file to identify his intersection of interest. User can
%define specific portion of GPS dot traces in order to examine runs %individually. The user is given the
option to define truck priorities %and the script will then determine which points fall within the %defined
polygon and use them in tracktruck and trackpriority to %determine if any changes to current speed are
required. Finally the %script will output the new parameters of interest and plot the circles %and path
taken.

clear all;
% Used to differential time of interest for Truck 1 based on given .mat
% file

load July24.2_G.mat
hour_truck1 = hour;
minute_truck1 = minute;
second_truck1 = second;
lat_truck1 = G_lat;
long_truck1 = G_long;

clear hour minute second G_lat G_long;

% Used to differential time of interest for Truck 2 based on given .mat
% file

load July21.3_G.mat
hour_truck2 = hour;
minute_truck2 = minute;
second_truck2 = second;
latt_truck2 = G_lat;
long_truck2 = G_long;

clear hour minute second G_lat G_long;

% max time sample = 3600

% loads the road network

load('truck03.mat');
load('truck04.mat');
load('truck05.mat');
load('truck06.mat');
load('truck07.mat');

% Splits the latitude and longitude into x and y vectors.

x = [ G_long03; G_long04; G_long05; G_long06; G_long07];
y = [G_lat03; G_lat04; G_lat05; G_lat06; G_lat07];
w = [x y];

% Allows used to choose pre-defined polygon

disp(' * * * * *POLYGON FILE SELECTION* * * * *');
polynametemp = input('Enter polygon filename to be processed: ', 's');
polynamelang = [polynametemp, '_polygons.mat'];

% load chosen polygon

f = fullfile('C:', 'Users', polynamelang);
load(f);

% For First Truck

disp(' * * * * *DATA FILE SELECTION* * * * *');
exst = exist('runfiles','var');
if exst == 1
    filetemp = char(runfiles(i));
load(filetemp);
end

% For First truck
% loads a GPS truck data file

% allows focus on specific part of run to force interaction analysis

hold all
tStart = find((hour_truck1==11)&(minute_truck1==41)&(second_truck1==57));
tEnd = find((hour_truck1==11)&(minute_truck1==42)&(second_truck1==14));

% defines new lat and lon which focuses in given range

lon = long_truck1(tStart:tEnd);
lat = lat_truck1(tStart:tEnd);

% checks if in polygon

for w = 1 : nsplits
    clearvars counttemp;
    str1 = ['poly_1' ';'];
    str11 = ['poly_2' ';'];
    eval(str1);
    IN = inpolygon(lon, lat, poly_1(:,1), poly_1(:,2));
    IN2 = inpolygon(lon, lat, poly_2(:,1), poly_2(:,2));
    %str2 = ['split(:, num2str(w) ')= IN*w;']
    %eval(str2);
    IN3 = IN+IN2;
end

% used to store part of the run

b3= [IN3 lat lon];
% Examines part up to intersection

i1 = find(b3==1,1,'first');
i2 = find(b3(i1:end)~=1,1,'first');
u1 = b3(i1:i1+i2-2,1);
u2 = b3(i1:i1+i2-2,2);
u3 = b3(i1:i1+i2-2,3);

%Outputs latitude and longitude associated with change zone

longy= u3;
laty= u2;

% Examines part in intersection

i3 = find(b3==2,1,'first');
i4 = find(b3(i3:end)~=2,1,'first');
y1 = b3(i3:i3+i4-2,1);
y2 = b3(i3:i3+i4-2,2);
y3 = b3(i3:i3+i4-2,3);

%Outputs latitude and longitude associated with intersection zone

longy2 = y3;
laty2 = y2;

%For Second Truck

% loads a GPS truck data file
% allows focus on specific part of run to force interaction analysis

hold all

%defines new lat and lon which focuses in given range

tStart2 = find((hour_truck2==11)&(minute_truck2==33)&(second_truck2==02));
tEnd2 = find((hour_truck2==11)&(minute_truck2==33)&(second_truck2==31));

%checks if in polygon

for w = 1 : nsplits
    clearvars counttemp;
    str1 = ['poly_1'; ' '];
    str11 = ['poly_2'; ' '];
    eval(str1);
    IN02 = inpolygon(lon2, lat2, poly_1(:,1), poly_1(:,2));
    IN202 = inpolygon(lon2, lat2, poly_2(:,1), poly_2(:,2));
    %str2 = ['split(., num2str(w) )= IN*w; '];
    %eval(str2);
    IN302 = IN02+IN202;
end

% used to store part of the run

b302 = [IN302 lat2 lon2];

% Examines part up to intersection
j1 = find(b302==1,1,'first');
j2 = find(b302(j1:end)==1,'first');
ut1 = b302(j1:j1+j2-2,1);
ut2 = b302(j1:j1+j2-2,2);
ut3 = b302(j1:j1+j2-2,3);

% Outputs latitude and longitude associated with change zone
longy02= ut3;
laty02= ut2;

% Examines part in intersection
j3 = find(b302==2,1,'first');
j4 = find(b302(j3:end)==2,'first');
yt1 = b302(j3:j3+j4-2,1);
yt2 = b302(j3:j3+j4-2,2);
yt3 = b302(j3:j3+j4-2,3);

% Outputs latitude and longitude associated with intersection zone
longy202 = yt3;
laty202 = yt2;

% Used to define if truck 1 is loaded or unloaded

disp( ' * * * * *Truck Priority Definition* * * * *' );
truck1 = input('Define if truck 1 is Loaded (1) or unloaded (0) ');

% Used to define truck 1 speed

disp( ' * * * * *Vehicle Speed Definition* * * * *' );
velmph = input('Input truck 1 speed in mph ');

%used to define if truck 2 is loaded or unloaded

disp(' * * * * *Truck Priority Definition* * * * *');
truck2 = input('Define if truck 2 is Loaded (1) or unloaded (0) ');

%used to define truck 2 speed

disp(' * * * * *Vehicle Speed Definition* * * * *');
velmph2 = input('Input truck 2 speed in mph ');

%outputs new velocities

% can be enabled to show all parameters of interest

[dist, dist2, time1, time2, totaldist, totaltime,velocity, dist02, dist202, time102, time202, totaldist02,
totaltime02,velocity2] = tracktruck1(longy,laty,longy2, laty2, velmph, longy02,laty02,longy202, laty202,
velmph2)

%velocityn2 is new velocity for truck 2
%velocityn1 is new velocity for truck 1

[velocityn2, velocityn1] = Truckpriority(truck1,truck2, time1, time102, totaltime, totaltime02,velocity,
velocity2,dist,dist02)

% Can be enables to show new times in intersection

inttimen2 = (dist02/velocityn2);
inttimen1 = (dist/velocityn1);
% Plotting the graphs

% axis definitions

axis equal;
title('X-Y View of Data')
set(gca,'XDir','normal')
xlabel('Longitude')
ylabel('Latitude')

% illustrating the intersection polygon

% used to show change zone

verts= [poly_2];
faces = [1 2 3 4]; % can be adjusted to accommodate complex polygons
p = patch('Faces',faces,'Vertices',verts,'FaceColor','y');
hold on

% used to show intersection zone

verts= [poly_1];
faces = [1 2 3 4 5]; % can be adjusted to accommodate complex polygons
p = patch('Faces',faces,'Vertices',verts,'FaceColor','b');

% plots the paths taken
hold on;

% path of first truck in red
plot(longy,laty,'r*');
plot(longy2,laty2,'r*');

% path of second truck in green
plot(longy202,laty202,'g*');
plot(longy02,laty02,'g*');
hold on;