RISK BASED FRAMEWORK FOR HAUL VEHICLE AND LIGHT VEHICLE INTERACTION WITHIN SURFACE MINING OPERATIONS

A Thesis submitted by

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ABSTRACT

Mining is an important industry in the Australian economy. However, the mining industry had the 3rd highest fatality rate of all Australian industries. Collisions between light and haul vehicles are a significant contributor to the injury rate with fatal collisions occurring in 2008 in Western Australia and 2013 in New South Wales. Research into government databases from these regions has identified numerous reportable incidents because of light vehicle and haul vehicle interaction. With such a high rate of incidents and fatalities within the industry, the research sets out to develop and test a risk-based framework for mitigating vehicle interaction risk with the use of separated road networks.

A review of literature identified numerous road design guidelines for light vehicles through Austroads publications and mining specific haul road design guidelines. However, industry wide standards are not currently available for the design of haul vehicle and light vehicle interaction situations. Vehicle separation can be achieved with the use of physical delineation devices such as earth berms and the use of separate roads for the two vehicle types. This risk mitigation method requires a significant investment from mining companies and therefore a profit optimisation approach was incorporated into the risk-based framework.

The research tests a risk-based framework with the use of an existing mine. The framework examines the employer, societal and employee costs and benefits using discounted cash flow quantitative methods over a timeframe for an incident to statistically occur. Traffic modelling is utilised to determine the layout efficiencies through improved speeds and reduced vehicle density. Different scenarios were considered altering the framework inputs, including by increasing the mine size (Case Study 2), reducing the volumes of haul vehicle traffic(Cases Study 3), and reducing the volumes of light vehicle traffic (Case Study 4).

All the case studies showed a financial benefit of a separated network if there was a high likelihood of a light vehicle- haul vehicle collision in the short to medium term.

Incidents between light vehicles and haul vehicles are prevalent in the mining industry however the number of fatal collisions has reduced over recent years due to technological improvements such as the use of vehicle detection systems. Current advances in technology, such as the use of autonomous vehicles, will have a role to play in improving safety, however such technological advances do not eliminate risk, and vehicle separation could also be an effective strategy to utilise if financially feasible.

CERTIFICATION OF THESIS

This Thesis is entirely the work of Samuel Birkbeck except where otherwise acknowledged. The work is original and has not previously been submitted for any other award, except where acknowledged.

Principal Supervisor: Ron Ayers

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Student and supervisors signatures of endorsement are held at the University

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ACRONYMS

BCR	Benefit Cost Ratio
CADG	Collision Avoidance Design Guidelines
CADP	Collision Avoidance Design Process
CAS	Collision Avoidance Solutions
HV	Haul Vehicles
LV	Light Vehicles
MIA	Mine Infrastructure Area
MISA	Mine Incident Statistical Analysis
PA	Per Annum
ROM	Run of Mine
TM	Traffic Modelling

1. INTRODUCTION

1.1 THE ROLE AND IMPORTANCE OF MINING

Mining has been pivotal in the development of Australia and its economy. The early gold rush years from 1851 to 1871 resulted in the Australian population booming from 430,000 people to 1.3 million. During this time, mining helped create a wealthy and liberal society with a standard of living that was the envy of the world. (National Museum Australia, 2020). Mining booms continued in the 1960s, mid 1980s with increased demand for iron ore and coal, particularly from China and India (Parliament of Australia, 2021).

Australian mining provides natural occurring materials such as coal, copper, lead, silver, zinc, bauxite, phosphate rock, magnesium, silica sand, gems, iron ore, and gold. The materials from mining are necessary for utilisation by other industries, such as energy, production and storage, manufacturing, construction, and transport.

Mining has benefited the Australian society in numerous ways; however, the main benefit was increasing employment and creating more jobs (CSIRO, 2020). Although this increase in employment has benefited many Australians, it is particularly important to the job opportunities provided in regional areas. Furthermore, mining is considered to deliver positive employment benefits to Indigenous Australians and women within these communities (CSIRO, 2020).

The mining industry in Australia has employed 252,100 people as of February 2021, which is approximately 1.9% of the Australian total workforce (Australian Government, 2021). The global metal and mining industry is forecasted to have a value of US$2,697.5 billion by 2023 within the Asia Pacific region (which includes Australia), accounting for approximately 70% of the industry value (MarketLine, February 2020).

1.2 RISKS AND INCIDENTS IN MINING

A review of the mining incidents that occur in the industry can provide an understanding of the risks. The Australian mining industry has a 5-year average of 8 fatalities per year over the period from 2014 to 2018, which results in a 5-year average fatality rate of 3.4 deaths per 100,000 workers within the industry during the same period. During this time, the mining industry had the 3rd highest fatality rate of all Australian industries. The mining industry was third to the Agricultural forestry and fishing industry with 11.2 fatalities per 100,000 workers and the Transport postal and warehousing industry with 5.9 fatalities per 100,000 workers (Safe Work Australia, 2018). Many collisions and fatalities occur due to the interaction of vehicles in surfacing mining operation.

The State Government of Western Australia has reviewed 172 collisions that occurred in the 2015-2016 period in Western Australia (WA). More than half of the reviewed collisions comprised of HV-LV interactions, either together or separately. The data also showed that the collisions were not contained to a specific area of the mine. The HV-LV collisions occurred within various areas, such as the park-up areas, intersections, ramps, stockpile yards, waste dumps and workshops. (Department of Mines Industry Regulations and Safety, 2019).

Reportable mining incidents have been provided from WA and New South Wales (NSW) mining departments for this research. These incidents included material damage, injury, fatalities, and high potential incidents. The data consisted of approximately 40,000 incidents from 2007 to 2020 period which was examined in relation to HV-LV interaction to develop an average incident rate for the region. The WA data showed HV-LV interaction incidents occurred at an average annual rate of 113 out of one million people employed within the WA mining industry, within the 2010-to-2020-year dataset. The NSW data showed LV-HV interaction incidents occurred at an average annual rate of 82 out of one million people employed within the NSW mining industry, within the 2007-to-2016-year dataset.

The most recent fatal collisions identified between HV-LV were within WA in 2008 and NSW in 2013. Both fatal collisions resulted in the death of the LV driver and occurred at intersections of main haul roads, which have the highest speed environment within the mine site. The HV drivers involved in the fatal collisions sustained no major injuries.

Australian state mining regulators, such as the Department of Natural Resources and Mines located in Queensland, have regularly provided recommendations to mining operators to consider segregating HV-LV traffic due to past incidents within this region.

1.3 RESEARCH BACKGROUND

Surface mining sites are unique operating environments with a diverse range of interaction between vehicles, and road users. The risks associated with such interactions need to be understood, as well as the knowledge, skills and experience applied to mitigate the risk exposure. Industry wide standards and guidelines are not available in this technical area of HV-LV interaction, either internationally or within Australia. Individual mines or mining companies have developed documents, however, vary in terms of coverage, the level of road safety, traffic engineering, and traffic management knowledge (NSW Mine Safety Investigation Unit, 2015).

Light vehicles within mine sites transport operators, engineers, managers, planners, safety inspectors, maintainers, drill and blast crews as required. Whereas haul vehicles are required to transport product from its natural state to processing plants. Mine sites also have a range of road maintenance fleets utilising the road networks, which are usually undertaken on live roads under traffic management.

The design of HV-LV roads to mitigate fatal collisions and achieve vehicle separation can be undertaken with different industry guidelines, which are typically suited to the specific vehicle class. Austroads has numerous design guidelines for LV, while haulage design guidelines are typically vehicle specific developed by the mining company. These guidelines set out the features such as road width, horizontal and vertical geometry, operational speeds, drainage, pavement, intersections, and control measures for the vehicle delineation. With knowledge of the road design requirements to mitigate HV-LV collisions a risk-based framework can be developed.

1.4 FUTURE OF TECHNOLOGY IN MINING

HV-LV fatal collisions have reduced due to the incorporation of technology advancements. These include camera/radar technologies, for improving operator awareness of other vehicles, as well as autonomous systems, which remove the HV driver from the risk.

HV manufacturers such as CAT and Komatsu have heavily invested in technology improvements, such as autonomous vehicles, over the past 15 years. Autonomous HV are equipped with vehicle controllers, a high precision GPS system, an obstacle detection system, and a wireless network system, which can also be integrated with the dozers, loaders and shovels that are also autonomous. Although technology may remove HV operators from the high-risk environment and fatigue-related crashes, the drivers of the LV are still prone to a fatal risk.

A review of the QLD Government department, Resources Safety and Health Queensland, found that technology is still not suitable as the risk mitigation, but an added control. As well as technology, other forms of controls must be considered. Such as hard control changes in mine traffic design, road layout, and equipment design changes, together with process controls and softer controls, such as improved communications and procedures (Resources Safety & Health Queensland, 2021). With no complete elimination of the risk currently available through technology advancement the research will investigate a risk-based framework which incorporates the company financial needs.

1.5 RISK BASED FRAMEWORK AND INVESTMENT EVALUATION

The evaluation of risk and the systematic targeting of high-risk areas for risk elimination are ongoing components of managerial responsibility within the mining industry. Therefore, every mine has the responsibility to manage the risk of HV-LV interaction while still maintaining a financially viable mine site.

Currently no risk-based financial evaluation framework exists where it examines all the elements of HV-LV interaction and specifically how to mitigate the risk with separate road networks. Such a framework would need to include the design of the mine layouts, investigate any negative impacts such as construction and maintenance costs, and the financial benefits such as increased employee productivity through improved vehicle cycle times and collision mitigation. A suitable framework that investigates all these elements will provide mining companies the ability to approve capital expenditure to mitigate HV-LV fatal collisions and ensure profit optimisation.

The cost of introduction and operation of new work procedures and equipment is a major consideration for any mining operation. When applying the risk mitigation control method to HV-LV interaction, it is currently acknowledged that elimination may only be achievable by segregation or separation of the vehicles. This results in numerous factors to consider when dealing with the quantitative economics of the risk, such as the construction and maintenance costs of the LV road networks and the financial benefits to the employer, employee, and society.

Financial benefits of mitigating fatal collisions to society includes avoiding public health care costs, as well as investigation, travel, legal and tax losses in the event of a fatal collision. The benefits of the risk elimination for the employer includes avoiding production delays to the mine, replacement costs for the employee, damage to assets, and investigation costs. Other benefits due to the additional road networks in the form of productivity and efficiency gains would also be applicable to increase cycle speeds and reduced vehicle density on the road networks. To understand the quantitative aspects of this element, traffic modelling will be undertaken on multiple layouts as required.

The financial benefit of the risk elimination for the employee is the loss of income over the long term, which is equal to the present value of the individual’s expected income over the period between leaving work and retirement.

The framework developed for this research incorporates the problem and solution related to Risk Management Framework and Profit Optimisation. This will include three measures of values to inform the decision of implementing the financial investment, including the Discounted Cash Flow (DCF), payback method and sensitivity analysis.

1.6 RESEARCH AIMS, EXPECTED OUTCOMES AND BENEFITS

The research aims to deliver a risk-based framework for HV and LV interaction within surface mines by utilising inputs from a real world mine. Due to the nature of the mining industry and confidential agreements, the mine details will not be disclosed. Overall, it is anticipated that incorporating a financial assessment process into the risk management process to develop the framework, would provide guidance for mining companies to determine if mitigating the risk of HV and LV interaction is a suitable investment. A surface coal mine with strip mining operations shall be utilised for the framework, however it is envisaged the methodology could be utilised for numerous mining operations that have HV and LV interaction.

The expected outcome to the mining community would be a deeper understanding of the risk of HV and LV interaction utilising statistical analysis of existing incident databases, and how this relates to a particular mine. Additional outcomes of the research would be applicable to the mining community to understand how the vehicles could be separated through physical delineation methods for different areas of the mine site. The research will also determine how separating the HV and LV vehicles with additional road networks will impact the productivity and efficiency of the mining employees with the use of traffic modelling software. Creating traffic models and testing the future unbuilt road networks will provide an understanding of the positive impacts of additional road networks, including the increased speed, and reduced vehicle density. Although this research has adopted vehicle separation as the risk elimination method, it is noted that further research could be undertaken to identify the reliance on technology solutions such as autonomous vehicles and collision avoidance systems.

1.7 RESEARCH APPROACH AND OUTLINE

To achieve the aims and objectives of the research a review of current literature will be undertaken, prior to outlining the research methodology, results, and discussion of the research findings.

The literature review will investigate the mining incidents and fatalities within Australia to consider the scale of the problem of HV and LV interaction. A review of the mine operations will be undertaken with particular interest in the operations of haul and light vehicles within mines. Examining the aspects of the mine layout and different road design standards further provide an understanding of how the vehicles operate and how they can be separated.

The methods of crash mitigation for both the infrastructure and mining industry will be examined with a view to better understand how the vehicle interaction and separation can be achieved. The methods shall include a quantitative assessment of the benefits and costs to mitigate the vehicle interaction. Finally, the literature review will investigate the current technologies utilised within Australian mining and how they relate to the problem of HV / LV interaction.

Following the review of crash mitigation strategies, the research will develop a risk-based framework for use within the mining industry. The framework will utilise a staged based approach of initial scoping, gaining the inputs, processing the data, and developing the outputs for decision making purposes. The processes shall include a review of the statistical analysis of an incident and fatality occurring within a mine site, collision avoidance solutions and design guidelines, traffic modelling of differing solutions and a quantitative assessment for decision making. The company decision making process will not be included within the research report as they are dependent on the company board approval policy and procedures.

The risk-based framework will test four case studies, with the base case mine being Case Study 1. The inputs of this Case Study will be altered as a sensitivity analysis to develop 3 additional Case Studies. Case Study 2 alterations will increase the total road network length within the mine site by 20%. This is expected to increase the cost to mitigate the vehicle interaction, however, provide greater benefits to the LV travelling within the mine unimpeded by HV for greater distances. Case Study 3 will reduce the volumes of HV within the road network. Case Study 4 will reduce the volumes of LV within the road network. It is anticipated the reduction in LV and HV volumes on the road network will provide less efficiency in the traffic model.

2. LITERATURE REVIEW

The literature review will consider the major background aspects of the current research, including vehicle crash investigations, risk economics, mine layout and operation, mine design, and recent technology advancements in mining. The review of the vehicle crash incidents in the mining industry will provide an understanding of the probability of collision between the haul vehicles (HV) and light vehicles (LV) within mines, while the risk economics will assess the relevant financial impacts. The review of the mine layout, design components, and technology advancements will assist in formulating ways to mitigate and manage vehicle collision risks in the future.

2.1 FATALITIES AND INJURIES IN THE MINING INDUSTRY

The research has investigated both fatal incidents within the mining industry in Australia and overseas. It also features detailed analysis undertaken of reportable incident data within Australia, which was sourced from Australian State Government departments.

2.1.1 INCIDENT TRENDS IN THE USA

A review of incidents from outside of Australia will provide a broader perspective of the mining industry in other international regions. Coal mining in the United States of America (USA) and Australia has been using the same methodology of extraction and processing since 1900. In both countries, workplace health and safety has developed significantly over the past 40 years with improvements in technology, a greater emphasis on safe working conditions, and personal protective equipment making workplaces safer. This is shown by statistics of USA's mining industry since 1983, where analysis of the history of mining fatalities identifies that in the year 1983, 31 in 100,000 miners suffered a work-related incident resulting in fatality. This is compared to 2019, where 8 in 100,000 miners suffered the same fate (Centers for Disease Control and Prevention , 2021). The USA reduction in mining related incidents is shown in Figure 2-1 below.

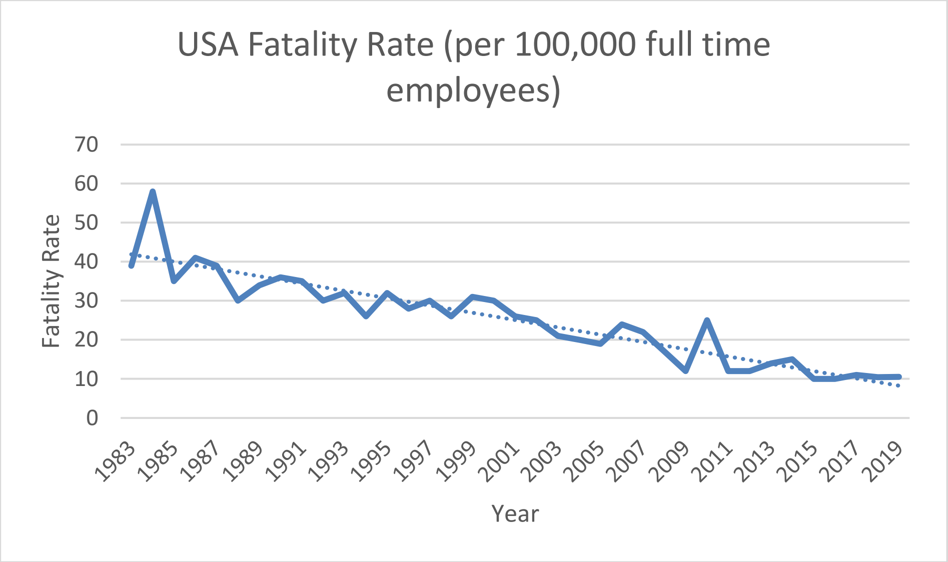


Figure 2-1: USA fatality rate per 100,000 full time equivalent employees - Source: (Centers for Disease Control and Prevention (CDC), 2021)

Figure 2-1 shows that reductions in fatalities have been a trend over the last 40 years and it is therefore imperative to examine the most recent data available to ensure a snapshot of the mining industry operations within the current market. This research shall include a review of the current reports and publications within Australia, as outlined in the following section.

2.1.2 AUSTRALIAN INCIDENT DATA

The research investigated current publications regarding mining crashes in relation to HVs and LVs within Australia to develop an understanding of the problem.

The safety of the mining industry in Australia can be compared with all other industries by considering the number of fatalities per year, and more specifically by the number of fatalities per 100,000 workers in their respective industry. The mining industry has averaged a total of 8 fatalities over the 5-year period from 2014 to 2018, which results in a fatality rate of 3.4 deaths per 100,000 workers within the industry. This results in the mining industry having the 3rd highest fatality rate in Australian industries, and a notably higher rate than the construction industry (Safe Work Australia, 2018).

Examining the inherent risks within mining has identified that between 2001 and 2015 being hit by moving objects accounted for 18% of compensation claims, with one quarter (4.5%) of these were due to being hit by mobile plant and transport. This is compared to 25% of all claims arising from slips trips and falls and 39% by body stressing (manual handling) (Safe Work Australia, 2022)

According to Australian Coal Industry Research Program (ACARP) (Kizil G, Rasche T, 2012), where 310 mining collision incidents were reviewed, 16% were caused by vehicle-to-vehicle interaction in Australia and the United States mining industry from 1995 to 2010. The main organisational factors reported relating to the incidents involved procedures, training programs, risk assessments, mine road design, traffic management, and vehicle brake maintenance. The main individual and team action factors relating to the incidents involved less than adequate awareness and lack of communication with other operators and equipment.

Most Australian mining regulators will issue guidance on mine safety emanating from incidents that occur. For example, the Queensland Government through its Department of Natural Resources and Mines has issued ‘Safety Alerts’ and ‘Safety Bulletins’, which are based on incidents recorded, to assist mining companies eliminate risks (e.g., Department of Natural Resources and Mines, 2002a and b, 2008, 2009 a and b). Safety Alert Nos 218, 179, 232 and Safety Bulletin 135, 34 all have recommendations to *“consider segregating heavy vehicle and light vehicle traffic”.* This is definitive evidence that regulatory bodies are taking an active role and are aware of the problems caused by the interaction of HV-LV. Research into fatal incidents in Queensland had identified an incident that occurred in 1997 at Blackwater Open-cut Coal Mine, where a diesel fitter was fatally injured by crushing injuries in the cabin of a land cruiser, after the vehicle was run over by a water truck (Department of Natural Resources and Mines, 2012).

Research undertaken by the Government of Western Australia (*Fatal Accidents in the Western Australian Mining Industry 2000 – 2012* 2014, p. 15) outlined the details of fatal incidents that occurred in 2008. A particular incident description stated, *“A haul* *truck was approaching a junction with the main haul road. There were two other trucks on the haul road. As the driver entered the main traffic flow, he did not see an approaching light vehicle. The driver of the light vehicle was killed in the accident".* A Mine Safety Significant Incident Report was developed by the Department of Mines and Petroleum and is attached to this report as Appendix A (Department of Mines Industry Regulations and Safety, 2019).

The State Government of Western Australia (Department of Mines Industry Regulations and Safety, 2019) has also identified 172 collisions that occurred in the 2015-2016 period in Western Australia. Surface haul trucks (82) and light vehicles (71) represent more than half of the total number of collisions. Furthermore, the most frequently contacted secondary vehicle is a light vehicle, which was contacted by a much larger vehicle in 33 of the 36 collisions. The data also showed that the collisions were not contained to a specific area of the mine, as HV (primary vehicle) and LV (secondary vehicle) collisions occurred within park-up areas, intersections, ramps, stockpile yards, waste dumps and workshops.

The NSW Mine Safety Investigation Unit (2015) released an investigation report into an incident that occurred with HV-LV interaction in NSW. The report described an incident that occurred November 30th, 2013, where a HV operator was hauling coal along the main haul road. As the HV operator approached the T-intersection he saw the LV enter the main haul road to his right, and then he lost sight of it. The LV driver turned right onto the main haul road into the path of the HV. The HV and LV collided, with the driver being crushed, and dying immediately from multiple injuries.

The contents of this specific incident are attached in Appendix A and the findings highlighted the following: "*The hazard has been recognised in mine safety legislation, which requires that a Major Hazard Management Plan be established for surface transport operations… Investigators will examine… haul road design, including intersection design… control measures for separating heavy from light vehicles".* The report also noted *"mine sites are unique operating environments with many different functions and uses taking place, with a diverse range of vehicles (in terms of size,* *performance, fields of view etc.) and vulnerable road users. Their interactions and the risks associated with such interactions need to be understood, and knowledge, skills and experience applied".*

Australian Road Research Board (ARRB) was consulted because of the incident and noted*: "definitive industry standards and guidelines do not currently exist in this technical area, either internationally or within Australia. Many documents have been developed, either by individual mines or mining companies which all tend to vary in terms of coverage and the level of road safety, traffic engineering and traffic management knowledge and experience displayed".*

This literature review has identified two fatal incidents that occurred within 2008 in WA and 2013 in NSW within the last 13 years. Numerous recommendations have been identified for the provision of separation of HV-LV to mitigate the risk, with an acknowledgement that the industry is lacking definitive industry standards for HV-LV interaction.

The incidence rates can also be examined with the assistance of government databases of historical incidents. This will be discussed in the following section.

2.1.3 HAUL VEHICLE – LIGHT VEHICLE INTERACTION CRASHES

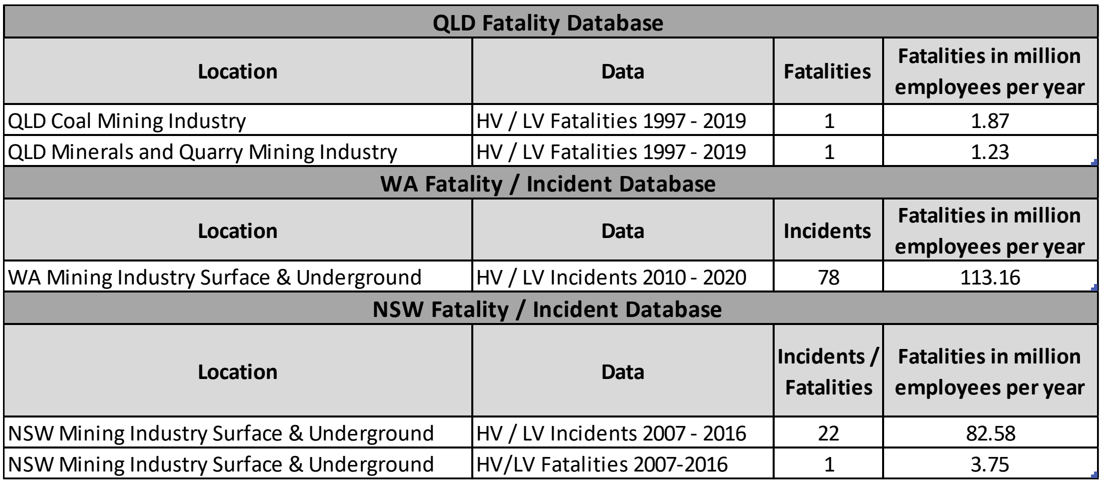
The HV-LV interaction resulting in crashes, reportable near misses and fatalities are reported to the state governments within Australia. This is to ensure health and safety practices within the mining industry are improved with lessons learned. Access was gained to NSW, WA, and QLD databases for the purpose of examining them to determine the statistical probability of an incident or fatality occurring within a population. Fatality rates per head of population are commonly used in crash analysis in Australia (Thompson et al. 2018). The government databases examined totalled over 40,000 incidents.

WA has provided data from 2010 to 2020 specifically relating to LV incidents. QLD data was available online from 1997 to 2017 (Queensland Government, 2020). The

Department of Planning and Environment in NSW has provided data from 2007 to 2016 involving fatalities and near misses.

The WA and NSW data has been evaluated with an output of incidents and fatalities (where applicable) involving HV and LV, while the QLD data has been evaluated with HV-LV fatal collisions only as it did not have incident or near miss data. The NSW data was the most complete in terms of being unfiltered prior to being provided by the government for analysis. Both NSW and WA information required a non-disclosure agreement of the specifics of the incident details. All the incident data analysis has been summarised as shown in Table 2-1 below.

Table 2-1: Summary of crash analysis



QLD Fatality Database			
Location	**Data**	**Fatalities**	**Fatalities in million employees per year**
QLD Coal Mining Industry	HV / LV Fatalities 1997 - 2019	1	1.87
QLD Minerals and Quarry Mining Industry	HV / LV Fatalities 1997 - 2019	1	1.23

WA Fatality / Incident Database			
Location	**Data**	**Incidents**	**Fatalities in million employees per year**
WA Mining Industry Surface & Underground	HV / LV Incidents 2010 - 2020	78	113.16

NSW Fatality / Incident Database			
Location	**Data**	**Incidents / Fatalities**	**Fatalities in million employees per year**
NSW Mining Industry Surface & Underground	HV / LV Incidents 2007 - 2016	22	82.58
NSW Mining Industry Surface & Underground	HV/LV Fatalities 2007-2016	1	3.75

One fatal incident involving HV and LV was identified in the QLD data that occurred in 1997 within the coal industry. This results in a fatality rate of 1.87 people per annum within 1,000,000 people averaged over the dataset period of twenty-two years.

No fatal incidents involving HV and LV were recorded in the WA data within the dataset period of 2010 to 2020. However, from the research within the previous section, a fatal incident had occurred within 2008 in WA as attached to this report in Appendix A. The incident rate of HV and LV was developed from near misses and conflicts between the vehicles, which did not result in fatality. This results in a reportable average incident rate of 113 people per annum in 1,000,000 people over the dataset period of ten years.

One fatal incident involving HV-LV was identified in the NSW data within the dataset period of 2010 to 2016, in 2013. This results in a fatality rate of 3.75 people per annum within 1,000,000 people averaged over the dataset period of seven years. The incident rate of HV-LV was developed from near misses and conflicts between the vehicles, which did not result in fatality. This results in a reportable average incident rate of 83 people per annum in 1,000,000 people over the dataset period of seven years.

Although the fatalities have only occurred in 1997, 2008 and 2013 from the analysis undertaken, it is acknowledged that significantly more reportable incidents and near misses have occurred that have the potential to contribute to this specific risk into the future. With the NSW data of 22 near misses and 1 fatality, there is approximately a 4% probability that a near miss can result in a fatality.

A factor to consider when examining incident rates is to determine if an increase in the risk will occur in the future with a growth in workers exposed to the risk as examined in the following chapter.

2.1.4 GROWTH IN THE NUMBER OF AUSTRALIAN MINE WORKERS

With mining investment increasing throughout Australia, an analysis of the growth rates of the number of workers in the mining industry including surface and underground mines was undertaken. This was to determine if increasing numbers of personnel in the industry would be likely to significantly increase the likelihood of exposure to the risk of collisions between HV and LV. A report written by National Skills Commission has suggested that the employment growth in mining operations will increase by 21,700 persons from 2020 to 2025, which equates to an annual growth in employment of 8.3% (National Skills Commission, 2021). This growth rate is relatively large in comparison to many other industries. Therefore, in the absence of the introduction of new controls, it is likely that the incidences in HV/LV collisions will grow.

2.2 MINE OPERATIONS

Mine operations review how the vehicles will operate and the environmental influences the operators will be subjected to within the mine site.

2.2.1 MINE VEHICLES

Mines require many classes of vehicles to operate on their road networks, including the light vehicles and haul vehicles. Mine sites also have a range of road maintenance fleets utilising the road networks. The maintenance procedures are usually undertaken under traffic management conditions. Comparing the light and haul vehicles characteristics provides an understanding of the difference in the vehicles as shown in Table 2-2 below.

Table 2-2: Comparison of light and heavy vehicles – Source: (Caterpillar,2010 CarsGuide,2021)

Characteristics	Light Vehicle	Haul Vehicle
Weight	1,780kg	1,023,690kg
Wheelbase	2.95m	7.195m
Height	1.85m	7.709m
Wheel Track	1.775m	9.529m
Max Speed	100kmh+	60kmh

How these heavy and light vehicles operate around the mine site will be discussed in the following chapter.

2.2.1.1 HAUL VEHICLE OPERATIONS

The simplified view of the mining haulage and loading operations is shown in Figure 2-2 below. Once the mine pit is prepared the trucks are loaded and the product is moved through haul road network to the processing plant (Nebot, 2007).

Figure 2-2: Simplified view of haul vehicle operations within mines

A large loading and hauling unit can create a very dangerous working environment (Botin 2009). Attention must be paid to the design and placement of haulage roads. The minimum width and sight distance must also be carefully designed and implemented. Keeping all material handling units isolated as much as possible will also significantly reduce workers' exposure to unsafe conditions. There are federal, state, and local laws and regulations, as well as those set by the companies, related to safe equipment operation that must be followed.

These laws and regulations are based on many years of experience, observations, studies, and experiments. Operators and managers must follow and enforce these laws and regulations. This is because accidents will result in loss of time, production, equipment, and worst of all, potential loss of life. Delays at the loading or dumping sites, as well as crossing points, will increase the cycle time of the haul units and cause major reduction in overall job efficiency.

Loading and hauling represents a major part of material handling in the mining industry. After processing, loading and hauling is the most energy-intensive process and therefore is accountable for the second highest operating cost for the industry (Botin 2009). The success and sustainability of a mining operation is heavily dependent on the overall efficiency and productivity of the loading and hauling system. The estimated cost of haulage accounts for 40%-50% of the surface mine operating expenses (Mukhopadhjay 1989), therefore alterations to cycle time via removing LV from the HV network could be cost effective and should be examined with the use of traffic simulation software.

2.2.1.2 LIGHT VEHICLE OPERATIONS

The light vehicle operations relate to the operational support to the mining operations. These include planning, engineering, maintenance crews, operator transports, drill, and blast teams, and transporting people around the mine site. With light vehicle operations having a critical role in operations of mines, the daily costs associated with light vehicle operations is often overlooked (International Mining, 2021).

2.2.2 OPERATIONAL AND ENVIRONMENTAL INFLUENCES

The literature review of mining operator limitations will include the typical driver demographics and behaviour impairment of both haul vehicle and vehicle operators.

2.2.2.1 DRIVER DEMOGRAPHICS

The driver demographics of operators are important to determine the risk category they represent in terms of age and health. For example, it has been identified that both road users in NSW and coal miners need to have their health monitored due to the high percentage of overweight and obese people. Such people are found to suffer fatigue more readily in the workplace. For coal miners, this fatigue resulted in many workers running off the road on their way to or from work (Mabbot, Cornwell, Lloyd, & Koszelak, 2005). This type of demographic information can have a direct correlation to the performance of both HV and LV operators.

2.2.2.2 BEHAVIOUR IMPAIRMENTS

Many workers within the mining industry work shifts in order to achieve 24 hours of production. This may result in sleep deprivation and fatigue for the workers. Sleep deficits build up from lack of sleep or working during normal sleep times can cause hypo-vigilance. This hypo-vigilance will often lead to inattention, slow reaction times, poor lane tracking, poor judgement, and micro sleeps, which can lead to fatal mistakes (Hartley L, Mabbott N, 1998). The 2013 fatal incident report described in Appendix A, identified that the mine may consider revising their roster to reduce night work after a survey of the workforce requested more effective strategies to improve sleep quality (NSW Mine Safety Investigation Unit, 2015).

2.2.2.3 SHIFT TIMES

The shift times are dependent on the company and the fatigue management policy that they have in place. Data released by the Australian Bureau of Statistics shows that 35% of the mining industry workers work more than 70 hours per week (Australian Mining, 2015). According to Safe Work (2013) a guideline for shift length states that if a 12-hour shift is worked then no overtime should be worked in addition, and that workers should avoid working more than 50 hours per week. The mining industry has excessive working hours mainly due to their rolling rosters and isolated locations.

2.2.2.4 ENVIRONMENTAL INFLUENCES

The environment can influence be both a positively and negatively influence on the number and intensity of incidents. According to the NSW Mine Safety Investigation Unit investigation report (Appendix A), a contributing factor to a fatal incident was the background lighting near the intersection. This was due to the intersection having water ponding. This resulted in reflections of secondary lighting, and in addition, the haul vehicle’s lighting was covered in mud and recessed into the vehicle. All these elements could have contributed to the incident and made it difficult to detect other moving vehicles. These factors are shown in Figure 2-3 extracted from the report (NSW Mine Safety Investigation Unit, 2015).

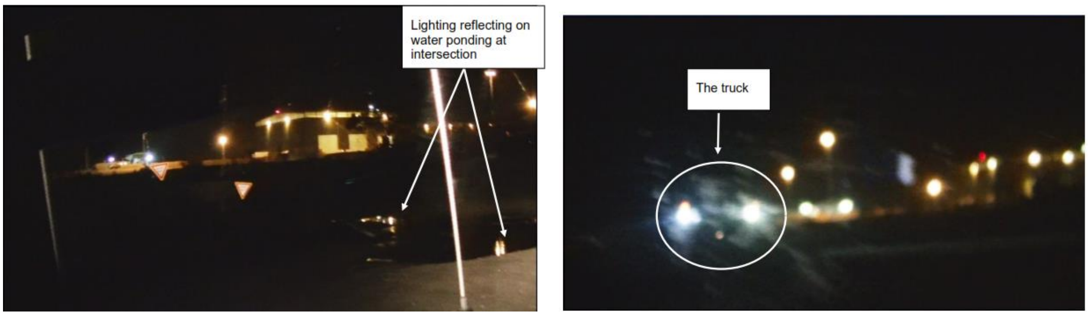


Figure 2-3: (L) Light reflecting off ponded water (R) Haul vehicle lights at intersection

2.3 MINE LAYOUT

This section will review the mine layout design elements, and the factors influencing the mine design. The haul road's features and requirements are critical when it comes to developing separation options for the risk mitigation. Key components of the road design are examined in the following sections.

2.3.1 GEOMETRIC DESIGN OF ROADS

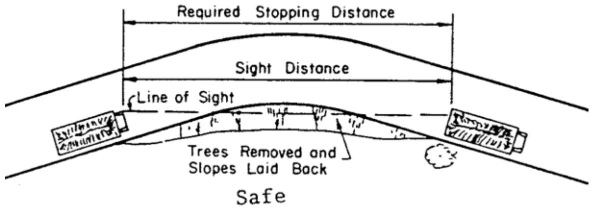
The geometric design of roads includes the required widths of the road, operational speed environment, as well as the horizontal and vertical geometry. The principles of road design are outlined in the Austroads Guide to Road Design (2021), and the specific design of mine roads is treated by Thompson (2011, 2013).

2.3.1.1 ROAD WIDTH

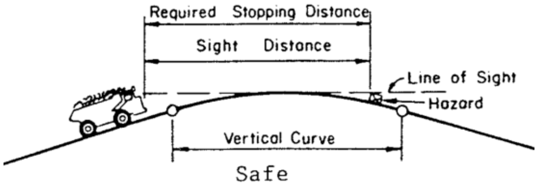
Haul road width is dependent on the vehicles travelling on the road and whether it is a one direction or bi-directional road. Within QLD, haul road width is governed by the Coal Mining Safety and Health Regulation, where the width is required to be at least 3.5 times the width of the largest vehicle regularly using the road (Queensland Parlimentary Counsel, 2017). Given haul vehicle outside body widths can be in the vicinity of 9.7m, this would equate to the road width needing to be approximately 34m for two-way traffic.

2.3.1.2 HORIZONTAL AND VERTICAL GEOMETRY

Horizontal and vertical geometry is important to ensure good operator visibility on crests/sags and around corners. A vertical curve shall be provided to transition a vehicle from one gradient to another gradient comfortably and with enough visual stopping distance suitable for the vehicles to brake to avoid a collision. Similarly with horizontal geometry, a sufficient curve radius should be provided with superelevation and suitable sight distances for the operator to stop their vehicle (Walter , Kaufman, & Ault, 1978). Figure 2-4 below depicts the horizontal and vertical geometry requirements.



(a) Horizontal Curves



(b) Vertical Curves

Figure 2-4: (L) Horizontal curves (R) Vertical curves - Source: (Tannant & Regensburg 2001)

2.3.1.3 OPERATIONAL SPEEDS

A central aspect in traffic safety is the driver’s speed and how fast the vehicle is going. The vehicle speed limit posted on the haul road show maximum speeds and can influence the driver’s speed choice whilst driving. However, other aspects are also important, such as road message cues and how a driver selecting speed using perception (American Association of State Highway and Transportation Officials, 2010).

A significant perception aspect that increases speeds of haul vehicles is speed adaption, where the drivers are used to driving on the same stretch of road for durations of time. Haul vehicle drivers are used to their surroundings as they are driving the same route from loading to unloading repeatedly throughout a shift. This results in the driver’s adaption to the road and a tendency to develop higher operating speeds.

Road message cues result in drivers interpreting the roadway environment to encourage fast or slow speeds. This depends on the effects of geometry, terrain, and other elements, such as weather conditions. Aspects of geometry that can affect the drivers speed can be the width of the road, available sight distances, radius of the horizontal curves, vertical curves, and the presences of cliffs. Furthermore, different areas of the mine can have different topography, which should be considered in the design and layout of mining roads.

Layouts of mines and the speed of haul vehicles

A review of the mine site, its layout, and the hauling operations can identify the grouping of the main areas and operations of its haul vehicles. The operational speeds for these areas have been developed from industry experience and the major grouping can be summarised as follows:

- Pit area;
- Main haul roads; and
- Processing plant bin loading and overburden spoil piles.

Pit areas (ramps and in pit) generally use lower design speeds to minimise the amounts of bulk earthworks, as mineral products being extracted may be located under many metres of overburden material. It is therefore generally expected that the pit would be a low-speed environment, as gradients are at the upper limit of the vehicle capacities, and horizontal and vertical radii are at a minimum. Ramp gradients generally utilise a maximum of 8% grade, which reduce the haul vehicle speeds significantly to first and second gear operations.

Main haul roads use higher design speeds due to the longer distances from the pit ramps to processing plant, and overburden spoil piles. Another factor is the construction cost of the main haul road networks, which is generally cheaper as they are built at natural surface levels. It is expected that haul vehicles travelling on the main haul roads utilise the vehicle’s maximum speed capacity in sixth and seventh gear operations.

Processing plant bin loading and overburden spoil piles operate as a low-speed environment as the vehicles are manoeuvring into a position for unloading. Furthermore, steep vertical grades may be present at processing plant bins for haul trucks to dump into the top of the bins. Due to vehicle manoeuvring and high gradients, the vehicle speeds are kept at a minimum with first gear operations in these areas.

The expected speeds of haul vehicles based on the gear operations outlined above are shown in Table 2-3 for a Cat 797 haul truck.

Table 2-3: Cat 797 vehicle speeds - Source: (Caterpillar, 2013)

Transmission	Speed (Km)
Forward 1	11.3
Forward 2	15.2
Forward 3	20.5
Forward 4	27.7
Forward 5	37.2
Forward 6	50.3
Forward 7	67.6
Reverse	11.9

In summary, the speeds in the ramps, pit areas, processing plant bin loading and overburden spoil piles areas would be in the vicinity of 5-15km/hr for the Cat 797. The main haul roads would have the length of road and the grades to fulfil the higher speed of the haul vehicles. Therefore, the speed of the vehicles would be up to 67.6km/hr for a Cat 797. The main haul road has the highest speeds and therefore produces the greatest vehicle energy in the event of collisions of vehicles.

The speed of light vehicles for the mine site are generally limited to the HV speeds when light vehicles are within the shared haul vehicle road network. This is due to a LV not being able to overtake an operating HV due to poor sight distance and traffic management policy, which is discussed in later sections.

2.3.2 DRAINAGE

The haul road pavement needs to be a shape that allows for safe operation of haul vehicles, yet allows easy maintenance for long life. Cross slope should be used with caution, as it can increase the risk of collision and incidents. Haul road cross fall should be in the range of two to three per cent as defined by and shown in Figure 2-5 below (Thompson R. , 2011).

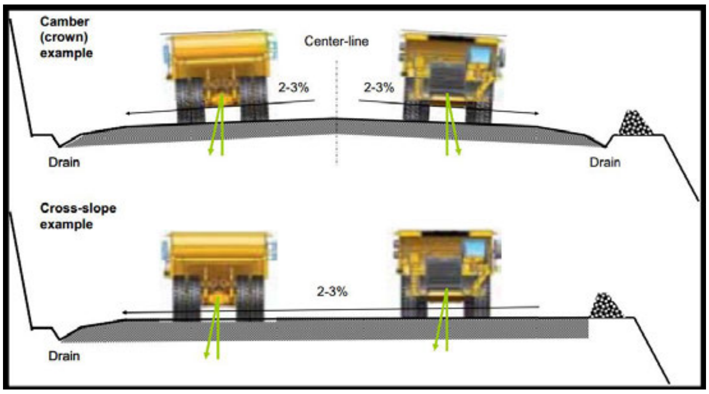


Figure 2-5: Haul road cross falls - Source: (Thompson, 2011)

The haul road pavement surface is critical to achieving adequate surface runoff from the haul road carriage way, hence why the cross fall is also important for drainage. Water infiltration into haul roads increase maintenance cost, resulting in potholes, rutting, erosion, and unravelling. Water infiltration and overland flows are controlled by a series of longitudinal and transverse open channels and drainage structures as shown in Figure 2-6 below.

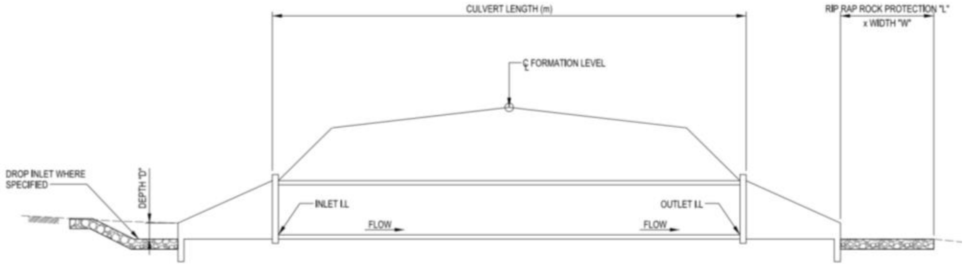


Figure 2-6: Typical culvert drainage structure

2.3.3 PAVEMENT

Haul vehicles have a significant amount of weight and can haul substantial loads, which need to be supported without depressing and deforming the pavement surface. If the pavement surface is deformed, it can create an unsafe environment. The elements that form the pavement include the wearing surface, base material, sub-base, and sub-grade as shown in Figure 2-7 below.

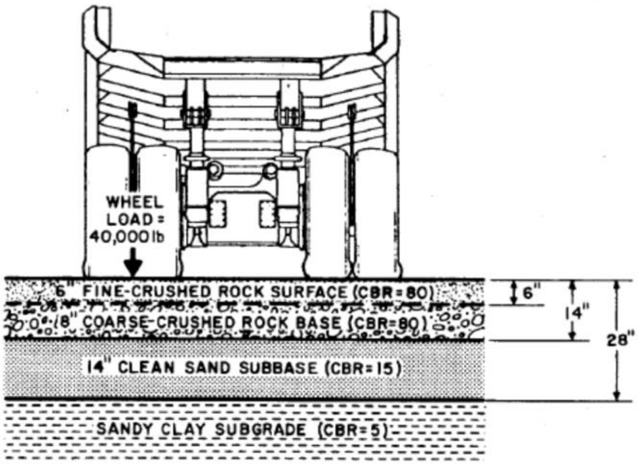


Figure 2-7: Pavement elements - Source: (Kaufman, W. Ault, J, 1977)

The haul road pavement should be designed for the vehicle with the largest loads on the site. One method of developing the composition of the haul road pavement is with the use of the California Bearing Ratio charts. This method uses wheel load and the subgrade strength. A typical design chart is shown in Figure 2-8 below.

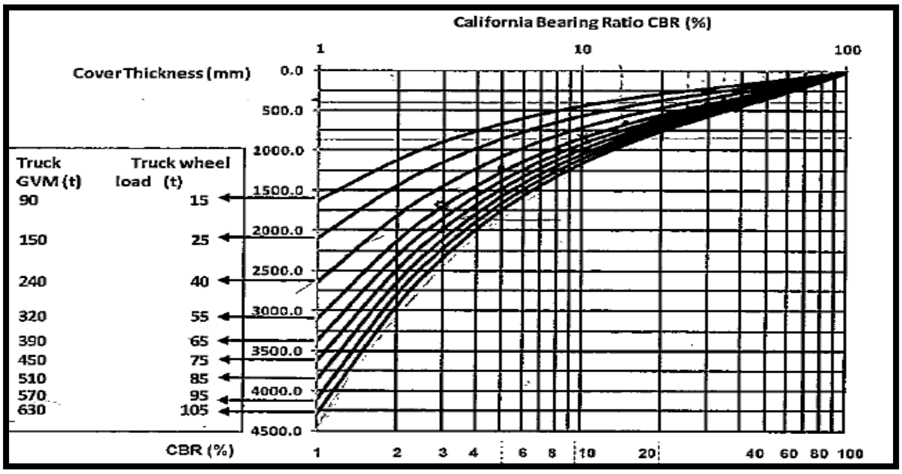


Figure 2-8: California bearing ratio pavement chart - Source: (Thompson R. , 2011)

The above figure shows that a pavement thickness of 1.75m would be required for a CBR 5 subgrade with a truck gross vehicle mass of 630 tonnes. It is noted that the above method may only be utilised for estimating purposes as other methods, including software are more accurate and, can be utilised for haul road pavement design (Strack, 2015).

2.3.4 VEHICLE DELINEATION CONTROL MEASURES

Vehicle delineation control measures refer to the physical device utilised to separate the haul vehicle from a hazard. Kaufman and Ault, (2001) state: *"Whenever the potential exists for an accident that could be avoided by the existence of a berm, the initial cost of constructing and extended cost of maintaining a berm is small in comparison to alternative safety features. If the berm is successful once in preventing a potentially serious accident, it has more than paid for itself in relation to the costs of haulage equipment replacement as well as in lost production time… As well as being a safety factor for haulage vehicles, berms serve … as effective safety devices for smaller maintenance vehicles that use the haulage road".*

The control measure is usually in the form of earth berms, large boulder berms, tyre berms and concrete structures that is outlined in the following sections.

2.3.4.1 EARTH BERMS

The earth berm purpose is to re-direct the haul vehicle. The steeper the slope adjacent the road, the more effective the berm will be. There are two principal earth berms that are common in use, which are triangle berms and trapezoidal berms. The height of the berm must be equal to or greater than the rolling radius of the vehicles tyre, and formed from unconsolidated, relatively homogeneous material (Kaufman W., Ault J, 2001).

Other design guidelines (Tannant & Regensburg, 2001) suggest that the height should be ¾ of the largest haul vehicle tyre diameter using the road. With all berm heights being 1m minimum regardless of tyre size. The berm material is constructed from loose granular material, usually overburden spoil material with slope angles of 1H:1V. This is shown in Figure 2-9 below.

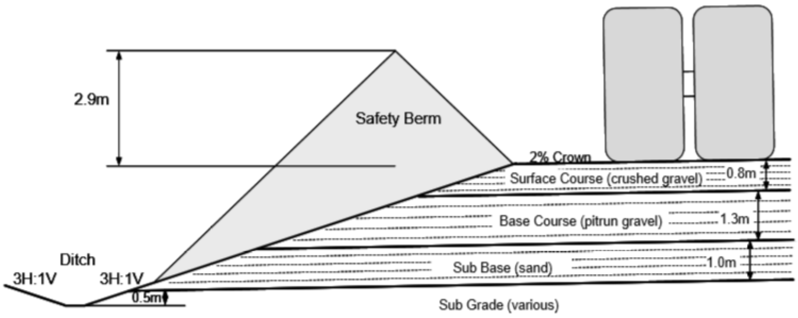


Figure 2-9: Earth Safety Berm for 360t truck - Source: (Tannant & Regensburg, 2001)

Testing undertaken has shown that earth berms should be much larger than the axle height to stop a vehicle at speed. The berm would be required to be at least four times the axle height for vehicle over 85 tonnes, based on 48km/hr, and an impact angle of 30 degrees (Work Safe New Zealand, 2015). Berms of this size are best suited to adverse conditions such as steep declines with sharp corners. Suitable berm configurations according to Work Safe New Zealand for adverse conditions and normal operating conditions are shown in Figure 2-10 below.

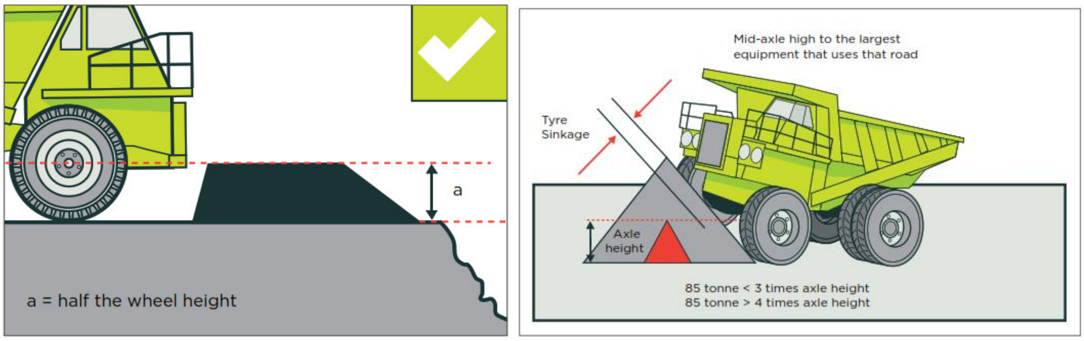


Figure 2-10: Suitable berm (L) & berm in adverse conditions (R) - Source: (Work Safe New Zealand, 2015)

2.3.4.2 LARGE BOULDER BERMS

A large boulder berm consists of large boulders lining the haulage road carriage way with an earthen backing material (Kaufman W., Ault J, 2001). This type of berm presents the impacting vehicle with a near vertical face that deflects the vehicle for slight angles of incidence. There are however some downsides to this type of berm. Some downfalls include difficulty to construct, and damage to the haul vehicle when struck. The height of the boulder berm should be the height of the tyre to ensure minimal chance of overturning.

2.3.4.3 TYRE BERMS

Tyre berms can be utilised in much the same way as boulder berms. In this scenario, the tyre replaces the boulder and is filled with earth material. The tyres utilised no longer have any use as they are worn from the haul vehicles, therefore this may only be utilised in existing mines where used tyres are available.

2.3.4.4 CONCRETE STRUCTURES AND OTHER CONTROL MEASURES

Concrete structures can be utilised for deflection of haul vehicles, although this is not utilised very often as it carries a high installation cost for such a structure. They are usually only adopted to protect critical structures such as bridge columns. An example of a concrete structure protecting bridge columns is shown in Figure 2-11 below.

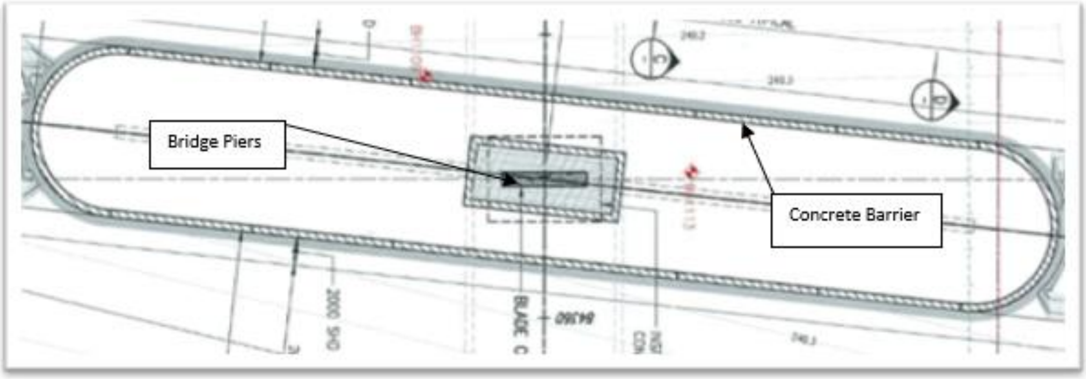


Figure 2-11: Example plan of concrete structure as haul vehicle control measure

2.3.5 INTERSECTIONS

The types of intersections that can be utilised within the mining industry is similar to standard road engineering, which, according to Austroads (2009), is a T-intersection, Y-intersection, four-way intersection and a multileg intersection. Other considerations within road design include the operation of the intersection with traffic controls, signage, channelisation, sight distance and layouts.

The review of the accident databases has identified that fatal incidents have occurred at intersections. Removing the interaction of these vehicles at intersections is critical to eliminate the risk, and can only be undertaken with options such as directing the LV under, or over, the haul road with an elevated platform or bridge.

From industry experience, crossing the LV under the haul road would be undertaken with a variety of methods, including cut and cover tunnels and by using materials such as earth retaining arch structures or drainage structures. Loads from the haul vehicle would need to be designed accordingly to ensure structural failures do not occur. For the best operational efficiency, a LV underpass would be required to be two-way to ensure the best results are achieved from the traffic model (Birkbeck, 2014). An example of a proposed arrangement is shown in Figure 2-12 below:

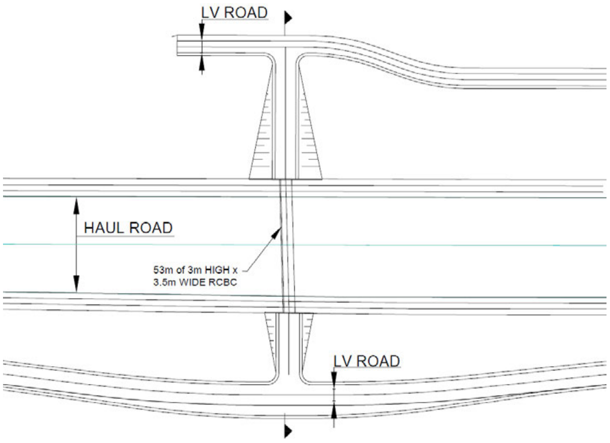


Figure 2-12: Plan - Crossing of HV and LV – Underpass

A typical section through the haul road is shown in Figure 2-13 below:

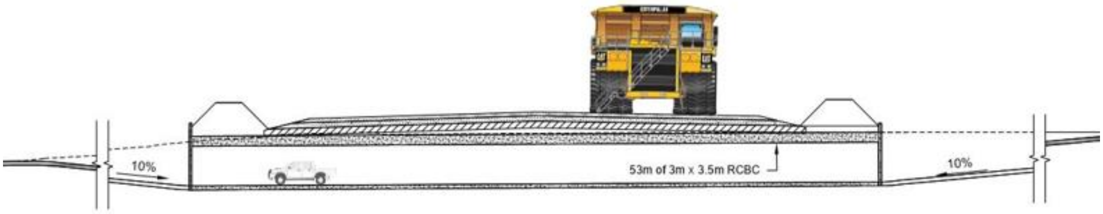


Figure 2-13: Section - Crossing of HV and LV – Underpass

Crossing the LV over the haul road can be done through the means of a concrete bridge structures. The clearance would need to allow for loose material in the HV tray piled up above the height of the vehicle. For optimal efficiency the operation of the HV road would remain bi-directional, although could be split into two one-way carriageways to reduce the spans of the bridge. The piers would be protected with concrete structures. The abutments and ramps would be earth fill and would be in the vicinity of 150m in length (Birkbeck, 2014). A section of the proposed solution is shown in Figure 2-14 below:

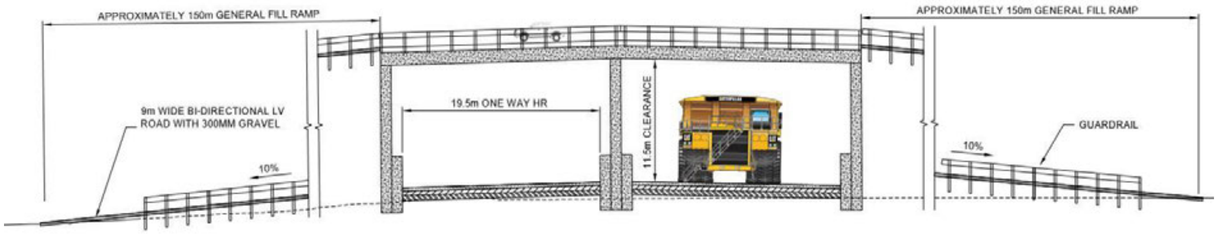
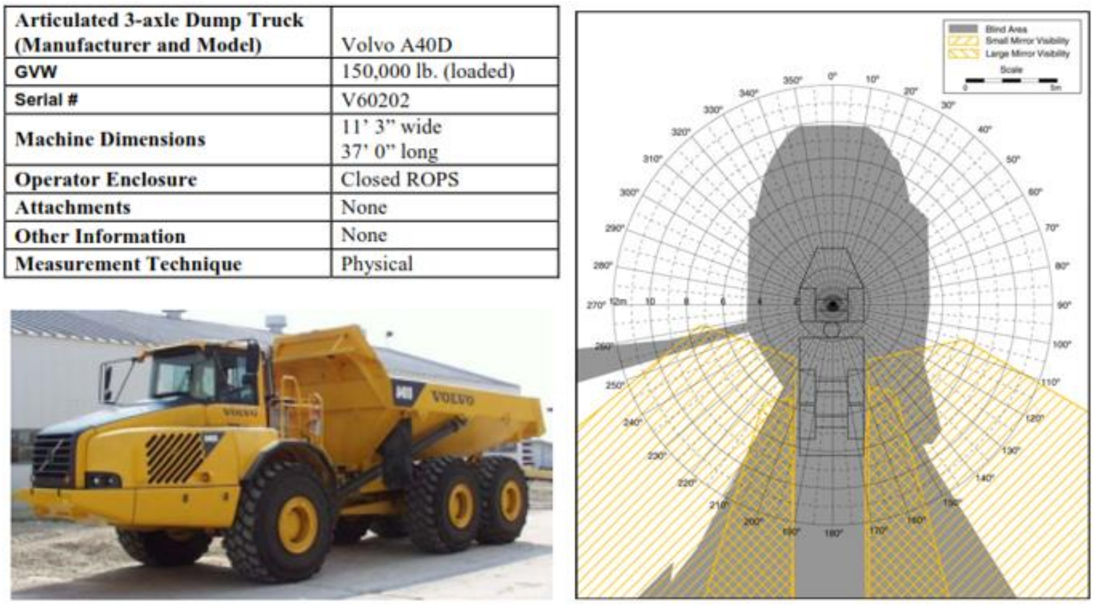


Figure 2-14: Section - Crossing of HV and LV – Overpass

A critical aspect of the layout of intersections within mining is the applicable sight distance of the vehicles, as examined in the following sections.

2.3.5.1 SIGHT DISTANCES

The factor of driver visibility is significant to consider for haul vehicles and the collision occurrences. Many of the collision incidents that have occurred can be contributed to limited visibility around the equipment (Caterpillar Inc, 2004). As a result, blind area diagrams for operators have been developed to understand the risk. An extract of one of their diagrams is shown in Figure 2-15 below.



Articulated 3-axle Dump Truck (Manufacturer and Model)	Volvo A40D
GVW	150,000 lb. (loaded)
Serial #	V60202
Machine Dimensions	11' 3" wide 37' 0" long
Operator Enclosure	Closed ROPS
Attachments	None
Other Information	None
Measurement Technique	Physical

Figure 2-15: Haul vehicle driver visibility - Central operator

The figure shows that the driver cannot see objects on the ground in front of the vehicle for up to 10 metres. The above diagram shows a central driving position; however, right-side cab haul trucks have far worse driver visibility, especially in Australia where HV operators drive on the left-hand side. A blind spot diagram for the right-side cab haul truck is shown in Figure 2-16 below.

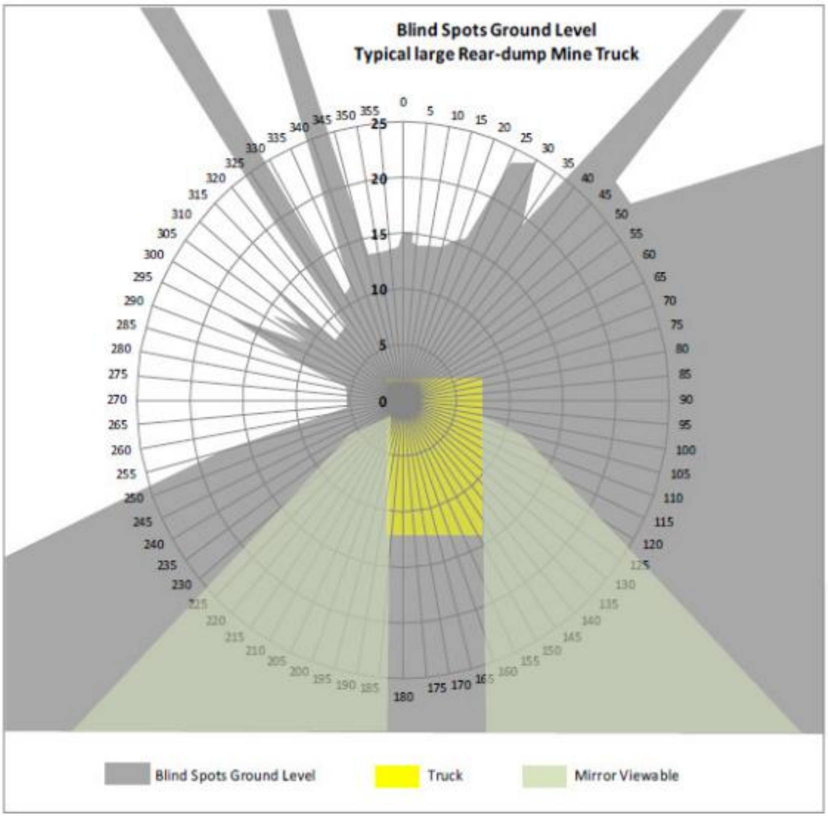


Figure 2-16: Haul vehicle driver visibility – Right hand side operator - Source: (Thompson R. , 2013)

Figure 2-16 shows that the entire right-hand side of the haul vehicle is not visible to the HV operator and therefore would not see light vehicles overtaking or on the right-hand side of an intersection. The extent of such limited visibility is shown in Figure 2-17 below, where plant was set up around a haul truck and is not visible to the driver (Glynn, 2001).

Figure 2-17: Haul vehicle limited visibility from driver's cab - Source: (Glynn, 2001)

When examining over 200 haul truck incidents over the 10-year period of 1989 to 1999, researchers found evidence that the vast majority occurred not due to speed, but due to lack of driver visibility (Mark & Verhof, 1999). A possible solution or risk reduction method being investigated in the mining industry is the use of technologies to improve driver visibility.

The 2013 incident report attached to this report as Appendix A highlighted a factor of the incident was the poor sight distance where it described the *operator's cab being situated on the left-hand side of the truck and is almost five metres above the ground. As can be seen in the figure below, the truck operator has very limited vision for at least 20 metres off to the right side (blind-side) of the truck for anything that is less than two metres tall. The truck operator's vision is further restricted by the cab rollover protection structure, mirrors, handrails, and other equipment on the truck cab deck* (NSW Mine Safety Investigation Unit, 2015).

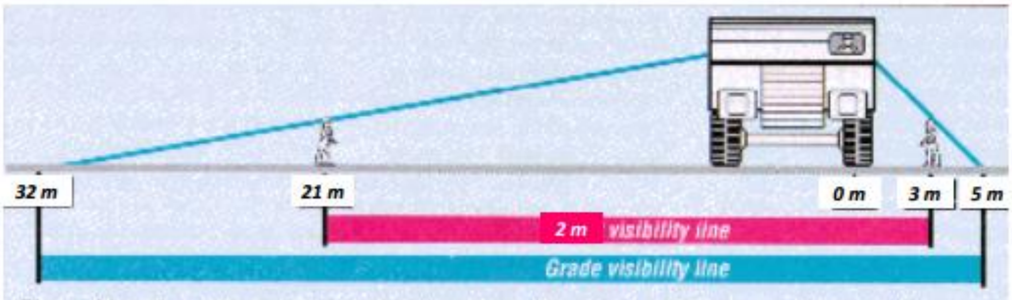


*Figure 2A.—Front view of vision limitations from the cab of a 150-ton rear-dump truck**

Illustration of blind spots around a mining truck (from Miller, 1975)^2
Illustration indicative of vision from a large RDT, distances shown are approximate.

Figure 2-18: Haul vehicle blind spot - Source: (NSW Mine Safety Investigation Unit, 2015)

Gaining an understanding of how the vehicles are managed on the mine site is critical to eliminating the risk. This is outlined in the below sections.

2.3.6 TRAFFIC CONTROL

The Traffic Management Plan set outs the requirements of the traffic operations in a mine. However, generally regulatory road rules apply, where operators must obey all signs and traffic rules (NSW Mine Safety Investigation Unit, 2015).

The following traffic control items have been highlighted from a reputable mining operator within Australia:

- Speed limits of 80km/h for haul road & 40km/h for in-pit roads;
- Large machines have right of way over smaller machines;
- LVs entering/exiting haul roads must give way to all other vehicles;
- All vehicles are to announce their presence in a work area; and
- No vehicle can overtake any other vehicle unless safe to do so.

A LV overtaking a HV is not recommended as there is a risk of being run over if the HV is turning and the LV is within blind spots (Department of Mines and Petroleum, 2011). This is due to the poor sight distance of the haul vehicles and not being able to see approaching light vehicles.

2.3.7 TRAFFIC MODELLING SOFTWARE

Traffic modelling can be undertaken to develop an understanding of the efficiency of an additional road network. The research had undertaken a review of current traffic modelling packages within the infrastructure industry to determine which software could be utilised in the mining industry. The review has identified Aimsun as a suitable package as the software was able to alter road characteristics to match haul roads within the model. The software also allowed the creation of haul vehicle characteristics both spatially and operationally. The software was also able to alter the vehicle operations to remove the ability for vehicles to overtake which matches the traffic operation within mines. Finally, after consultation with the software developer, a copy of the software was provided to the University of Southern Queensland for the purpose of this research.

The process of traffic modelling included developing the mine layouts within the software, creating the vehicles with spatial and operational characteristics, and distributing traffic volumes to each carriageway segment throughout the mine. The result would be two separate models with the base case of HV-LV sharing the road network and a comparison model with HV-LV separated carriageways, as shown in Figure 2-19 below.

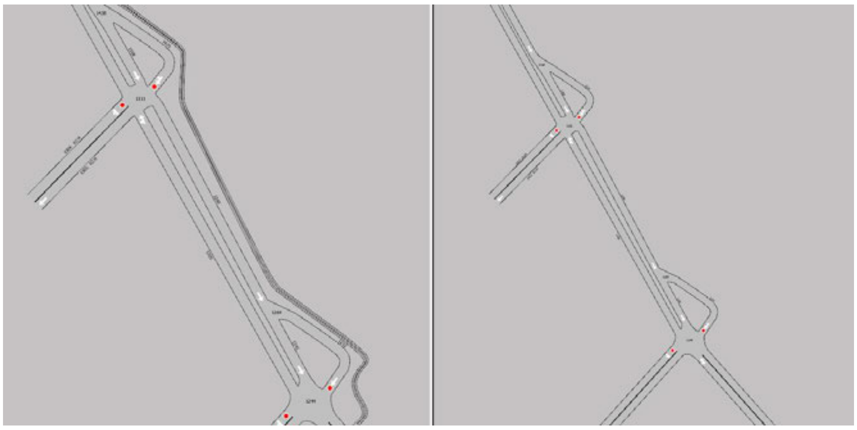


Figure 2-19: Plan view traffic model – separated network (Left) - shared network (Right)

The traffic simulation software is typically utilised in the modelling of urban road networks. However, mine roads have significantly fewer traffic volumes than urban roads. Therefore, it is proposed to alter the traffic volumes and distributions of the haul vehicles and light vehicles to determine how it impacts the interaction of HV and LV interaction.

2.4 METHODS OF CRASH MITIGATION

It has been identified in the previous sections that incidents between HV and LVs are occurring within the industry. The most relevant method of crash mitigation identified from the mine operators, government authorities, and industry leaders is providing physical separation of the vehicles where financially viable. Ultimately providing a hard separation of the vehicles can only be undertaken with the provision of separate road networks, which results in capital outlay to the mine operators.

Mining companies are operated as businesses that require a detailed analysis of production and safety changes prior to approval and expenditure on projects. This section will investigate the current methodologies available for decision making within the mining and transportation industries.

2.4.1 CRASH MITIGATION WITHIN THE TRANSPORTATION INDUSTRY

The transportation industry has utilised the Safe System approach, which is regarded as the best practice in road safety internationally and provides an outcome whereby death and serious injury are virtually eliminated. A general introduction to the Safe System approach can be found in several Austroads publications (Austroads, 2020). Safe System is the management and design of the road system such that impact energy on the human body is firstly avoided or secondly managed at tolerable levels by manipulating speed, mass, and crash angles to reduce crash injury severity (Wooley et al. 2018). The use of such methodology for the investigation of HV-LV interaction will result in complete separation of the vehicle classes, as the human body cannot tolerate the crushing forces of a HV impacting with a LV due to the significant difference in vehicle mass.

Historically, identifying road improvements based on safety considerations has tended to be of a reactive nature, where improvements have been identified via historical crash data. The Safe Systems Framework builds on the reactive approach with a proactive approach to road improvements at a corridor level, which evidence suggests can have a better outcome than the incremental sum of individual site treatments from reactive improvements (Levett et al. 2009).

Utilising the transport industry’s Safe System approach to design mining haulage roads and intersections will result in complete separation due to the significant energy in the event of HV-LV collision. Using the proactive approach to design will result in a complete mine re-design to implement vehicle separation.

However, there are some negatives. Utilising the transport industry’s approach may not be entirely suitable as capital expenditure would require different approval processes as outlined.

2.4.2 CRASH MITIGATION WITHIN THE MINING INDUSTRY

The mining industry has a different structure to the transport industry, as the stakeholders are private companies with a greater focus on cost effective decision making than government departments. Many risks are present, although these can be managed with the use of appropriate risk management processes.

According to the NSW Resources Regulator, Mines within NSW are required to prepare a Principle Hazard Management Plan which identifies, examines and manages the risks throughout the mine site. The most effective safety control measure involves eliminating the hazard as shown in Figure 2-20 below (NSW Resources Regulator, 2016).

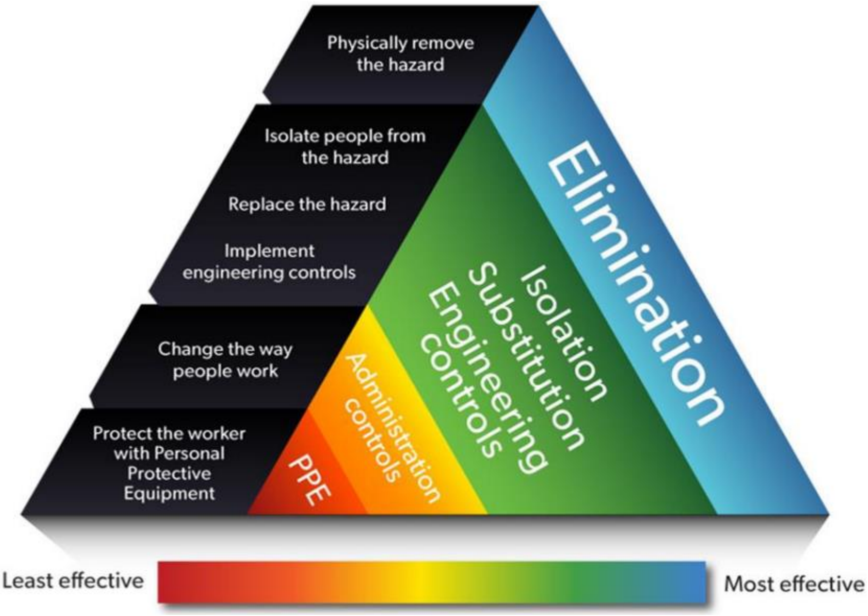


Figure 2-20: Hierarchy of controls – Source: (*Preparing a Principle Hazard Management Plan* 2016).

When applying the risk elimination control method to the risk of HV-LV interaction, it is generally acknowledged this is only achievable by segregation or separation of the vehicles. However, tasks may still be required where LV would be required to approach HV within a mine site, and therefore can only eliminate as much of the interaction where possible. This results in numerous factors to consider when dealing with the quantitative economics of the hazard. With that being stated, understanding the costs and benefits of the risk elimination is important.

A more detailed approach to the HV-LV separation would be a methodology that incorporates the problem and solution related to the Risk Management Framework and Profit Optimisation. The methodology known as the risk optimisation decision-making model, RODMMODEL, (Yilmaz 2014) determines if the project has the potential to deliver substantial savings through profit optimisation, by a proactive assessment of risk management strategies. This leads to an investment in those strategies and the savings achieved, as a result of eliminating the impact of potential major unwanted events. Implementation of the appropriate risk management strategies along with securing stable positive operational cash flows leads to business sustainability. This methodology utilises the following frameworks, as shown in Figure 2-21 below.

Figure 2-21: Risk management framework stages - Source: (Yilaz, 2014)

The analysis tools utilised is an important component within the risk management framework. The key analysis tools utilised for decision making from Yilaz's Risk Management Framework are also consistent with other mining practices as identified by Runge (1998). These analysis tools include measures of values to inform the decision of implementing the financial investment, such as the Discounted Cash Flow (DCF), payback method and sensitivity analysis tools.

Almost every decision in mining involves cash flows occurring at different points in time (Runge 1998). Therefore, decision making with a DCF is utilised by developing a complete tabulation of cash flows occurring through each year of the mine life.

Present values are determined by utilising a discount rate to convert future values to a present value. The range of the discount rates can vary dependent on the industry, country, and the project stage. Research shows that 3.5% is utilised by the American

Association of State Highway and Transportation for highway projects (American Association of State Highway and Transportation Officials (AASHTO), 2010) and 7% is utilised for Australian transport infrastructure projects (Rockliffe et al. 2012). Rates recommended by the Centers for Disease Control and Prevention, which utilises a calculator for fatal incidents within mining in America, recommend a real discount rate of 3%-5% (Centers for Disease Control and Prevention , 2021). The rate utilised by Safe Work Australia (Safe Work Australia, 2015) is a rate of 3.4%, which utilises numerous components such as savings and wage increases. A suitable approach of this mining study would utilise a weighted discount rate considering the project stage (Feasibility study 3%-5%) and project category (Adding a new project to an existing complex (8% to 10%) (Taheri & Ataee-pour 2010). This research is considered a feasibility study, therefore a discount rate of 5%.

The Payback method determines the timeframe for the initial cost of the project to be paid back utilising the financial values of mine production in current value. Sensitivity analysis is essential to identify the critical aspects of the investment model that affect model output uncertainty (Haahtela 2011). The purpose in sensitivity analysis is to determine which input parameters are important and contribute most to the output variability (Helton, J. Davis F, 2000). The sensitivity analysis will investigate how elements such as the timeframe for an incident to occur will affect the DCF.

2.5 ECONOMICS ASSOCIATED WITH INTERACTION AND THEIR MITIGATIONS

The cost of introducing and operating new work procedures and equipment is a major consideration for any mining operation. When new safety procedures are introduced, a key consideration will be the cost of implementation weighed against the anticipated savings in human suffering and production losses.

Typical costs for segregating the vehicles would occur due to the additional construction for more roads, and on-going maintenance required in the future. The financial gains for this would be evident in eliminating future incidents and fatalities from the mine, along with efficiency gains in production.

2.5.1 CONSTRUCTION COSTS

Where existing mines do not have vehicle separation, construction costs would be applicable for the new road networks to provide the separation, including new drainage infrastructure and new intersections to eliminate the risk. The construction costs for incorporating additional road networks within deep pits also requires additional overburden removal to maintain safe batters. The literature reviewed provided generalised construction costs (Rawlinsons, 2020), but these were determined to not reflect the costs of earthworks projects in remote locations on private mining sites. Therefore, the costs utilised for the research were actual costs from recent mining projects, and this costing information was confidential in nature.

2.5.2 MAINTENANCE COSTS

Where new roads are constructed, the operators will be required to maintain the road networks into the future. Maintaining HV-LV roads to standards that would provide good riding surfaces, carry the expected traffic loads, meet mine expectations, minimise safety hazards, and provide free draining surfaces for the life of the roads is what would be expected of a usual maintenance regime (Birkbeck, 2014).

There are two types of maintenance to be considered with gravel roads (Giummarra 2009) which includes:

- On demand maintenance for unforeseen events and when a significant defect occurs; and
- Preventative maintenance, both routine and periodic.

2.5.2.1 ON DEMAND MAINTENANCE

On demand maintenance is identified by utilising the patrol method. This can be undertaken during the mine’s day-to-day activities. Cost for on demand maintenance is best achieved using past maintenance cost data. However even with this method, an allowance must be made for infrequent catastrophic events, such as a cyclone and severe storm damage.

2.5.2.2 PERIODIC MAINTENANCE

Mine site roads might be privately owned but they still need to meet the safety requirements of regulations and acts. Therefore, maintenance needs to be undertaken on a regular basis and is usually scheduled. Table 2-4 below shows maintenance schedules that were developed from Giummarra (2009).

Table 2-4: Periodic maintenance of light vehicle roads

Activity Description	Frequency
Light Formation work on pavement and shoulders – no water added	Annually
Light formation grading – with added water on pavement and shoulders	1/8 of all roads Annually
Clean and restore table drains and cut off drains	1/8 of all roads Annually
Re-sheeting of pavement and shoulders including preparation of bed	1/30 of all roads Annually

2.5.3 BENEFITS OF RISK MITIGATION – SOCIETY

By mitigating the risk of haul vehicle and light vehicle interaction there are benefits accruing from the fact that incidents won’t occur in the future. These benefits will be examined in the following sections, and are treated as benefits to society, the employer, and the employee.

According to Safe Work Australia (Safe Work Australia, 2015) the current average cost to the community would be $585,000 for a fatal injury and $1,578,800 for a full incapacity injury. This cost would include public health care, investigation, travel, legal, tax losses, and be subject to inflation to calculate future sums.

2.5.4 BENEFITS OF RISK MITIGATION - EMPLOYER

The benefits of the risk mitigation for the employer would include reducing production delays to the mine, replacement costs for the employee, damage to assets, company reputation, and investigation costs. These elements are outlined in the following sections.

2.5.4.1 PRODUCTION DELAYS

The employer would suffer financial losses due to loss and delay of mining production in the event of an incident. The size of this loss being dependent on the production value and duration of the incident impact. News sources often identify that mine shutdowns occur following incidents in mines. According to the Herald, following an incident on the 30th of November 2013 at Ravensworth Mine in NSW, operations were shut down on the 2nd of December, and were only going to resume in a staged manner, which would consider people's needs (Herald, 2013).

The Mining Weekly outlined that operations at Daisy Complex in WA were suspended on the 10th of June 2021. This was after the death of an underground contractor at the mine in Mount Monger, with production activities resuming the 15th of June and mine development resuming the 21st of June (Mining Weekly, 2021).

Mine shutdowns and financial losses are also initiated by the regulators. An enforcement method available to the Queensland Mines Inspectorate (QMI) is a directive to shut down while rectification occurs. An interview with a QMI office stated: *"I'm a great believer in shutting down if they don't comply. If you shut a coal mine down for a day it's – minimum, a million dollars they have lost"* (Queensland Ombudsman, 2008).

With shutdowns occurring following mining incidents and fatalities, it's reasonable to expect a significant shut down in duration in the event of a HV-LV incident in the vicinity of one week.

2.5.4.2 EMPLOYEE REPLACEMENT COSTS

There are several expenses to be paid to run administrative tasks during and after a fatal crash in the mining sector. The employers will bear the cost of running a compensation board as well as recruiting new staff to replace the deceased. The cost of recruitment varies; however, the financial costs would include advertising costs, consulting costs, on boarding costs and training costs (SignatureStaff, 2017). According to Sylvia Vorhauser's Model, if an employee leaves within 12 months, the cost to the organisation can be up to 55% of their salary (Workplace Info, 2017). Therefore, with an average wage in the mining industry to be $123,844PA (IMinco, 2020), the financial impact for employee replacement would be approximately $70,000.

2.5.4.3 ASSET DAMAGE COSTS

In the event of a HV-LV collision, damage to LV and HV will occur, where given the significant difference in size of the vehicles the LV is most likely to be non-repairable. This was evident in the identified 2008 and 2013 fatal collisions where the LV was not repairable and minor damage was sustained to the HV. Therefore, the asset cost is equal to the cost of replacement of the LV, plus incidentals that would include the employee's time to undertake the transaction and convert the car to be mine site compliant. Vehicles requiring mine site compliance include radio communication systems, roll cages, visibility flags, high visibility markings, first aid equipment, reversing alarms, and lighting as shown in Figure 2-22 below.

Figure 2-22: Typical mining light vehicle setup – Source: (Fleet Crew, 2021)(*Fleet Crew - What Makes a Mine Spec Vehicle Suitable for the Mines?* 2021)

Discussions with companies that fit out LVs to be mine site compliant has determined that a vehicle would cost approximately $100,000 after all incidentals to be compliant.

2.5.4.4 COMPANY REPUTATION

The company reputation is a valuable and intangible asset. According to a research report undertaken by Citi (Sydney Morning Herald, 2014) it states *"From a shareholder perspective, a poor safety record can have a detrimental impact on a company's share price and earnings performance, particularly if it results in production disruptions or the shutdown of a mine or plant or rig. In the case of contractors, a poor safety record can impede its ability to win contracts, particularly with governments and big resources companies".* While the larger companies are listed within the stock exchanges, the impact in terms of stock value may be impacted because of mining safety incidents. Company reputation would be difficult to quantify as the financial impact would be different for most companies and depend if the company is listed on a stock exchange and the company valuation.

2.5.4.5 INVESTIGATION COSTS

Investigations is another form of administrative cost that is borne by the employer as the organisation would be required to delegate a team to carry out the investigation, employ a detective, or outsource it to an agency (Duguay et al. 2013). It would be logical for a company to contract a third-party reviewer of policy and procedures of HV road operation to ensure compliance with legislation.

2.5.4.6 INCREASED PRODUCTIVITY AND EFFICIENCY

There would also be value in implementing separation of the vehicles due to increased productivity and efficiency recognised with additional road networks. Productivity and efficiency increases would be the outcome with additional road networks available for the LV and subsequently reducing vehicle interaction of HV. As LV can travel at faster speeds than haul vehicles, the overall efficiency of the LV utilising the mine site would be improved with increased cycle times between destinations. It is important to identify that any increased speed from the LV is due to the slower HV operating on the road network. The increased productivity would not account for speeds faster than the posted speed.

Also removing LV from haul roads would reduce delays experienced due to vehicles giving way at intersections, resulting in faster cycle times. When cycle times are faster for HV, the more product gets hauled and loaded. However, there can be other improvements that may be beneficial to mining operation, including vehicle maintenance savings due to less braking, which reduces wear and tear on haul trucks brakes and transmission. When a truck stops or slows for LV, the fuel consumption is increased to accelerate to the original speed (Viewpoint Perspectives on Modern Mining, 2021).

To gain an understanding of the actual economics of productivity and efficiency gained with vehicle speed, delay and density, traffic modelling software can be utilised.

2.5.5 BENEFITS OF RISK MITIGATION - EMPLOYEE

The largest costs of fatal incidents for the employee are the loss of income over the long term. This cost is approximately equal to the present value of the individual's expected income over the period between leaving work and retirement (Safe Work Australia, 2015). With the median working age within the mining industry being 41 years (Australian Government, 2021) and with the age eligibility for retirement being 67 years (Department of Social Services, 2021), that equates to an average of 26 years of lost income.

The review of these economics relating to haul vehicle and light vehicle interaction has the identified numerous costs and benefits of risk elimination. With mining companies operating as a financial entity reporting to stakeholders, the economics of the risks are an important input to decision making frameworks. However, understanding how the economics can be utilised within risk-based decision making is an equally important factor.

Given the risks involved with HV-LV interaction, technology advancements have been occurring as a result, and are examined in the following sections.

2.6 ADVANCES IN TECHNOLOGY AND CRASH MITIGATION

Technology advancements is inevitable in almost all industries and is true within the mining sector. As companies and machinery suppliers strive to gain a cheaper, more productive, and safer environment, technology evolves. This section will investigate the current technologies in the marketplace, the level of technology being utilised in Australia and the influence in LV and HV collisions.

2.6.1 CURRENT TECHNOLOGY

HV suppliers such as CAT and Komatsu have been developing technology solutions to commercialise this niche market. Caterpillar has developed an integrated mine operation and mobile equipment management system, with multiple capabilities to meet the user’s needs. Their MineStar system has several levels of technology, scalability ranging from standalone systems to systems that require software, and radio communications. The system includes cameras on all four sides of the vehicle for object identification, and short (7m) and medium (20m) range radars that will detect the presence of other objects and determine distances to them. This information is then presented to the driver on a touch screen display located in the cab with audible alarms. This technology is developed for low-speed environments as the radar system goes on standby after 20m is travelled or 8km/h is achieved. Therefore, it is not suitable for all operating environments of the mine, such as haulage roads (Caterpillar, 2011). Some of the aspects of this system are shown in Figure 2-23 below.

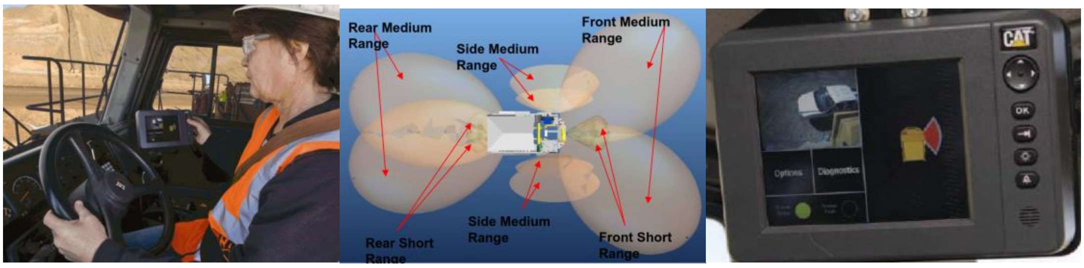


Figure 2-23: (L) Display position - (C) Radar coverage - (R) Display content – Source: (Caterpillar, 2011)

The other systems that require software and radio communications are site awareness based, which track machines and LVs via GPS. The machines send their coordinates via a wireless network and the office broadcasts all the machines' positions back to the operators. Elements of this technology include setting up no-go zones, speed limit tracking, tracking hazards, proximity awareness of machines and lane tracking, all with audible alarms to the operator (Caterpillar, 2011).

The next level of technology advancement is autonomous HVs, which have been developed by Komatsu. Each autonomous HV is equipped with vehicle controllers, high precision GPS system, an obstacle detection system, and a wireless network system. This allows the HV to safely operate through a complex load, haul, and dump cycle. The system can also be integrated with the dozers, loaders, and shovels that are also autonomous. Some of the benefits of this system are the increased safety by removing the HV driver from the remote working environment, reduced operating costs by extended tyre life, increased productivity, and efficiency (Komatsu Australia, 2017).

Collision avoidance system technology are increasing at a substantial rate and now include the use of autonomous haulage systems. Hitachi Construction Machinery Co., Ltd. has established an autonomous driving system for haul vehicles that operates continuously in the difficult communication environments that prevail at mine sites (Hamada, 2018)

The operation consists of driverless haul vehicles which locate the haul vehicle by global navigation satellite systems and inertial measurement units (IMU). The IMU is controlled by path tracking undertaken by the operator within the central control system and detects obstacles using millimetre-wave radar and LIDAR. This operation is depicted within the below figure.

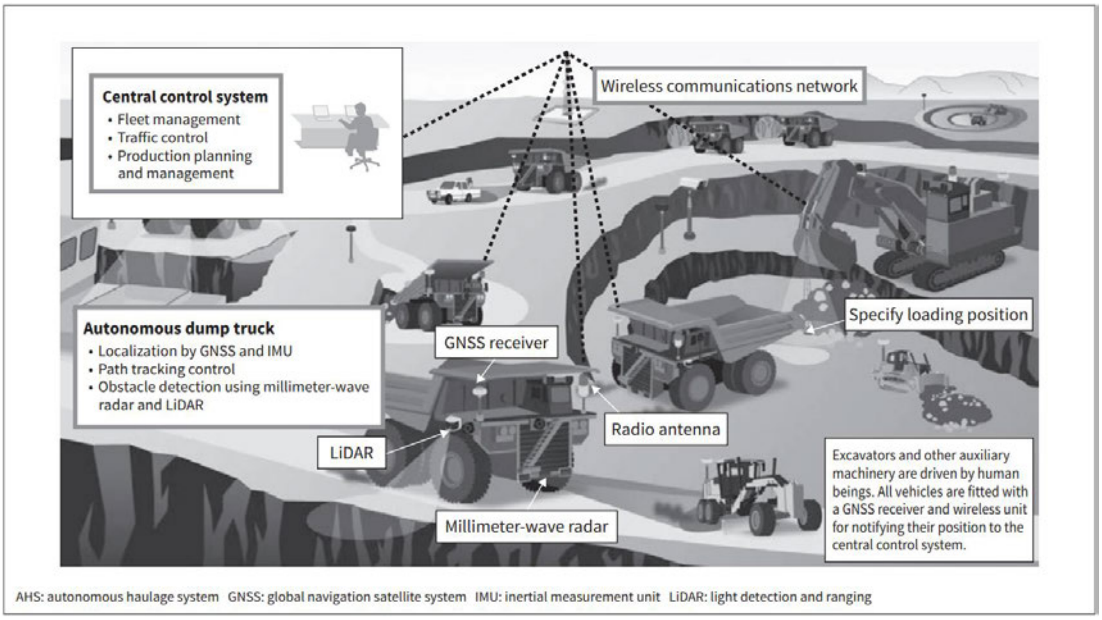


Figure 2-24: Overview of Autonomous Haulage Systems (Hamada, 2018)

The use of machine control is able to reduce the human error of driving haul vehicles that should improve the safety. (Hamada, 2018). Other advantages include the vehicles can work 24/7, with no idle time due to no shift breaks, which can increase productivity up to 20% and improve fuel usage by 4% (GRT, 2022).

Rio Tinto is running ADTs at its pits at Yandicoogina and Nammuldi mine sites, which are being operated 1,200 kilometres away in Perth (Diss, 2015). The mine sites have been digitally mapped and put into a system that determines how to manoeuvre the HVs through the mine. Currently, the company operates sixty-nine driverless HVs, twenty-four hours a day, three hundred and sixty-five days a year without a driver who needs bathroom or lunch breaks. This results in around 500 work hours a year that can be saved.

Since the Covid-19 pandemic has created new working environments, it has been recognised by the top 40 mining companies that embracing automation within the mining industry is the new normal. Automation reduces the workers onsite, which increases health and safety. It also lowers the chance of the coronavirus spreading among the workers (PWC, 2021). This health issue has also been recognised by a major company announcing that they would be investing US$800 million in autonomous haul trucks within iron ore and coal mines in Australia (Rockeman, Attwood, & Deaux, 2020).

2.6.2 TECHNOLOGY PITFALLS

Although technology may remove HV operators from the high-risk environment and reduce fatigue related crashes, the drivers of the LV are still prone to the fatal risk. The LV is in the mine site for engineering inspections, planning and, maintenance, therefore, these operators cannot be eliminated from the hazardous environment, with the use of automated vehicle (AV) technology.

Disengagements of software and hardware systems utilised for AV may be more regular for the mining industry due to the remote nature of sites and high geographical structures, such as large cuttings. Human reaction times in the event of disengagements can be a factor in collisions, along with the distance for the vehicle to come to a stop. A trial of stopping tests for a Cat 785 haul truck were undertaken by Holman (1989), which resulted in 170m stopping distance at a speed of 65km/hr. Therefore, there is still a significant risk of collision after the LV has entered the path of a HV and the Autonomous HV system automatically detects a collision and engages brakes.

Although automation of large machines is already well advanced, this technology is limited by the extent to which automated trucks interact with other non-automated equipment (Nebot, 2007). Automation can improve the productivity because the human factors are either eliminated or reduced. However, such advanced technological systems can become too complex and expensive (Botin, 2009). Therefore, technology may not be a suitable or cost-effective solution for HV-LV interaction for a large range of operating mines.

Autonomous operations require the transfer of data between the vehicles and the control centres and can be at risk of Cyber attacks. Cybersecurity of the mining operations would also need to be considered to ensure the safety of the mining environment as well as providing reliable communication. Cyber physical systems such as autonomous haul systems are also vulnerable to malicious attacks such as WI-Fi De-Auth attacks, GPS attacks and camera Attacks If a lack of security is provided at with the operation, this can result in equipment damage, loss of production, sever injuries and fatalities (Gaber, 2021).

Furthermore, this research has identified a collision that occurred at the Rio Tinto mine with interaction of ADT and non-autonomous fleets, such as with the road maintenance crew. It has also identified incidents that occurred with camera and proximity detection installed. Therefore, regardless of the systems in place, human action and judgement will always remain a factor in vehicle collisions.

Resources Safety and Health Queensland has identified that technology is still not suitable as the “silver bullet” but an added control. Hard controls, such as changes in mine traffic design, road layout, and equipment design changes, together with process controls and softer controls, such as improved communications and procedures, must also be considered (2021).

The hierarchy of controls for risk management would identify proximity detection systems as an engineering control, which is the third preference for risk mitigation measures under elimination and substitution (NSW Government - Industry and Development, 2011).

While technology may add further level of protection, such systems cannot replace existing mine design/layout, engineering and administrative controls, and therefore does not completely eliminate collision type incidents (Department of Natural Resources, Mines and Energy, 2017).

2.7 SUMMARY

This literature review has identified that the mining industry in Australia employs 1.9% of the Australian workforce and is expected to grow at an 8.3% rate per year. Of the Australian states reviewed, two fatalities occurred with haul and light vehicle collisions in 2008 and 2013, with numerous more reportable near misses. To eliminate the interaction and collisions of haul and light vehicle, full separation would be required as recommended by government bodies. However this separation would incur capital costs to the mining company. With that being said, the separation may provide financial benefits by removing possible near misses and fatal collisions, or by providing a more efficient and productive mine site, which is currently a research gap in the mining industry.

The framework of determining if the capital expenditure is suitable to eliminate the risk of interaction of haul and light vehicles would form a risk management strategy that incorporates cash flows to ensure business sustainability.

Although technology in the form of automated vehicles can reduce the risk of collision and fatalities, there is still a risk to light vehicle drivers, unless they are completely separated. The literature review has uncovered a research gap within current guidelines specific to the interaction of light vehicle and haul vehicles, and the economics of risk elimination. Most notably, measuring the efficiency and productivity with traffic modelling packages pre and post separating the HV and LV with different road networks.

The methodology will incorporate the financial and lifecycle analysis of incorporating vehicle separation and compare it to the same mine site which has not incorporated the separation. The methodology will also alter inputs such as mine size and vehicle traffic volumes within the traffic modelling process to examine how it relates to other mines. The methodology will be outlined in detail, in the following section.

3. RESEARCH METHODOLOGY

The methodology will be tested with the use of Case Studies 1 to 4. Case Study 1 will utilise real world data from an existing mine site that shall remain confidential. Case Studies 2 to 4 will alter the input data in various ways as a sensitivity analysis to examine how the framework outputs varies between different types of mines. All four case studies and alterations to the data is shown below:

- Case Study 1 - Base Case
- Case Study 2 - 20% increase in road network length
- Case Study 3 - 20% Less HV traffic volumes
- Case Study 4 - 20% Less LV traffic volumes

The case studies have redacted elements due to confidentiality agreements and liability of third-party data. Therefore, elements such as the mine name, mining personnel, mining company involvement/decision making processes and outcome will not be shown or discussed within these case studies.

The methods for the risk-based framework have been determined with the development, understanding of the collision issues, and ensuring profit optimisation is maintained. Management strategies within the mining industry is aligned with securing positive operational cash flows, which leads to business sustainability. Therefore, key analysis financial tools are the ultimate goal to inform the decision makers within the industry.

To achieve these elements, the risk-based framework has developed the following methodology that was adapted from Yilaz (2014) as shown in Figure 3-1 below.

Figure 3-1: Risk based framework procedure

The stages and how they will be applied is discussed in the following sections.

3.1 STAGE 1: SCOPING THE FRAMEWORK

The initial stage starts with the holistic scoping, which includes extent of the area of the study and how it will be involved, as shown in Figure 3-2 below.

Figure 3-2: Stage 1 – Scoping the framework – Flowchart

The first step is the company engagement meeting and consultation. The outputs achieved was to gain an understanding of the mine location, type and risk profile characteristics of the light vehicles and haul vehicles within the mine. The key contacts and lines of communication would also need to be established and confirmed.

3.2 STAGE2: FRAMEWORK INPUTS

This stage identified the key inputs to supplement the processes that will be undertaken in the following framework stage. The inputs can be categorised as shown in Figure 3-3 below.

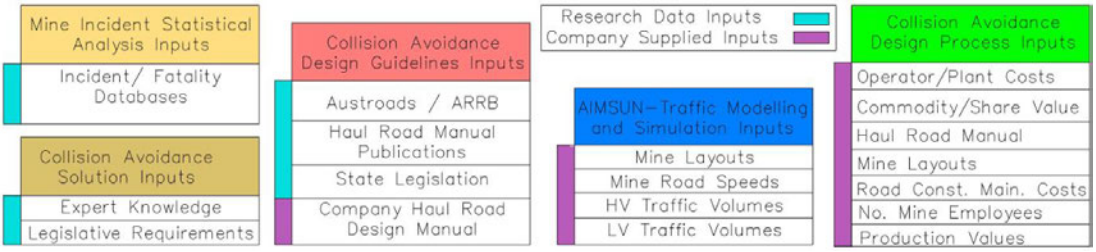


Figure 3-3: Stage 2 – Framework inputs

3.2.1 MINE INCIDENT STATISTICAL ANALYSIS INPUT

The Mine Incident Statistical Analysis (MISA) inputs will include a fatality and incident rate per million people employed in the mining industry. These statistics are developed from analysis of government databases and the number of people employed at the mine.

3.2.2 COLLISION ADVOIDANCE SOLUTION INPUTS

The Collision Avoidance Solution (CAS) inputs will include working knowledge of HV-LV separation solutions.

3.2.3 COLLISION ADVOIDANCE DESIGN GUIDELINES INPUTS

The Collision Avoidance Design Guidelines (CADG) inputs will collate published guidelines from the transportation, mining industry, and company design guidelines to examine current practices.

3.2.4 AIMSUN – TRAFFIC MODELLING AND SIMULATION INPUTS

The inputs for Traffic Modelling (TM) will include previous processes, such as CAS, and designed in accordance with CADG. It will also require mine layouts, vehicle speeds, HV-LV traffic volumes, and distributions for both, the existing mine and incorporating HV-LV separation.

3.2.5 COLLISION ADVOIDANCE DESIGN PROCESS INPUTS

The Collision Avoidance Design Process (CADP) inputs from previous processes, such as MISA, CAS, CADG and TM. It will also include construction/maintenance costs of mine layouts, production/employee values, and commodity values. All the outputs from the framework inputs stage will be developed into the framework processes.

3.3 STAGE 3: RESEARCH PROCESSES

The framework process will utilise the framework inputs developed from Stage 2 and evaluate the data with processes to achieve results for decision making. The framework process and how it is all interrelated is shown in Figure 3-4 below.

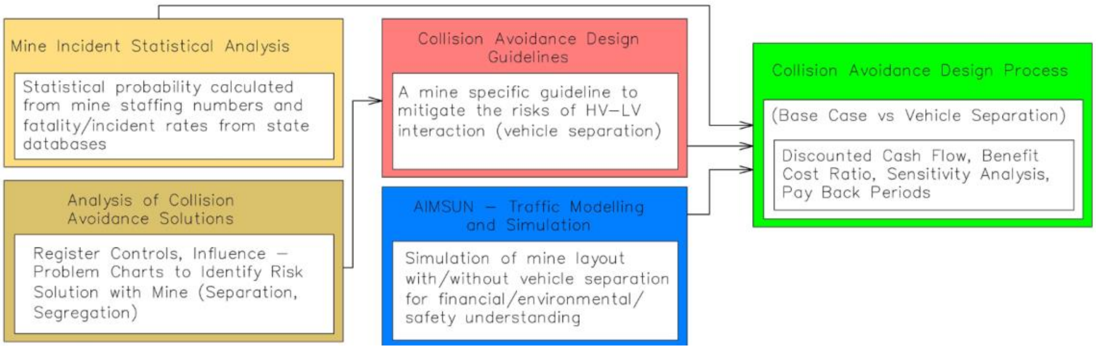


Figure 3-4: Stage 3 – Framework processes

3.3.1 MINE INCIDENT STATISTICAL ANALYSIS PROCESSES

The MISA will be developed from government databases/employee figures to achieve a fatality/incident rate per million people employed in the mining industry. This information will be correlated to the number of people employed in the mine to develop timeframes for a probable incident/fatality to occur at the mine. The output of timeframe for a fatality/incident is an input the duration of CADP tools, including the discounted cash flow analysis.

3.3.2 COLLISION ADVOIDANCE SOLUTION PROCESSES

The CAS is a process to examine the risk of HV-LV interaction and develop solutions, including separation of the vehicles. It is undertaken by mining professionals to develop risk analysis tools such as bow-tie, fault-tree, and risk registers. The output from this process will be confirmation of HV-LV separation as a risk control/elimination solution to be further examined.

3.3.3 COLLISION ADVOIDANCE DESIGN GUIDELINES PROCESSES

The CADG will determine how the risk control of HV-LV separation should be implemented using transport and industry standards. The output will define the critical elements of vehicle separation and develop a feasibility layout of base case (do nothing) and post HV-LV separation. The output from this will be fed into the TM and CADP.

3.3.4 AIMSUN – TRAFFIC MODELLING AND SIMULATION PROCESSES

TM will compare the base case and post separation to examine changes in speed and congestion. The output from the TM will then be input into CADP. The outputs from Aimsun modelling include the

3.3.5 COLLISION ADVOIDANCE DESIGN PROCESSES

The CADP will consist of financial decision analysis of both, the base case and post separation to supplement decision making, risk elimination, and profit optimisation goals of the mine. It will utilise discounted cash flow analysis, and occur over a timeframe for an incident to occur (Input from MISA /mine design life). It will also include financial costs and benefits of the base case and post separation. The discounted cash flow will include construction/maintenance costs of the separation, and benefits such as present value costs borne by the mining company in the event of a future incident, and improved employee productivity congestion reduction

(Input from TM) due to additional road networks. The CADP outputs will include tools such as sensitivity, cost-benefit, and pay-back period analysis.

3.4 STAGE 4: FRAMEWORK OUTPUTS

This stage will consist of process output documentation and the development of a mine specific Framework Output Report (FOR), that will be utilised for mine consultation, data presentation and for decision making processes. This will include summarising each of the process outputs. The framework outputs from each of the process is shown in Figure 3-5 below.

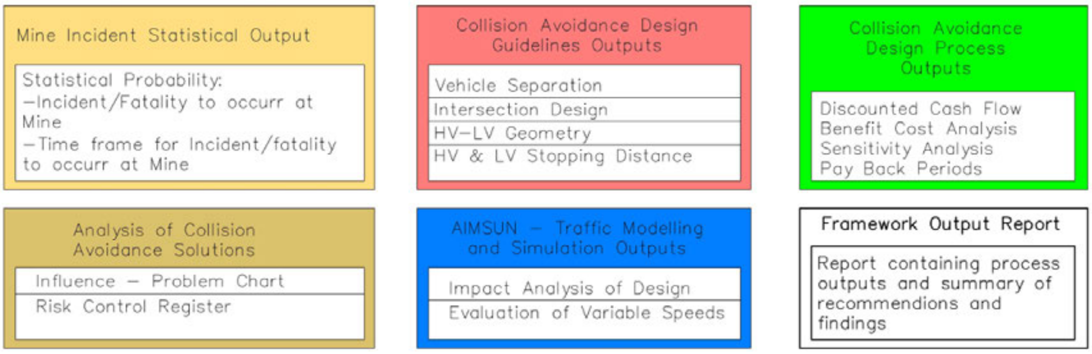


Figure 3-5: Stage 4 – Framework outputs

3.5 STAGE 5: DECISION MAKING

Stage 5 is the decision-making process to determine whether risk elimination in the form of HV-LV separation is suitable to the mining company. It will consist of internal scope from the framework's author, to present and consult with the mine about the findings of the FOR. The stakeholder will then take the FOR into their board approvals process for expenditure. The process is shown in the Figure 3-6 below.

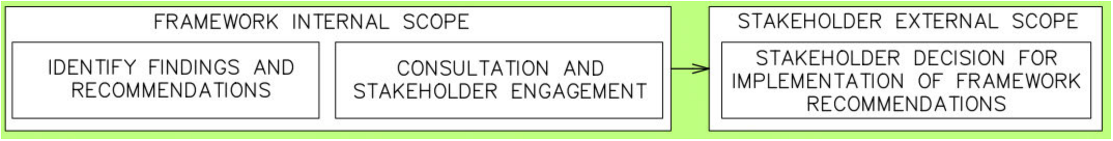


Figure 3-6: Stage 5 – Decision making

4. RESULTS

The results will examine Stages 1, 2 and 3 outlined within the methodology section. This will scope the framework and detail the inputs and processes. Case Study 1 consisting of the base case will be examined prior to altering the inputs for Case Studies 2 to 4.

4.1 STAGE 1 – SCOPING THE FRAMEWORK

As forementioned, due to confidentiality restrictions the scoping of the framework stage results is limited. However, the mine examined for this study was an open cut mine located within Queensland. Approval for the analysis to be undertaken was achieved through contacts within the mine, and operational knowledge was achieved through technical meetings and industry work experience.

The risk of HV-LV interaction within the mine has been reduced where possible and there is a separation of the vehicle's classes within the main haul road network, haul vehicle parking, and maintenance areas. No separation is provided for pit ramps or in pit travel. For the purpose of this case study, it will be assumed that no vehicle separation is implemented and will provide greater understanding of the risk.

4.2 STAGE 2 AND 3 – FRAMEWORK INPUTS AND PROCESSES

The results from the framework inputs and process will be discussed for each process as outlined below.

4.2.1 MINE INCIDENT STATISTICAL ANALYSIS INPUTS AND PROCESSES

As outlined in the methodology, the inputs consist of fatality and incident rate per million people employed in the mining industry, including contract workforces. These statistics are developed from analysis of government databases and the number of people employed at the mine. The fatality rate and incident rates from the literature review of government databases are shown in Table 4-1 below.

Table 4-1: Statistical analysis of Australian government data bases

QLD Fatality Database			
Location	**Data**	**Fatalities**	**Fatalities in million employees per year**
QLD Coal Mining Industry	HV / LV Fatalities 1997 - 2019	1	1.87
QLD Minerals and Quarry Mining Industry	HV / LV Fatalities 1997 - 2019	1	1.23
WA Fatality / Incident Database			
Location	**Data**	**Incidents**	**Fatalities in million employees per year**
WA Mining Industry Surface & Underground	HV / LV Incidents 2010 - 2020	78	113.16
NSW Fatality / Incident Database			
Location	**Data**	**Incidents / Fatalities**	**Fatalities in million employees per year**
NSW Mining Industry Surface & Underground	HV / LV Incidents 2007 - 2016	22	82.58
NSW Mining Industry Surface & Underground	HV/LV Fatalities 2007-2016	1	3.75

The inputs will consist of a fatality rate and incident rate of 3.75 fatalities per 1,000,000 people employed, and 113 incidents per 1,000,000 people employed at a mine. The number of people employed at the case study mine is 1,500.

The MISA process shall determine a probability for an incident and fatality to occur at the mine based on the number of employees. This is achieved by multiplying the fatality rate and number of people in the mine as shown in the equation below.

$$Prob. = \frac{Statistic}{1,000,000}\ x\ Mine\ Staff\ No.$$

Furthermore, the time for an incident to occur can be developed by determining when the probability will achieve 100%, noting the statistic timeframe was developed on an annual rate, i.e., when the event will be likely to occur. This can be determined by the equation below.

$$Time\ for\ Incident\ (years) = \frac{1}{Prob.of\ incident}$$

The below Table 4-2 was developed for the MISA.

Table 4-2: Mine incident statistical analysis

Incident Description	Statistic (X in 1M)	Mine Staff (No.)	Prob. of HV LV Incident (%)	Time for Incident (years)
NSW HV/LV Incident	82.58	1500	12.39%	8.1
WA HV/LV Incident	113.16	1500	16.97%	5.9
NSW HV/LV Fatality	3.75	1500	0.56%	177.6
QLD HV/LV Fatality	1.87	1500	0.28%	355.8

The above table shows that the mine has a probabilistic timeframe for an incident to occur in the range of 5.9 to 8.1 years, and a fatal collision to occur in the range of 177 to 355 years. The MISA can be utilised for the CADP to depict the duration of financial analysis and sensitivity analysis.

4.2.2 COLLISION ADVOIDANCE SOLUTIONS INPUTS AND PROCESSES

The inputs for collision avoidance design solution are to develop the underlying influences on the problem of HV-LV collisions. All the influences can be developed into an influence problem chart as shown in Figure 4-1 below.

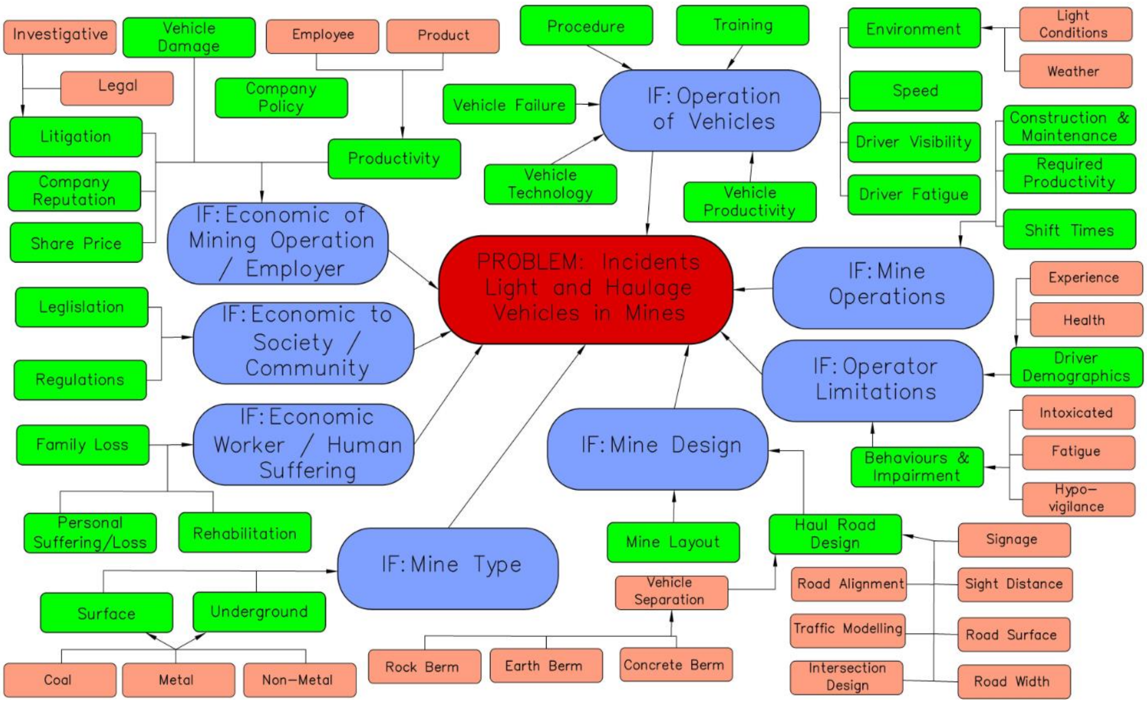


Figure 4-1: Problem / Influence chart - Incidents LV and LV in mines

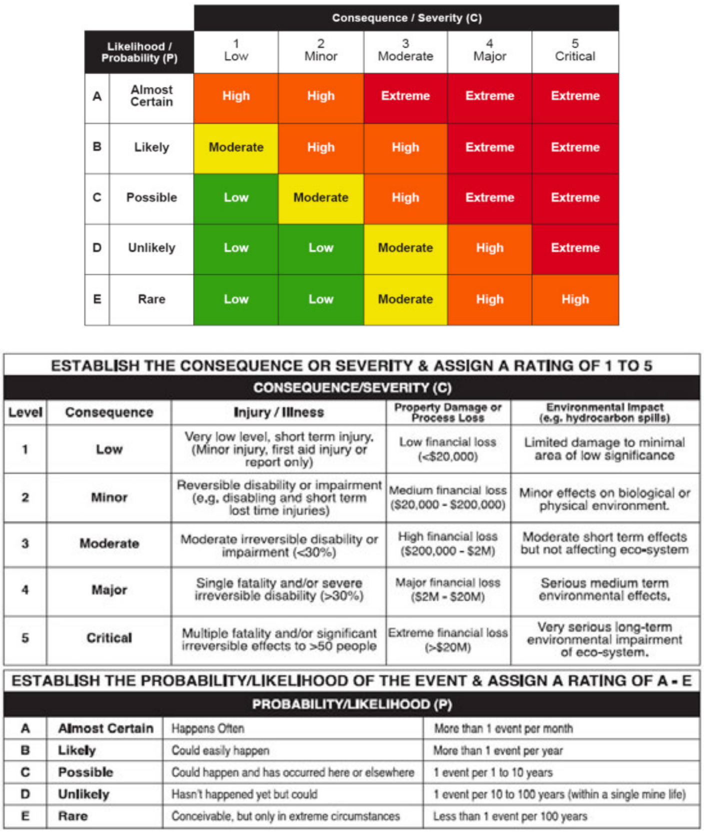
The above figure shows that there are numerous influences on the HV-LV incidents in mines, including the financial influences of society, employer and employee, vehicle operations and the mine design. Gaining an understanding of all the interrelated influences is critical to analyse the risks via a risk assessment.

The CADS process will examine the risk and develop a suitable control. The specific risk has been assessed with existing controls and scored as per the Risk Matrix. This was done with the base scenario of no vehicle separation, and re-evaluated with the additional control of vehicle separation as shown in Table 4-3 below.

Table 4-3: LV and HV incidents on mine road – Risk assessment

Activity	Hazard	Outcome	Causes	Current Controls	Current Risk Score			Additional Controls Required	Residual Risk Score		
					C	L	R		C	L	R
LV Incidents on Mine Roads	Collision (Kinetic energy)	Single/Multiple Fatality	HV Interaction	Design standards	5	D	E	Physical Vehicle Separation - Berms	2	E	L
			LV Interaction	Signage							
			Interaction with stationary structures and road furniture.	Driver Training							

Figure 4-2 below show the Risk Matrix that was utilised for risk scoring.



Likelihood / Probability (P)		Consequence / Severity (C) 1 Low	2 Minor	3 Moderate	4 Major	5 Critical
A	Almost Certain	High	High	Extreme	Extreme	Extreme
B	Likely	Moderate	High	High	Extreme	Extreme
C	Possible	Low	Moderate	High	Extreme	Extreme
D	Unlikely	Low	Low	Moderate	High	Extreme
E	Rare	Low	Low	Moderate	High	High

ESTABLISH THE CONSEQUENCE OR SEVERITY & ASSIGN A RATING OF 1 TO 5

CONSEQUENCE/SEVERITY (C)

Level	Consequence	Injury / Illness	Property Damage or Process Loss	Environmental Impact (e.g. hydrocarbon spills)
1	Low	Very low level, short term injury. (Minor injury, first aid injury or report only)	Low financial loss (<$20,000)	Limited damage to minimal area of low significance
2	Minor	Reversible disability or impairment (e.g. disabling and short term lost time injuries)	Medium financial loss ($20,000 - $200,000)	Minor effects on biological or physical environment.
3	Moderate	Moderate irreversible disability or impairment (<30%)	High financial loss ($200,000 - $2M)	Moderate short term effects but not affecting eco-system
4	Major	Single fatality and/or severe irreversible disability (>30%)	Major financial loss ($2M - $20M)	Serious medium term environmental effects.
5	Critical	Multiple fatality and/or significant irreversible effects to >50 people	Extreme financial loss (>$20M)	Very serious long-term environmental impairment of eco-system.

ESTABLISH THE PROBABILITY/LIKELIHOOD OF THE EVENT & ASSIGN A RATING OF A - E

PROBABILITY/LIKELIHOOD (P)

A	Almost Certain	Happens Often	More than 1 event per month
B	Likely	Could easily happen	More than 1 event per year
C	Possible	Could happen and has occurred here or elsewhere	1 event per 1 to 10 years
D	Unlikely	Hasn't happened yet but could	1 event per 10 to 100 years (within a single mine life)
E	Rare	Conceivable, but only in extreme circumstances	Less than 1 event per 100 years

Figure 4-2: Risk matrix

Initially, the risk score without vehicle separation was ‘Extreme’, due to the ‘Unlikely’ probability of an event occurring within a single mine life, and ‘Critical’ consequence of multiple fatalities due to multiple LV occupants. Post implementation of HV-LV separation, the risk score reduced to ‘Low’, due to the ‘Rare’ probability occurring in extreme circumstances, and ‘Minor’ due to HV property damage with berm interaction and minor injuries.

Therefore, the use of earth berms for HV-LV separation has been utilised for the purpose of this case study. However, alternative vehicle delineation measures may be more suitable for different areas of the mine site depending on location within the mine, and adjacent infrastructure. For example, significant earthworks cut within deep pits or significant structures.

4.2.3 COLLISION ADVOIDANCE DESIGN GUIDELINES INPUTS AND PROCESSES

The inputs for the CADG consist of knowledge from the CADS, published design guidelines and company supplied items. The following design guidelines were identified as design inputs.

- Published Guidelines;
- Good Practice Guidelines – Health and Safety at Open Cast Mines, Alluvial Mines and Quarries;
- Guidelines for Mine Haul Road Design;
- Austroads Design Manuals;
- State Legislation; and
- Company Supplied Haul Roads Design Manual.

While these guidelines are suitable for the region of these subject areas, projects undertaken within different regions and countries may have differing inputs.

The CADG process will apply the design guidelines inputs to specific elements of the road network to designing out the risk of HV-LV interaction. A summary of the elements, background information, recommendation and design guideline utilised is outlined in Table 4-4 below as well as discussed in the following sections.

Table 4-4: Design guidelines elements

Element	Background	Recommendation	Resources/Reference
Intersections	An assessment of the conflict points at different intersection layouts can be undertaken	Intersections should consist of legs at 90 degrees with a T intersection preferred over a 4 way intersection	Conflict assessment – Austroads design guidelines
Road width haul vehicles	Determined by the vehicle widths utilising the road	Consultation with the mine of the largest vehicle utilising the road	Legislation and design guidelines
Road width light vehicles	Rural roads utilised within the public road network is typical	Two way operations are utilised for safe operations	Austroads and ARRB unsealed roads manual
Vertical geometry haul road and light vehicle roads	Eye height in haul vehicles are in excess of light vehicles therefore can have greater lengths of visibility over vertical curves	Vertical geometry design for haul roads to utilise light vehicle design guidelines due to the reduced eye height	Resource ARRB unsealed roads manual
Horizontal geometry haul road and light vehicle roads	A light vehicle can track at much larger radius within a haul road due to the width of the road	The use of haul vehicles for horizontal geometry for the worst case scenario	Haul Road Design guidelines
Stopping Sight Distance	Stopping sight distances can vary for haul vehicle types therefore is mine specific, although is the greater between light and haul vehicles	Consultation with mine to develop stopping distances. Stopping distance to include intersection spacing requirements	Company haul road guidelines and ARRB unsealed roads manual
Vehicle separation methods	Earth berms, boulder berms, tyre berms or concrete structures	The most cost effective method of separation is earth berms	Haul Road Design guidelines

4.2.3.1 Intersections

To design out the risk of HV-LV interaction the intersections required complete separation and therefore a grade separated intersection would be required. This would need either the LV traveling over or under the haul road as shown in Figure 4-3 and Figure 4-4 below.

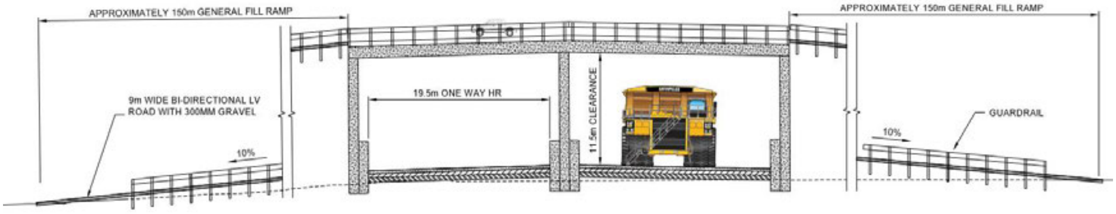


Figure 4-3: LV overpass of HV

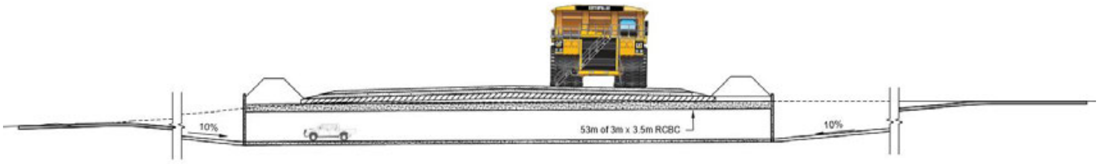


Figure 4-4: LV underpass of HV

For minimal impact to operation, ease of construction and cost effectiveness, the LV underpass of the HV was determined to be the optimal choice for HV-LV separation at intersections.

4.2.3.2 HAUL VEHICLE ROAD WIDTH

The haul road width is related to the width of the largest vehicle utilising the road. Published design guidelines indicate the haul road width shall be designed to 3.5 to 4 times the width of the largest truck using the road for two-way operation. However, according to the government regulations, the road width shall be at least 3.5 times the width of the largest vehicle regularly using the road. Therefore, utilising a Caterpillar (CAT) 797B width of 9.15m, the carriageway cross-section width would be in the vicinity of 33.1m to 36.6m.

4.2.3.3 LIGHT VEHICLE ROAD WIDTH

According to published guidelines (Austroads, 2021) a 9m carriageway width is standard for an 80km/hr unsealed road.

4.2.3.4 VERTICAL GEOMETRY HAUL AND LIGHT VEHICLE ROADS

Vertical geometry of a shared HV-LV carriageway is determined as crest / sag curve values and maximum gradients. As the driver height of a light vehicle is significantly less than a haul vehicle, the crest / sag curves should be designed for light vehicles where applicable. Max gradients have a significant impact to haulage vehicle speeds, fuel usage and safety. The max gradient of 8% from the company guidelines was determined to be suitable for vertical gradients.

4.2.3.5 HORIZONTAL GEOMETRY HAUL AND LIGHT VEHICLE ROADS

Horizontal geometry of a shared HV-LV carriageway is determined with the use of design guidelines for haul vehicles, as the horizontal radius is directly related to the safety of the vehicle drivers seeing each other around a corner. The case study uses a preferred sight distance for haul vehicles of 170 metres, regardless of the speed.

4.2.3.6 SEPARATION OF HAUL AND LIGHT VEHICLE ROADS

The implementation of a cross section that provides separation for both HVs and LVs should consider the physical delineation required between the vehicle classes. The different types of berms consist of large boulders, tyres, concrete structures, and earth berms. Earth berms typically end up being the most common due to construction cost.

Guidelines suggest that earth berm height should be ¾ of the largest HV tyre diameter using the roads, with all berm heights being 1m minimum regardless of tyre size. For this case study, a berm constructed from compacted granular material with the characteristics as shown in Figure 4-5 will be utilised for the vehicle separation.

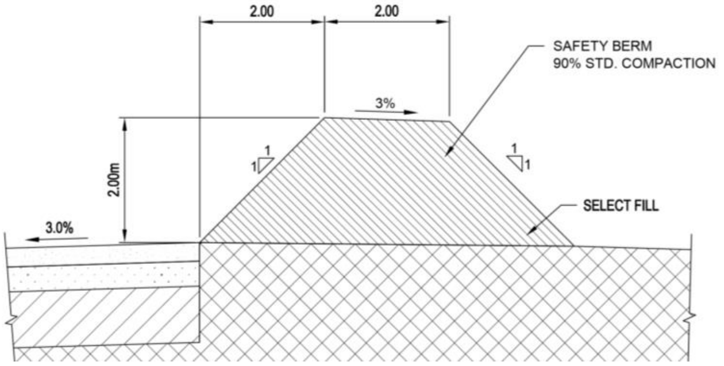


Figure 4-5: Earth berm

With all the design elements identified, the process of designing out the risk of HV-LV interaction can be undertaken for all the different areas of the mine. It was identified that the separation was required for the main haul road network, intersections as outlined above, and the pit area.

With the above design criteria in place, an important aspect of the CADG is to design out the risk with the complete separation of HV and LV. This will continue from the main haul road network through to the ramps, and on to the pit floor to achieve complete separation and hence, risk mitigation.

4.2.3.7 MAIN HAUL ROADS

The main haul road has the largest haul distances, the highest speed environment, and has the highest number of intersections with pit ramps. It also was the location of the identified fatal collisions due to the vehicle interaction. As the site is constricted, all light vehicles adjacent to the main haul road will be proposed with separation achieved by an earth berm as shown in Figure 4-6 below.

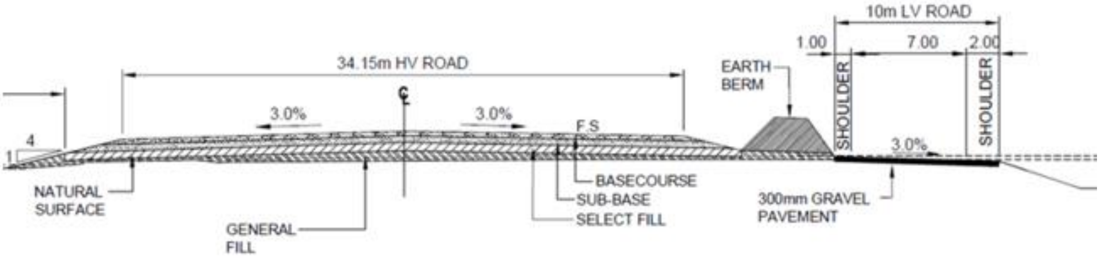


Figure 4-6: LV adjacent HV on main haul road

To achieve vehicle separation at intersections, the most cost-effective solution is to direct LVs under the HV road with the use of corrugated metal arches as shown in Figure 4-7 below.

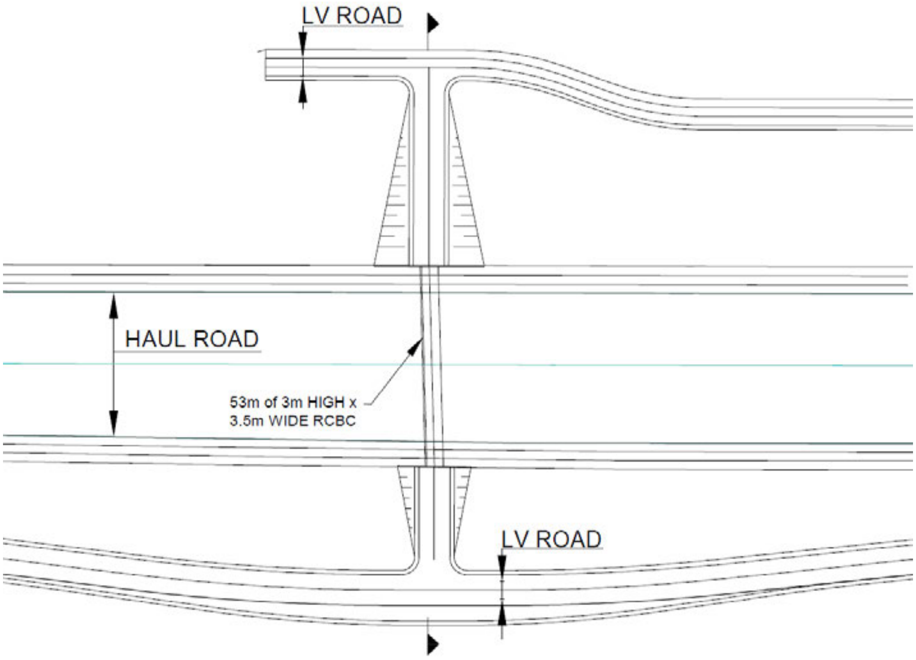


Figure 4-7: Plan view of intersection of HV and LV

Other considerations that would need to be included is the flow of water through the site that would be required by implementing HV-LV separation. This would include the increase in length of all haul road underground culvert structures where a light vehicle road was proposed adjacent. This is shown in Figure 4-8 below.

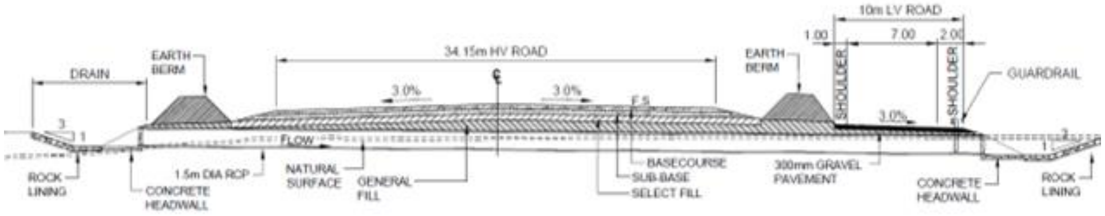


Figure 4-8: Separation at culvert crossings – Main haul road

4.2.3.8 PIT FLOOR

The pit floor is the area that was once covered by overburden at the raw product level. It has the slowest speed environment, with a work front where the product is situated and the rear that is the edge of the excavated overburden, which is always moving. It may not always be achievable to have separation of the vehicles in this environment. LVs which are there for shift changes, planning and management purposes can be separated from the HVs, however, maintenance vehicles for the plant and HVs would require closer access to the work front. A plan view and section of how the pit floor could possibly provide separation of the vehicle classes are shown in Figure 4-9 and Figure 4-10 below.

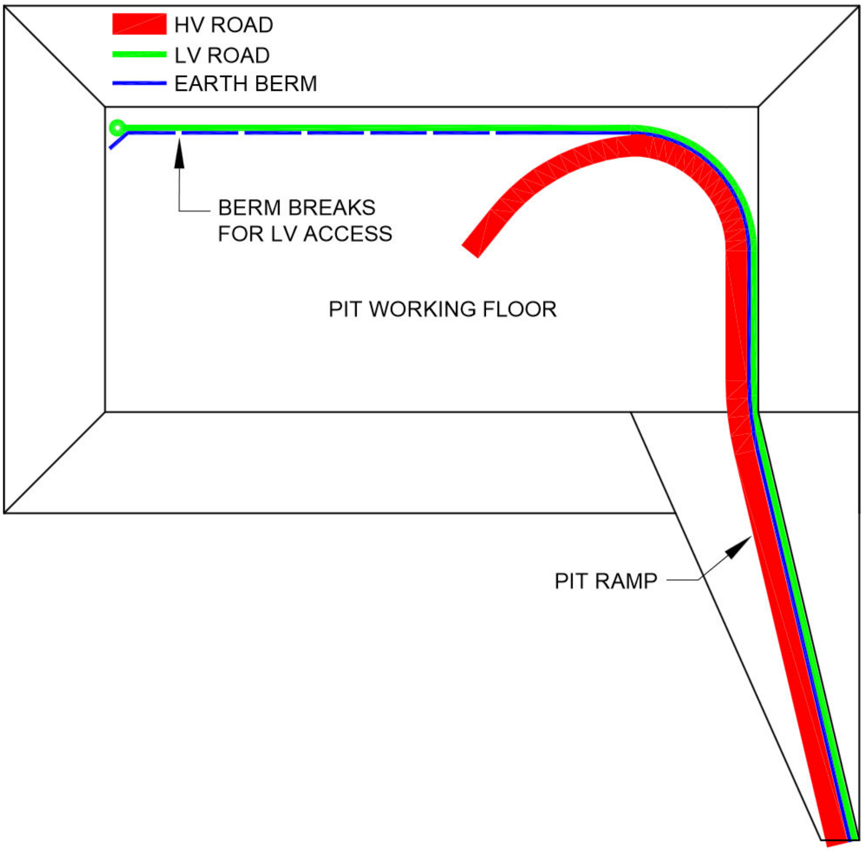


Figure 4-9: Plan view - Separation of HV and LV - Pit floor and Ramp

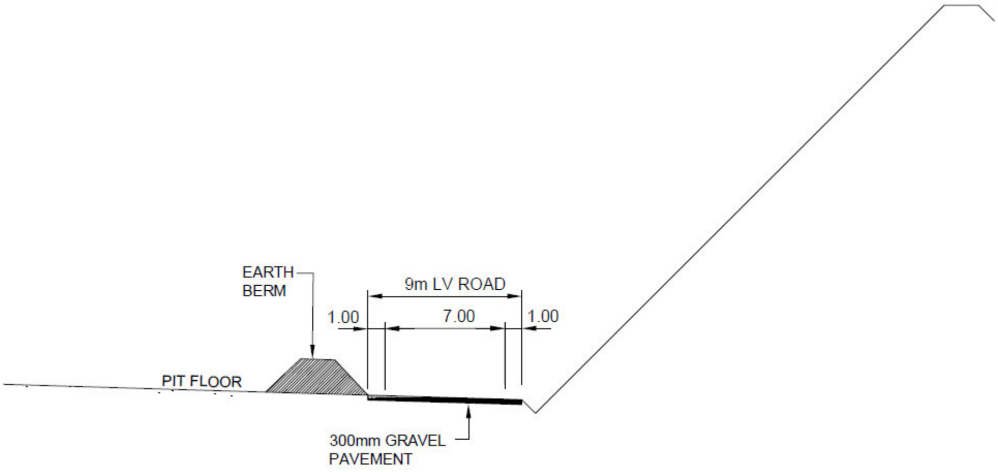


Figure 4-10: Section view – Separation of HV and LV - Pit floor

4.2.3.9 PIT RAMPS

The pit ramps for the case study mine had an average depth of 15m from the natural surface levels to the pit floor levels. Therefore, any increase in width of the haul road to accommodate the light vehicle road would include additional earthworks to achieve separation. An earth berm has been utilised for vehicle separation as shown in Figure 4-11 below. However, alternate control measures may be more cost effective in larger open cut mines with significant depths of excavation.

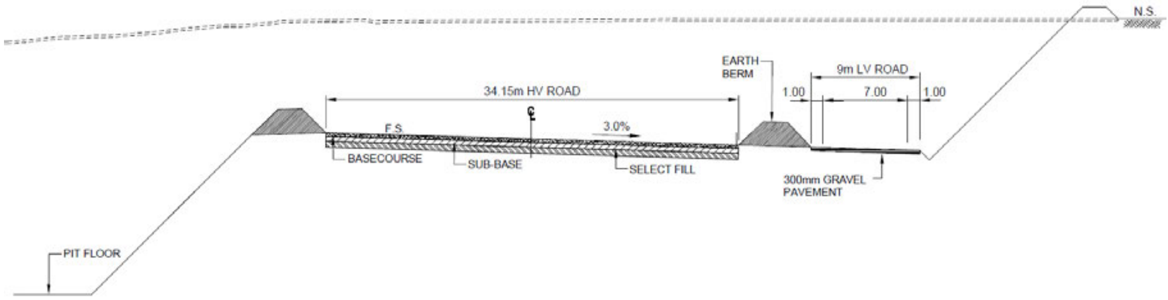


Figure 4-11: Separation of HV and LV within pit ramps

To complete the separation of the vehicles, a mine site plan was developed to show the route of all the HVs across the site and LVs as shown in Figure 4-12 below.

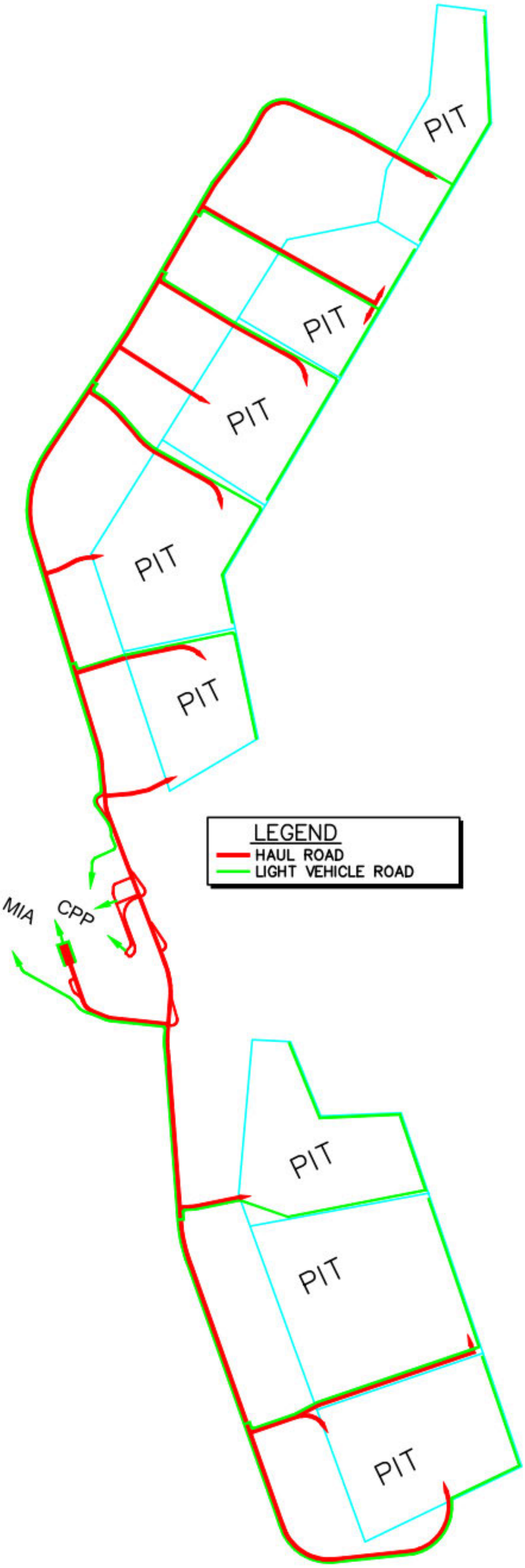


Figure 4-12: Plan view of complete mine site separation

When the design criteria and risk elimination method of vehicle separation determined by the CADG process is complete, the next stage of TM can commence.

4.2.4 AIMSUN – TRAFFIC MODELLING AND SIMULATION INPUTS AND PROCESSES

The inputs for this element were all supplied by the company and consisted of:

- Mining road layouts;
- Mining road speeds;
- LV asset register; and
- HV planning data.

The existing mine road layout can be developed from aerial imagery and available CAD data. The separated road network can be developed from applying the design guidelines to develop a suitable dual road network for HV and LV.

The asset register of light vehicles for the mine were used for the development of LV traffic volumes. This was undertaken by identifying the LV within the register that would be traveling on the haul road network, and the number of trips per day to calculate traffic volumes.

The haul vehicle mine planning data was utilised to develop the HV traffic volumes from the amount of overburden and product to be moved over a period.

After the inputs had been entered, the process of TM can be undertaken. The study has utilised Aimsun traffic modelling software, which is typically utilised within the infrastructure industry for socio economic analysis of road networks and future upgrades. Unlike other traffic modelling packages, it has the availability to alter the vehicle characteristics to achieve vehicles of similar size and operations as a HV. The methodology of the process is shown in Figure 4-13 below.

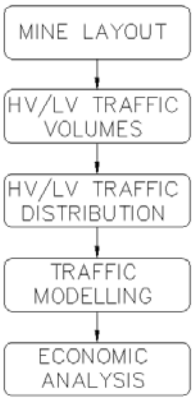


Figure 4-13: Traffic modelling process

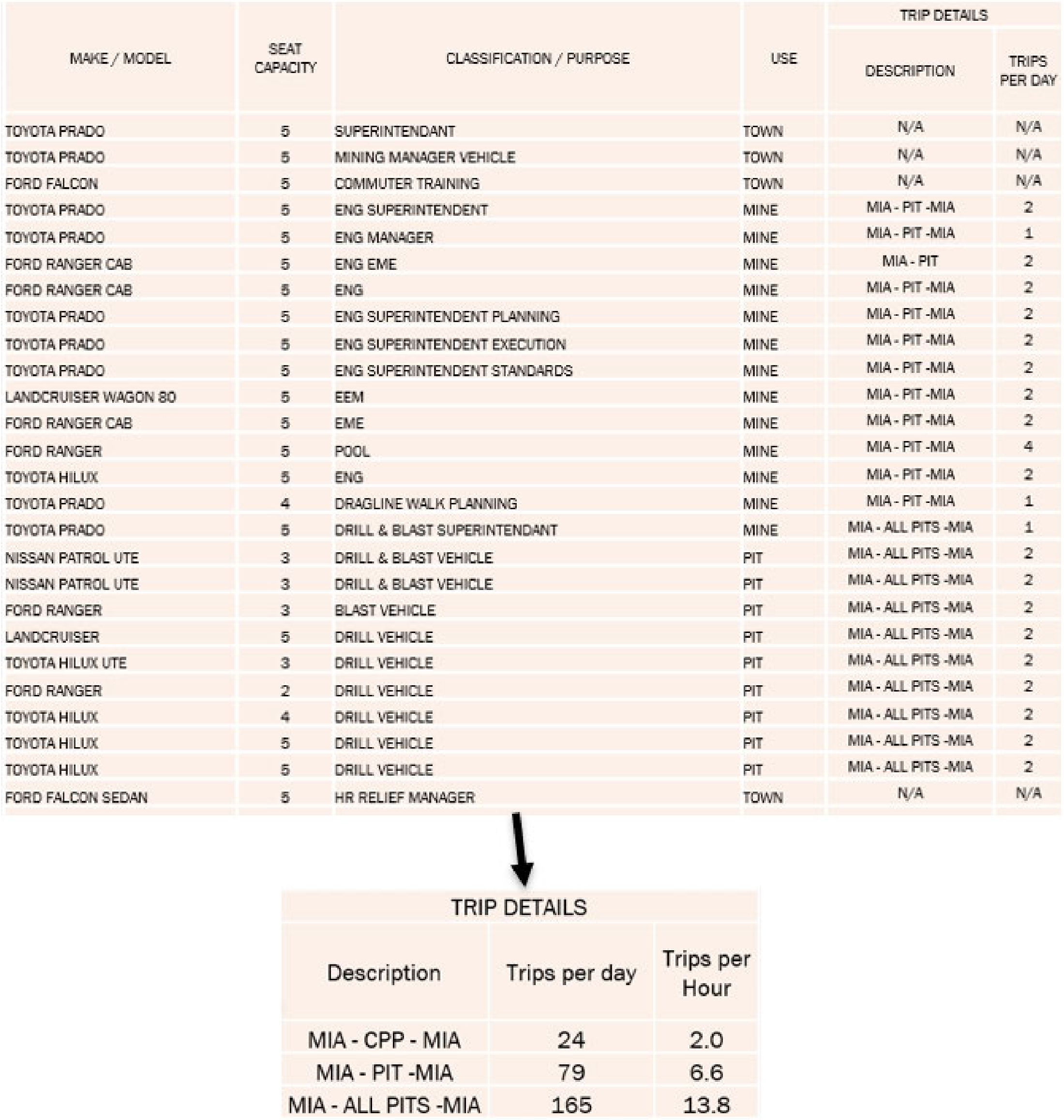
4.2.4.1 MINE LAYOUT

As outlined above, the mine layout shows the HV and LV road network across the site. The first step in TM is to develop the base case mine layouts, which is the do-nothing scenario of the LV sharing the road network with HV, and the risk mitigation scenario with the separate carriageways into the Aimsun Modelling software. After the two mine layout scenarios models are completed, traffic volumes can be distributed along the road network for LV and HV as outlined below.

4.2.4.2 LIGHT VEHICLE VOLUMES AND DISTRIBUTION

Light vehicle traffic volumes can be determined from various sources, including traffic counts in the field, interviews with site personnel, and examining the LV site vehicle asset registers.

The LV traffic volumes for this case study were determined by examining the asset register and determining which vehicle would have access to the haul road network. The next step is to determine where in the haul road network they would be travelling (pit/workshop) and the number of trips per day for each of the vehicles. For instance, the workshop vehicles will likely get called out to service vehicles daily. The people carriers would transport workers to the pit in the morning, lunch time, and end of shift. The drill and blast teams would travel to the worksite for work start, lunch time, and end of shift. Engineering and planning vehicles would visit the work front at least once a day, gaining access via multiple pit ramps. An extract from the light vehicle asset register and how the traffic volumes were developed is shown in Figure 4-14 below (Birkbeck, 2014).



MAKE / MODEL	SEAT CAPACITY	CLASSIFICATION / PURPOSE	USE	TRIP DETAILS	
				DESCRIPTION	TRIPS PER DAY
TOYOTA PRADO	5	SUPERINTENDANT	TOWN	N/A	N/A
TOYOTA PRADO	5	MINING MANAGER VEHICLE	TOWN	N/A	N/A
FORD FALCON	5	COMMUTER TRAINING	TOWN	N/A	N/A
TOYOTA PRADO	5	ENG SUPERINTENDENT	MINE	MIA - PIT -MIA	2
TOYOTA PRADO	5	ENG MANAGER	MINE	MIA - PIT -MIA	1
FORD RANGER CAB	5	ENG EME	MINE	MIA - PIT	2
FORD RANGER CAB	5	ENG	MINE	MIA - PIT -MIA	2
TOYOTA PRADO	5	ENG SUPERINTENDENT PLANNING	MINE	MIA - PIT -MIA	2
TOYOTA PRADO	5	ENG SUPERINTENDENT EXECUTION	MINE	MIA - PIT -MIA	2
TOYOTA PRADO	5	ENG SUPERINTENDENT STANDARDS	MINE	MIA - PIT -MIA	2
LANDCRUISER WAGON 80	5	EEM	MINE	MIA - PIT -MIA	2
FORD RANGER CAB	5	EME	MINE	MIA - PIT -MIA	2
FORD RANGER	5	POOL	MINE	MIA - PIT -MIA	4
TOYOTA HILUX	5	ENG	MINE	MIA - PIT -MIA	2
TOYOTA PRADO	4	DRAGLINE WALK PLANNING	MINE	MIA - PIT -MIA	1
TOYOTA PRADO	5	DRILL & BLAST SUPERINTENDANT	MINE	MIA - ALL PITS -MIA	1
NISSAN PATROL UTE	3	DRILL & BLAST VEHICLE	PIT	MIA - ALL PITS -MIA	2
NISSAN PATROL UTE	3	DRILL & BLAST VEHICLE	PIT	MIA - ALL PITS -MIA	2
FORD RANGER	3	BLAST VEHICLE	PIT	MIA - ALL PITS -MIA	2
LANDCRUISER	5	DRILL VEHICLE	PIT	MIA - ALL PITS -MIA	2
TOYOTA HILUX UTE	3	DRILL VEHICLE	PIT	MIA - ALL PITS -MIA	2
FORD RANGER	2	DRILL VEHICLE	PIT	MIA - ALL PITS -MIA	2
TOYOTA HILUX	4	DRILL VEHICLE	PIT	MIA - ALL PITS -MIA	2
TOYOTA HILUX	5	DRILL VEHICLE	PIT	MIA - ALL PITS -MIA	2
TOYOTA HILUX	5	DRILL VEHICLE	PIT	MIA - ALL PITS -MIA	2
FORD FALCON SEDAN	5	HR RELIEF MANAGER	TOWN	N/A	N/A

TRIP DETAILS		
Description	Trips per day	Trips per Hour
MIA - CPP - MIA	24	2.0
MIA - PIT -MIA	79	6.6
MIA - ALL PITS -MIA	165	13.8

Figure 4-14: LV traffic volumes

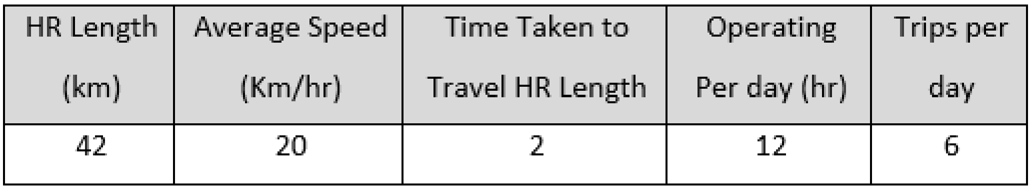
4.2.4.3 HAUL VEHICLE VOLUMES AND DISTRIBUTION

Most mines have detailed plans for many years into the future and this was evident with this case study. The mine had data that calculated how many haul trucks were required to perform the product and overburden haulage, taking into consideration the maintenance intervals and downtimes of each vehicle. The data had enough detail to extrapolate the haul vehicle traffic volumes from each pit to either the raw coal load out, overburden stockpiles, and reject spoil from the plant back to spoil stockpiles.

Maintenance requirements were also calculated for each vehicle based on the requirements of the manufacturer, and the operating hours of the mine’s modelling data. However, for the purpose of this case study, any minor maintenance would be included in the 50-hour maintenance trip and therefore, only included trips above this maintenance interval.

Other haul vehicles utilised across the site include dust suppression activities, which is undertaken with the use of a modified haul truck and runs consistently, depending on the weather at the site. The number of cycles were established utilising the amount of haul road to be watered (total length), the average speed of the vehicle, and how many hours per day the vehicle operates. This equates to 6 trips added to all areas of the mine site per day, as shown in Table 4-5 below.

Table 4-5: Trips generated from Cat 777 water cart



HR Length (km)	Average Speed (Km/hr)	Time Taken to Travel HR Length	Operating Per day (hr)	Trips per day
42	20	2	12	6

The operational strategy can increase or decrease the amount of trips generated significantly, so a strategy that is both cost effective and safe is of the utmost importance. Two aspects of operational strategy that can affect the trip generation is the re-fuelling and shift change process.

Re-fuelling

The Cat 797 is the largest haul vehicle in the mine and any unnecessary usage of this vehicle increases the fuel costs to mine operators. As the vehicle trips are predominately from the pit to the overburden spoil locations via main haul roads, it was determined for the purpose of this study, that the HVs would be re-fuelled at a location off the main haul road and therefore did not increase vehicles trips.

Shift changes

The case study mine operates with a workforce working on 7 days on and 7 days off, 12 hours a day roster. During a single day period the haul vehicle drivers would have a lunch/dinner break in MIA areas.

As the operational strategy for the CAT 797 is predominantly to stay in the pit, the workers will need to be transported to and from their vehicles. The trips generated per day were therefore a LV and not HV. Therefore, this trip was not included in the HV traffic volumes.

The Cat 793 is undertaking shift changes at the HV park up area, as the vehicle will be in close vicinity during ROM dumps. The trips generated per day for the purpose of this study will therefore be MIA – Pit for morning shift, Pit to MIA for lunch time, MIA to pit for afternoon shift and Pit to MIA for end of shift. This equates to two (2) cycles of MIA to pits for every Cat 793 vehicle (Birkbeck, 2014).

Therefore, a summary of the total trips developed from maintenance, refuelling and dust suppression can be developed, as shown in Table 4-6 below.

Table 4-6: HV Trips generated from maintenance activity

ACTIVITY	FROM	TO	TRUCK	CYCLES/ YEAR PER VEHICLE	NUMBER OF VEHICLES	CYCLES/ YEAR
Tyre Change	PIT	MIA	CAT 793	2	19	38
50 hour Service	PIT	MIA	CAT 793	110	19	2090
Visit Go Line	PIT	MIA	CAT 793	730	19	13870
Tyre Change	PIT	MIA	CAT 797	2	14	28
50 hour Service	PIT	MIA	CAT 797	110	14	1540
Dust Suppression	All Areas		Cat 777	2190	1	2190

Once the haul vehicle traffic volumes are known, a traffic distribution can be developed. The traffic distribution was developed with the following assumptions:

- The trips generated from HV maintenance, re-fuelling and shift changes were divided equally between all ramps;
- Trips generated from HV maintenance, re-fuelling and shift changes were from pit – MIA – pit;

- Dust suppression trips added to every movement on the site;
- The haul vehicles per hour are calculated by dividing the annual figures by the 5500 hours, which was derived from the planning report.
- Cycle for Cat 793 – Coal is from pit – ROM – pit
- Cycle for Cat 793 – Overburden is from pit – spoil dump – pit
- Cycle for Cat 797 – Overburden is from pit – spoil dump – pit
- Cycle for Cat 793 – Rejects is from rejects – pit
- The rejects do not increase the overall trip generation, as the Cat 793 dumping raw coal at the ROM diverts to rejects bin for loading, before dumping in the pit, and hence can be undertaken within Cat 793 – Coal operations.

In summarising the haul vehicle distribution, the high volumes of movements were in the vicinity of the ROM with 64,050 vehicles per year. The movements reduce along the ramps as it gets further from the ROM, as more haul vehicles divert off the main haul road and into its designated pit. The movements into the MIA area were relatively low with 19,757 movements per year, but this route could change significantly with different operational strategies or maintenance regimes. The ramps to the overburden stockpile had the most movements in the entire site with 85,232 haul vehicles per year (Birkbeck, 2014). These findings are summarised in Table 4-7 below.

Table 4-7: HV trips generated summary

Area	Vehicles per year	Vehicles per hour
MIA	19,757	3.59
ROM	64,050	11.65
Main Haul Road	51,807	9.42
Pits	85,232	15.50

An extract from the HV and LV traffic distribution diagrams for the case study is shown in Figure 4-15 and Figure 4-16 below.

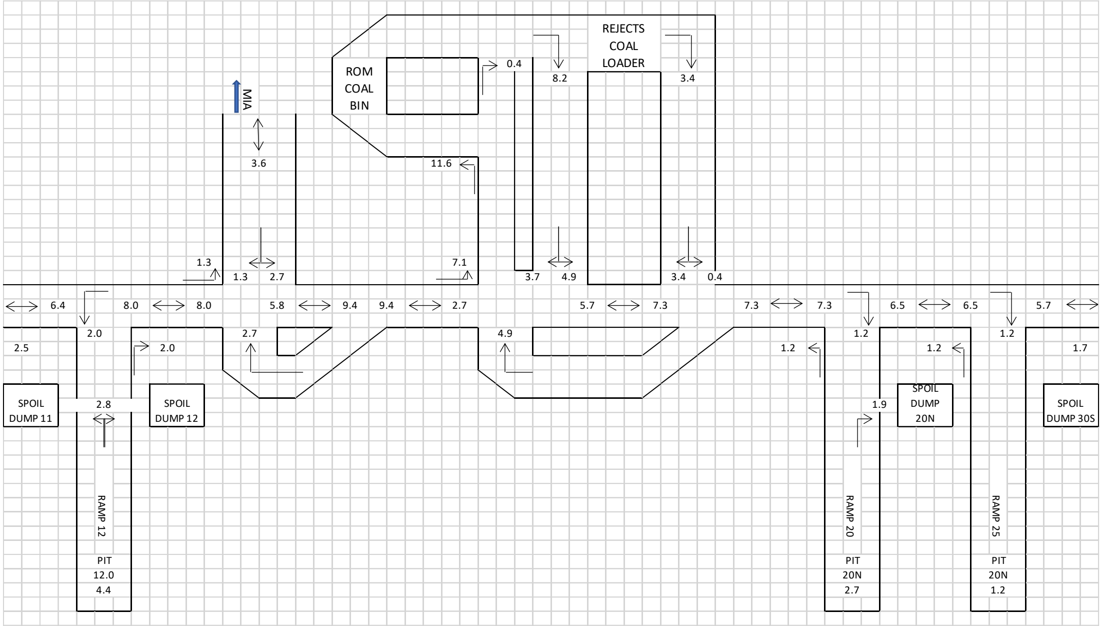


Figure 4-15: Traffic distributions – HV hourly traffic volumes

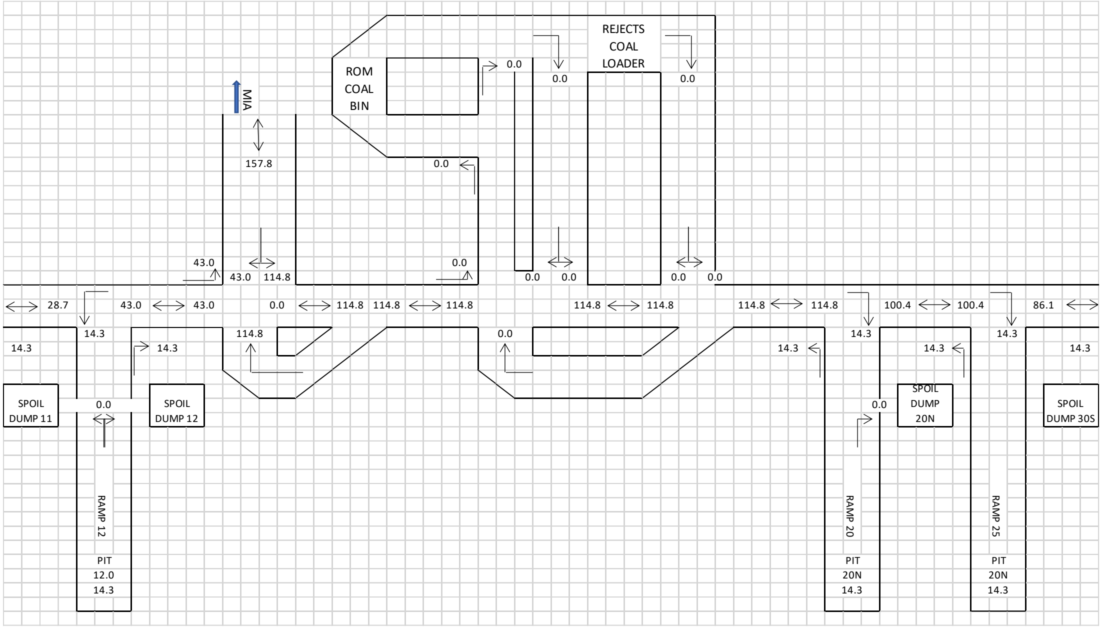


Figure 4-16: Traffic distributions – LV hourly traffic volumes

4.2.4.3.1 AIMSUN – TRAFFIC MODELLING DEVELOPMENT

Following the development of the traffic distributions and volumes, the data is input into Aimsun matching the layouts for the base case study and the HV-LV separated options. The project inputs in Aimsun are undertaken as shown in Figure 4-17 below.

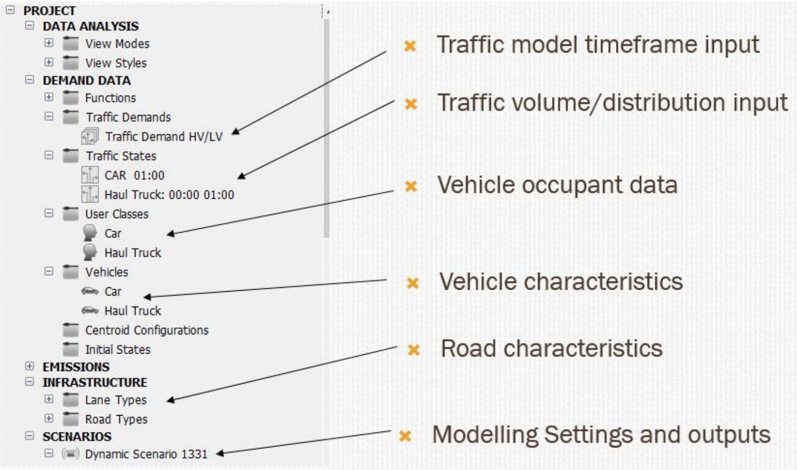


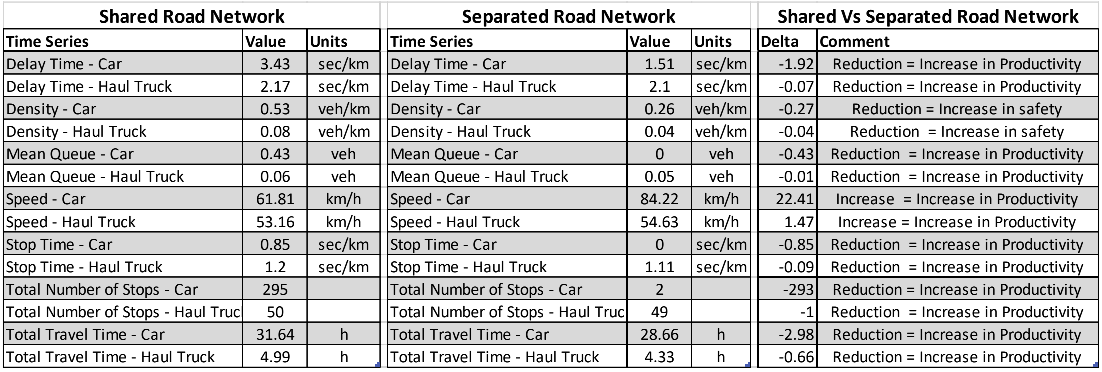
Figure 4-17: Aimsun - Inputs and program settings

An extract of the base case and vehicle separated case from Aimsun is shown in Figure 4-18 below.

Figure 4-18: Aimsun screenshot - Separated Layout (L) Base Case (R)

A set of the data that is extracted from the program is shown in Table 4-8 below. It depicts the base case study (shared road network) on the right, the separated carriageways on the left and a comparison between both scenarios. The data shows the delay time (seconds/kilometre), density (vehicles/kilometre), mean queue (vehicles), speed (kilometre/hour), stop time (seconds/kilometre), total travel time (hours) and the number of stops. All data is developed for an average hour period.

Table 4-8: Aimsun output - Base case (L) - HV / LV separated carriageways (R)



Shared Road Network			Separated Road Network			Shared Vs Separated Road Network	
Time Series	Value	Units	Time Series	Value	Units	Delta	Comment
Delay Time - Car	3.43	sec/km	Delay Time - Car	1.51	sec/km	-1.92	Reduction = Increase in Productivity
Delay Time - Haul Truck	2.17	sec/km	Delay Time - Haul Truck	2.1	sec/km	-0.07	Reduction = Increase in Productivity
Density - Car	0.53	veh/km	Density - Car	0.26	veh/km	-0.27	Reduction = Increase in safety
Density - Haul Truck	0.08	veh/km	Density - Haul Truck	0.04	veh/km	-0.04	Reduction = Increase in safety
Mean Queue - Car	0.43	veh	Mean Queue - Car	0	veh	-0.43	Reduction = Increase in Productivity
Mean Queue - Haul Truck	0.06	veh	Mean Queue - Haul Truck	0.05	veh	-0.01	Reduction = Increase in Productivity
Speed - Car	61.81	km/h	Speed - Car	84.22	km/h	22.41	Increase = Increase in Productivity
Speed - Haul Truck	53.16	km/h	Speed - Haul Truck	54.63	km/h	1.47	Increase = Increase in Productivity
Stop Time - Car	0.85	sec/km	Stop Time - Car	0	sec/km	-0.85	Reduction = Increase in Productivity
Stop Time - Haul Truck	1.2	sec/km	Stop Time - Haul Truck	1.11	sec/km	-0.09	Reduction = Increase in Productivity
Total Number of Stops - Car	295		Total Number of Stops - Car	2		-293	Reduction = Increase in Productivity
Total Number of Stops - Haul Truc	50		Total Number of Stops - Haul Truc	49		-1	Reduction = Increase in Productivity
Total Travel Time - Car	31.64	h	Total Travel Time - Car	28.66	h	-2.98	Reduction = Increase in Productivity
Total Travel Time - Haul Truck	4.99	h	Total Travel Time - Haul Truck	4.33	h	-0.66	Reduction = Increase in Productivity

Delay Time is the average delay time per vehicle per kilometre. This is the difference between the expected travel time (the time it would take to traverse the system under ideal conditions) and the actual travel time. It is calculated as the average of all vehicles and then converted into time per kilometre. It does not include the time spent in virtual queue. The data showed that both the HV (haul truck) and LV (car) experienced a decrease in delay on the network with LV achieving a reduction of 1.92 sec/km and the HV 0.07 sec/km.

Density is a measure of the average number of vehicles per kilometre for the whole network. The data showed that both the HV and LV experienced a decrease in density on the network with LV achieving a reduction of 0.27 veh/km and the HV 0.04 veh/km.

The mean queue is the average queue in the network during the simulation period and measured in vehicles. The data showed that both the HV and LV experienced a decrease in mean queue on the network, with LV achieving a reduction of 0.43 veh and the HV 0.01 veh.

Speed is calculated from the mean journey speed. The data showed that both the HV and LV experienced an increase in speed on the network, with LV achieving an increase of 22.41 km/h and the HV 1.47 km/h.

Total travel time is calculated from the number of vehicles to travel throughout the network for the hour period. The data showed that both the HV and LV experienced a decrease in total travel time on the network, with LV achieving a decrease of 2.98 h and the HV 0.66 h.

The outputs show that the increase in LV speed on the network was a significant contributor to the productivity increases with the relatively straight and lengthy distance roads. This is due to LVs not being able to overtake HV on the network and the slower operating speeds of the HV. This was evident when viewing the operational model, where LV would bunch behind HVs. The additional LV road network has also contributed to decreases in queueing, density, and delay for both the LV and HV.

4.2.5 COLLISION ADVOIDANCE DESIGN PROCESSES

The CADP will consist of financial decision analysis of both the base case and post separation to supplement the decision making, risk elimination and profit optimisation goals of the mine.

The inputs for this element include above forementioned inputs and company supplied data and research data applicable to a particular mine. Typical inputs to complete this process are stipulated below:

- Road construction and maintenance costs;
- Current product price and mine production rates;
- Average mining salaries;
- LV and HV plant costs

As outlined previously in the methodology, the inputs feed into the processes stage.

The CADP will utilise discounted cash flow analysis over a timeframe for an incident to occur (Input from MISA /mine design life) and will also include the financial costs as well as benefits of the base case study and post separation. The discounted cash flow will also include construction/maintenance costs of the separation and benefits, such as present values costs borne by the mining company in the event of a future incident, and improved employee productivity congestion reduction (Input from TM) due to additional road networks. The CADP outputs will include tools such as sensitivity, cost-benefit, and pay-back period analysis. The processes will be packaged into outputs as shown below.

The CADP will be examined within the sections of costs and benefits.

4.2.5.1 COSTS

The costs associated with the base case study, or do-nothing scenario, is zero, with no expenditure on additional road infrastructure and is business as normal. The costs associated with the HV-LV separation scenario is the additional construction costs for the additional road networks, including road construction costs, stormwater infrastructure costs, and ongoing costs for maintenance into the future.

The costing data utilised for this research was gained from consulting mining companies, and utilising existing contract award financials within the industry. The sources of the information shall remain confidential, however, the rates are shown for analysis purposes. The rates are inclusive of materials, directs (craft hire, placement costs, mobilisation, and demobilisation), however are excluding indirect costs such as engineering and management). The costing will be calculated by section of roads, including main haul roads, pit ramps, and intersections, in pit roads and culvert crossings. The costing calculations will be undertaken on a concept basis, where costs will be calculated by determining the typical section characteristics and multiplying by the length of the road applicable for the mine. The costs will be included into the Discount Cash Flow analysis in the following sections.

Construction costs - Main haul road light vehicle road

Material take off was developed for the light vehicle road adjacent to the main haul road for a normal section. They are shown in Figure 4-19 and Table 4-9 below.

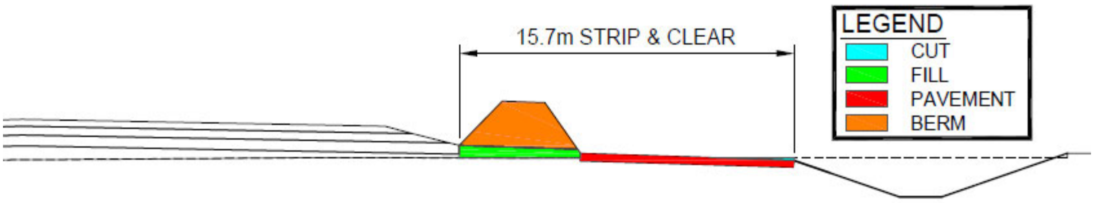


Figure 4-19: Additional works - Main haul road

Table 4-9: Material take off - Main haul road

Description	Qty	Calc. Contractor Rate	Unit	Cost per M	Length of LV Road	Total Cost
Site Preparation						
Clear Site of vegetation - Med Vegtation	15.7	$ 0.11	sqm	$ 1.70	24395	$ 41,364.16
Topsoil Stripping (200mm)	15.7	$ 0.39	sqm	$ 6.19	24395	$ 150,902.59
Excavation						
Mass Excavation - Cut to fill 1001 - 1500	3	$ 7.68	m3	$ 23.04	24395	$ 562,060.80
Filling						
Mass Excavation - Cut to fill 1001 - 1500	10.4	$ 7.68	m3	$ 79.87	24395	$ 1,948,477.44
Surface Treatments						
Ground Surface Treatment (GST)	14.2	$ 0.74	sqm	$ 10.51	24395	$ 256,342.66
Final Trim	15.7	$ 1.09	sqm	$ 17.11	34395	$ 588,601.64
Pavings						
Pavement - Base 1001 - 1500M	18	$ 1.71	sqm	$ 30.78	24395	$ 750,878.10
Drainage						
Trenching - Excavation	0.36	$ 3.42	m	$ 1.23	24395	$ 30,035.12
Subsurface drainage - 150mm dia subsoil drains	0.36	$ 25.65	m	$ 9.23	24395	$ 225,263.43
					Total Cost	4,553,926

Material take off undertaken with the following assumptions:

- Subsoil drains under LV road every 15m

Construction costs - Pit ramp light vehicle roads

Material take off was developed for the light vehicle road adjacent to pit ramps. They are shown in Figure 4-20 and Table 4-10. For this study, the pit depth utilised an average of a 15m deep pit, however deeper pits would incur substantially more excavation and therefore additional construction costs.

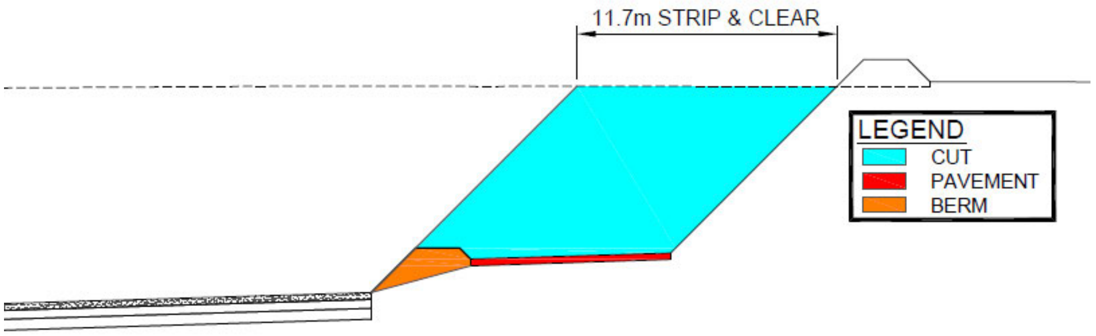


Figure 4-20: Additional works – Pit ramp

Table 4-10: Material Take Off – Pit ramp

Description	Qty	Calc. Contract or Rates	Unit	Cost per M	Length of LV Road	Total Cost
Site Preparation						
Cear Site of vegetation - Med Vegtation	11.7	$ 0.11	sqm	$ 1.26	1696	$ 2,143.07
Topsoil Stripping (200mm)	11.7	$ 0.39	sqm	$ 4.61	1696	$ 7,818.22
Excavation						
Mass Excavation - Cut to fill 1001 - 1500	98	$ 7.68	m3	$ 752.64	1696	$ 1,276,477.44
Filling						
Mass Excavation - Cut to fill 1001 - 1500	4.2	$ 7.68	m3	$ 32.26	1696	$ 54,706.18
Surface Treatments						
Ground Surface Treatment (GST)	11.4	$ 0.74	sqm	$ 8.44	1696	$ 14,307.46
Final Trim	11.7	$ 1.09	sqm	$ 12.75	1696	$ 21,629.09
Pavings						
Pavement - Base 1001 - 1500M	18	$ 1.71	sqm	$ 30.78	1696	$ 52,202.88
Drainage						
Trenching - Excavation	0.36	$ 3.42	m	$ 1.23	1696	$ 2,088.12
Subsurface drainage - 150mm dia subsoil drains	0.36	$ 25.65	m	$ 9.23	1696	$ 15,660.86
					Total Cost	1,447,033

Material take off undertaken with the following assumptions:

- 15m deep pit
- Subsoil drains under HV road every 20m

Construction costs - In pit light vehicle roads

Material take off was developed for the LV road in the pit. The pavement material thickness has been reduced due to decreased traffic volumes and short design life. They are shown in Figure 4-21 and Table 4-11 below.

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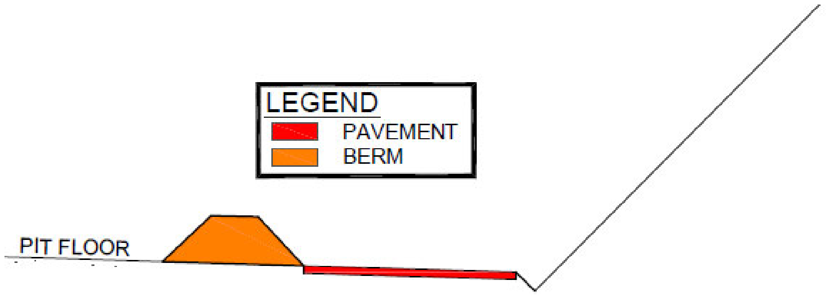

Figure 4-21: Additional works - In Pit

Table 4-11: Material take off - In Pit

Description	Qty	Calc. Contract or Rate	Unit	Cost per M	Length of LV Road	Total Cost
Filling						
Mass Excavation - Cut to fill 1001 - 1500	10.4	$ 7.68	m3	$ 79.87	20875	$ 1,667,328.00
Surface Treatments						
Ground Surface Treatment (GST)	7.65	$ 0.74	sqm	$ 5.66	20875	$ 118,173.38
Final Trim	11.7	$ 1.09	sqm	$ 12.75	20875	$ 266,218.88
Pavings						
Pavement - Base 1001 - 1500M	7	$ 1.71	sqm	$ 11.97	20875	$ 249,873.75
					Total Cost	2,301,594

Material take offs were undertaken with the following assumptions:

- Pavement of 150mm gravel 7m wide
- No additional excavation as pit floor has sufficient operation width

Construction costs - Drainage culvert crossing

Material take off was developed for LV road crossing drainage culverts. They are shown in Figure 4-22 and Table 4-12 below.

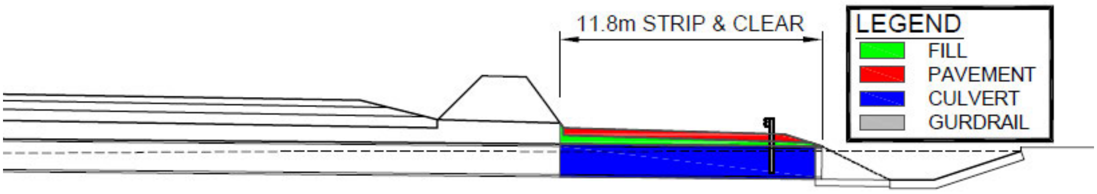

Figure 4-22: Additional works - Main haul road – Drainage crossing

Table 4-12: Material take off - Main haul road – Drainage crossing

Description	Qty	Calc. Contractor Rate	Unit	Cost per M	Length of LV Road	Total Cost
Site Preparation						
Cear Site of vegetation - Med Vegtation	12	$ 0.11	sqm	$ 1.30	60	$ 78
Topsoil Stripping (200mm)	12	$ 0.39	sqm	$ 4.73	60	$ 284
Excavation						
Mass Excavation - Cut to fill 1001 - 1500	20.5	$ 7.68	m3	$ 157.44	60	$ 9,446
Surface Treatments						
Ground Surface Treatment (GST)	12	$ 0.74	sqm	$ 8.88	60	$ 533
Final Trim	12	$ 1.09	sqm	$ 13.08	60	$ 785
Pavings						
Pavement - Base 1001 - 1500M	20	$ 1.71	sqm	$ 34.20	60	$ 2,052
Drainage						
Trenching - Excavation	6	$ 11.40	m3	$ 68.40	30	$ 2,052
Backfilling						
Trenching - Backfill	7	$ 31.58	m3	$ 221.06	12	$ 2,653
Pipe						
Drainage - Corrugated metal pipe 1500mm dia.	177	$ 512.00	m	$ 512.00	-	$ 90,624
Drainage - Cast in-situ headwalls	0.15	$ 1,351.00	m3	$ 202.65	12	$ 2,432
Guardrail						
Ezy Guard Smart - Guardrail light vehicle	1	$ 111.23	m	$ 111.23	140	$ 15,572
Guardrail - End terminals	2	$ 1,983.00	item	$ 1,983.00	-	$ 3,966
				Sub-Total		$ 130,476
				No. of Culverts		6
				Total		$ 782,857

Material take off undertaken with the following assumptions:

- Flows to be accommodated 3x1500mm diameter RCPs – width 12m
- Culvert excavation rate under excavation not trenching due to large trench width
- Price is for 6 drainage locations

Construction costs - haul vehicle/ Light vehicle intersection

Material take off was developed for the LV road crossing underneath the haul road. The culvert structures would be required to be specially built to support the load of the haul vehicles when loaded. They are shown in Figure 4-23 and Table 4-13.

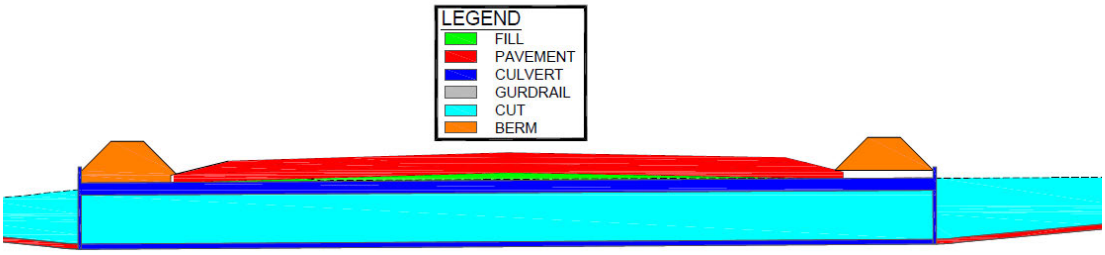

Figure 4-23: Additional works - Haul vehicle / light vehicle intersection

Table 4-13: Material take off - Haul vehicle / light vehicle intersection

Description	Qty	Unit	Calc. Contractor Rate	Unit	Total Cost
Site Preparation					
Clear Site of vegetation - Med Vegtation	700	sqm	$ 0.11	sqm	$ 75.60
Topsoil Stripping (200mm)	15.7	sqm	$ 0.39	sqm	$ 6.19
Excavation					
Mass Excavation - Cut to fill 1001 - 1500	5100	cum	$ 7.68	m3	$ 39,168.00
Surface Treatments					
Ground Surface Treatment (GST)	310	sqm	$ 0.74	sqm	$ 229.40
Final Trim	310	sqm	$ 1.09	sqm	$ 337.90
Pavings Haul Road					
Pavement - Base 1001 - 1500M	1900	sqm	$ 13.68	sqm	$ 25,992.00
Pavings Light Vehicle Road					
Pavement - Base 1001 - 1500M	150	sqm	$ 1.71	sqm	$ 256.50
Backfilling					
Trenching - Backfill	240	cum	$ 31.58	m3	$ 7,579.20
Concrete					
Drainage - Corrugated metal pipe arch 5m dia.	53	m	$ 1,500.00	m	$ 79,500.00
Drainage - Cast in-situ headwalls	9.8	m3	$ 1,351.00	m3	$ 13,239.80
Drainage - Cast in-situ Footings	38.16	m3	$ 1,351.00	m3	$ 51,554.16
			Sub-Total		217,939
			No. of intersections		6
			Total		1,307,632

Material take off undertaken with the following assumptions:

- Price is for all 6 intersection locations

Maintenance costs – light vehicle road

Maintaining the LV roads to a standard that would provide a good riding surface, carry the heavy traffic loads, meet mine expectations, minimise safety hazards and provide a free draining surface for the life of the road, is what would be expected of a maintenance regime. The literature review determined that two types of maintenance would be required: on demand maintenance and periodic maintenance.

The maintenance regime was estimated using the cost data for the proportion of length of road depicted in Table 4-2 within the literature review. The cost of the maintenance is shown in Table 4-14 below.

Table 4-14: Maintenance costs of light vehicle roads

Light Formation Work - No water							
Description	**Qty**	**Unit**	**Calc. Contract or Rate**	**Unit**	**Cost per M**	**Length of LV Road**	**Total Cost**
Final Trim	9	sqm	$ 1.09	sqm	$ 9.81	46966	$ 460,736.46
				Sub-Total			460,736
Light Formation Work - Including Water							
Description	**Qty**	**Unit**	**Calc. Contract or Rate**	**Unit**	**Cost per M**	**Length of LV Road**	**Total Cost**
Final Trim	9	sqm	$ 1.29	sqm	$ 11.61	5870.75	$ 68,159.41
				Sub-Total			68,159
Re-Sheeting of Pavement and shoulders including preparation of bed							
Description	**Qty**	**Unit**	**Calc. Contract or Rate**	**Unit**	**Cost per M**	**Length of LV Road**	**Total Cost**
Mass Excavation - Cut to fill 1001 - 150	9	cum	$ 7.68	m3	$ 69.12	1565.533	$ 108,209.66
Ground Surface Treatment (GST)	9	sqm	$ 0.74	sqm	$ 6.66	1565.533	$ 10,426.45
Pavement - Base 1001 - 1500M	9	sqm	$ 1.71	sqm	$ 15.39	1565.533	$ 24,093.56
Final Trim	9	sqm	$ 1.09	sqm	$ 9.81	1565.533	$ 15,357.88
						Sub-Total	158,088
						Periodic Maintenance Total	686,983
						On Demand Maintenance - 10% of all Periodic Maintenance	68,698
						Total Maintenance	755,682

In summary, costing has been developed for full LV separation for the main haul road area, pit ramps, and in pit. Table 4-15 below provides summaries of all the costing for this section.

Table 4-15: Summary of costs for light vehicle separation

Description	**Construction Cost**	**Maintenance Cost PA**
Main Haul Road - Inclusive of Culverts	$5,336,783	$755,682
Ramp Light Vehicle Road - Drain to Internal Pit	$1,447,033	
In Pit Light Vehicle Road	$2,301,594	
Intersections Separation	$1,307,632	

4.2.5.2 BENEFITS

The literature review examined the economics associated with interaction crashes and their mitigations and identified benefits within society, employer, and employee categories. The results of these benefits will be examined in the following paragraphs.

Benefits to society

The literature review identified the mitigation of a fatal injury would be approximately $585,000 and $1,578,800 for a full incapacity injury. This cost would include public health care, investigation, travel, legal, tax losses and would be subject to inflation to calculate future sums. The case study will utilise the fatality of a single LV occupant as the expected outcome of a HV-LV interaction incident.

Benefits to the employee

The literature review identified the largest cost of fatal incidents for the employee is the loss of income over the long term. This is estimated to be at 26 years of lost income from the average working age within mining. Additional costs would be incurred by the family such as funeral costs. The estimated costs for the case study are shown in Table 4-16 below.

Table 4-16: Summary of employee benefits from crash mitigation

Type of Loss	Cost AUD
Average Mining Wage PA	$ 123,844
Average Years of Service Lost	26
Total Revenue Lost	3,219,944
Funeral Costs	$ 15,000
	$ 3,234,944

The above table shows an estimated financial benefit of $3,234,000 would be identified from crash mitigation of the vehicle interaction.

Benefits to the employer

The literature review identified the mitigation of the interaction of the vehicles would provide benefits in production, employee replacement, plant damage and investigation costs.

Production Delays

The employer would suffer financial losses due to loss and delay of mining production in the event of an incident. The size of this loss being dependent on the production value and duration of the incident impact. The literature review identified a loss of production of seven days would be appropriate. Reviewing the mine’s annual production rates and product value, the anticipated production loss can be calculated as shown in Table 4-17 below.

Table 4-17: Employer production loss in the event of incident

Description	Value
Production Coal (t)	5,500,000
Price of Coal ($AUS/t)	$180
2017 Product Value	$990,000,000
Daily Product Value	$2,712,329
Days of Production Lost	7
Total Lost Production Value	$18,986,301

The above table shows that with the anticipated production loss over a seven-day timeframe would be equivalent to $18,986,301.

Employee replacement costs

As outlined within the literature review, the cost to the organisation can be up to 55% of their salary, which would be approximately $70,000.

Asset damage costs

As outlined within the literature review, the replacement cost of the LV would be in the vicinity of approximately $100,000 after all incidentals.

Incident investigation costs

As outlined within the literature review, the incident investigation costs would be required for any major incident. For this case study, a cost of approximately $30,000 has be utilised for third party investigation.

Increased productivity and efficiency

As outlined within the literature review and the TM section, increased productivity and efficiency is evident as a result of separate road networks. The outputs from the traffic model have highlighted the total travel times for the traffic volumes for both, the haul vehicles and light vehicles to travel throughout the network. Calculating the difference in travel times between the shared road network (base case study) and separated road networks, and applying the hourly rate of the vehicle occupants, the financial figure for the improved efficiency can developed. This is shown in Table 4-18 below.

Table 4-18: Operator productivity – LV (L) - HV (R)

LV Operator Productivity		HV Operator Productivity	
Travel Time Shared Road Network	31.64	Travel Time Shared Road Network	4.99
Travel Time Separated	28.66	Travel Time Separated	4.33
LV Operator Salary hr	$ 63.00	HV Operator Salary hr	$ 63.00
Hours Saved per Hour	2.98	Hours Saved per Hour	0.66
Average number of operators	1	Average number of operators	1
Hours Saved Per year	26104.8	Hours Saved Per year	5781.6
Value for employee productivity	**$ 1,644,602**	**Value for employee productivity**	**$ 364,241**

The above table shows that the reduction in travel time between the shared road network and separated road network equated to a financial improvement of $1,600,000 for the LV and $360,000 for the HV with a single occupant in each vehicle. LV with multiple occupants would result in further increased productivity and financial gains.

4.2.5.3 ECONOMIC ANALYSIS

The economic analysis will consist of financial decision evaluation which compares the do nothing and paying the costs of a fatal incident in the future (do nothing) and separating the HV/LV immediately. The economic analysis will supplement the decision making, risk elimination and profit optimisation goals of the mine. The decision making process involves cash flows over time utilising DCF and converting costs to present values. Other financial tools can be utilised to better develop an understanding of the Risk including the Benefit Cost Ratio (BCR), pay back periods from current production development rates, and sensitivity analysis over a timeframe for an incident to occur. For the purpose of this research the cost to society and employee are included within the economic analysis, however if the mining company was wanting to evaluate the impact from it's investment point of view these externalities could be removed.

This economic analysis has been undertaken and presented in Table 19 below.

Table 4-19: Economic analysis (discounted cash flow, benefit cost analysis)

Year	0	1	5	10	15	20	30	40
Costs								
Construction	$10,393,043							
PV Maintenance	$755,682	$719,697	$592,096	$463,923	$363,496	$284,809	$174,848	$107,341
Total Costs		$11,112,740	$10,985,139	$10,856,966	$10,756,539	$10,677,851	$10,567,890	$10,500,384
Benefits								
PV Risk Mitigation Employer	$19,184,416	$18,270,872	$15,031,492	$11,777,567	$9,228,032	$7,230,404	$4,438,841	$2,725,063
PV Risk Mitigation Employee	$3,234,944	$3,080,899	$2,534,663	$1,985,975	$1,556,063	$1,219,216	$748,493	$459,510
PV Risk Mitigation Society	$585,000	$557,143	$458,363	$359,139	$281,395	$220,480	$135,356	$83,097
PV Increased Productivity	$2,008,843	$1,913,184	$1,573,981	$1,233,255	$966,288	$757,112	$464,801	$285,348
Total Benefits		$23,822,098	$19,598,499	$15,355,937	$12,031,778	$9,427,213	$5,787,491	$3,553,017
Benefit Cost Ratio		2.14	1.78	1.41	1.12	0.88	0.55	0.34
Costs - Benefits		($12,709,358)	($8,613,360)	($4,498,971)	($1,275,240)	$1,250,638	$4,780,399	$6,947,367
Pay Back Period (Days of production to achieve CBA 1.0		(4.686)	(3.176)	(1.659)	(0.100)	0.099	0.377	0.547

The table shows the timeframe within the columns and cash flows within the rows. The cash flows over time have been discounted to achieve the present value (PV) for the different years. Discounting the benefits and maintenance at a discount rate of 5% to achieve PV has significantly reduced the benefits over time, whereas the initial construction cost is not discounted due to being an upfront cost in year 0.

If a fatal collision was to occur in the first year of operation, the costs of construction and maintenance would equate to $11.1M, compared to total benefits of $23.8M. This would provide a BCR of 2.14, with a positive value providing greater benefits. The BCR ratio does not go below one until the 18th year of operation, which shows it would be financially preferential for the operator to implement separation if a fatal collision was to occur within the 18-year period. However, from the statistical analysis, an incident is likely to occur before year 6 - 8 and a fatal collision before year 180-350 of operation.

The payback period in terms of daily production value at current value of the mine shows that only 1 day of production was sufficient to alter the BCR value to 1 up to 40 years.

4.3 CASE STUDY 2 – INCREASE IN ROAD NETWORK LENGTH

Case Study 2 has generally the same inputs as the base case study of the previous chapter, except the road network has been increased in length by 20%. This alteration has increased the construction cost of the LV road network and altered the traffic modelling outputs, as there is an increase in travel distance. This alteration in the inputs will determine how the scale of mines can differing the results.

The CADP has been undertaken and shown in Table 4-20 below.

Table 4-20: Case study 2 – Economic analysis (discounted cash flow, benefit cost analysis)

Year	0	1	5	10	15	20	30	40
Costs								
Construction	$12,471,651							
PV Maintenance	$906,818	$863,636	$710,516	$556,708	$436,195	$341,770	$209,817	$128,810
Total Costs		$13,335,288	$13,182,167	$13,028,359	$12,907,846	$12,813,421	$12,681,468	$12,600,461
Benefits								
PV Risk Mitigation Employer	$19,184,416	$18,270,872	$15,031,492	$11,777,567	$9,228,032	$7,230,404	$4,438,841	$2,725,063
PV Risk Mitigation Employee	$3,234,944	$3,080,899	$2,534,663	$1,985,975	$1,556,063	$1,219,216	$748,493	$459,510
PV Risk Mitigation Society	$585,000	$557,143	$458,363	$359,139	$281,395	$220,480	$135,356	$83,097
PV Increased Productivity	$4,237,277	$4,035,501	$3,320,017	$2,601,320	$2,038,202	$1,596,985	$980,410	$601,887
Total Benefits		$25,944,415	$21,344,535	$16,724,001	$13,103,693	$10,267,086	$6,303,100	$3,869,557
Benefit Cost Ratio		1.95	1.62	1.28	1.02	0.80	0.50	0.31
Costs - Benefits		($12,609,128)	($8,162,368)	($3,695,643)	($195,847)	$2,546,335	$6,378,368	$8,730,904
Pay Back Period (Days of production to achieve CBA 1.0		(4.649)	(3.009)	(1.363)	(0.015)	0.201	0.502	0.688

The analysis shows that there is a noticeable increase in construction cost, and a significant increase to the productivity results of the traffic modelling. This has resulted in a lower BCR then the base case, if an incident was to occur within the first year with 1.95. The BCR ratio does not go below one until the 16th year of operation, which shows it would be financially preferential for the operator to implement separation if a fatal collision was to occur within the 16-year period.

4.4 CASE STUDY 3 – DECREASE IN HV VOLUMES

Case Study 3 has generally the same inputs as the base case study, except the HV traffic volumes has been decreased by 20%. This alteration has altered the traffic modelling outputs as there is less HV travelling on the road network. This alteration in the inputs will determine if HV traffic volumes provides a differing result.

The economic analysis of the CADP has been undertaken and shown in Table 4-21 below.

Table 4-21: Case Study 3 – Economic analysis (discounted cash flow, benefit cost analysis)

Year	0	1	5	10	15	20	30	40
Costs								
Construction	$10,393,043							
PV Maintenance	$755,682	$719,697	$592,096	$463,923	$363,496	$284,809	$174,848	$107,341
Total Costs		$11,112,740	$10,985,139	$10,856,966	$10,756,539	$10,677,851	$10,567,890	$10,500,384
Benefits								
PV Risk Mitigation Employer	$19,184,416	$18,270,872	$15,031,492	$11,777,567	$9,228,032	$7,230,404	$4,438,841	$2,725,063
PV Risk Mitigation Employee	$3,234,944	$3,080,899	$2,534,663	$1,985,975	$1,556,063	$1,219,216	$748,493	$459,510
PV Risk Mitigation Society	$585,000	$557,143	$458,363	$359,139	$281,395	$220,480	$135,356	$83,097
PV Increased Productivity	$1,296,918	$1,235,160	$1,016,169	$796,195	$623,840	$488,795	$300,078	$184,222
Total Benefits		$23,144,074	$19,040,687	$14,918,876	$11,689,330	$9,158,896	$5,622,768	$3,451,892
Benefit Cost Ratio		2.08	1.73	1.37	1.09	0.86	0.53	0.33
Costs - Benefits		($12,031,334)	($8,055,548)	($4,061,911)	($932,791)	$1,518,955	$4,945,123	$7,048,492
Pay Back Period (Days of production to achieve CBA 1.0		(4.436)	(2.970)	(1.498)	(0.073)	0.120	0.390	0.555

The analysis shows that there is a noticeable decrease to the productivity results of the traffic modelling, which has resulted in a lower BCR then the base case study if an incident was to occur within the first year with 2.08. The BCR ratio does not go below one until the 17th year of operation, which shows it would be financially preferential for the operator to implement separation if a fatal collision was to occur within the 17-year period.

4.5 CASE STUDY 4 – DECREASE IN LV VOLUMES

Case Study 4 has generally the same inputs as the base case study, except the LV traffic volumes has been decreased by 20%. This alteration has altered the traffic modelling outputs as there is less LV travelling on the road network. This alteration in the inputs will determine if LV traffic volumes provides a differing result.

The economic analysis of the CADP has been undertaken and is shown in Table 4-22 below.

Table 4-22: Case Study 4 – Economic analysis (discounted cash flow, benefit cost analysis)

Year	0	1	5	10	15	20	30	40
Costs								
Construction	$10,393,043							
PV Maintenance	$755,682	$719,697	$592,096	$463,923	$363,496	$284,809	$174,848	$107,341
Total Costs		$11,112,740	$10,985,139	$10,856,966	$10,756,539	$10,677,851	$10,567,890	$10,500,384
Benefits								
PV Risk Mitigation Employer	$19,184,416	$18,270,872	$15,031,492	$11,777,567	$9,228,032	$7,230,404	$4,438,841	$2,725,063
PV Risk Mitigation Employee	$3,234,944	$3,080,899	$2,534,663	$1,985,975	$1,556,063	$1,219,216	$748,493	$459,510
PV Risk Mitigation Society	$585,000	$557,143	$458,363	$359,139	$281,395	$220,480	$135,356	$83,097
PV Increased Productivity	$1,434,888	$1,366,560	$1,124,272	$880,897	$690,206	$540,794	$332,001	$203,820
Total Benefits		$23,275,474	$19,148,790	$15,003,578	$11,755,696	$9,210,895	$5,654,691	$3,471,490
Benefit Cost Ratio		2.09	1.74	1.38	1.09	0.86	0.54	0.33
Costs - Benefits		($12,162,734)	($8,163,651)	($4,146,612)	($999,157)	$1,466,956	$4,913,200	$7,028,894
Pay Back Period (Days of production to achieve CBA 1.0		(4.484)	(3.010)	(1.529)	(0.079)	0.116	0.387	0.554

The analysis shows that there is a noticeable decrease to the productivity results of the traffic modelling, which has resulted in a lower BCR then the base case study if an incident was to occur within the first year with 2.09. The BCR ratio does not go below one until the 17th year of operation, which shows it would be financially preferential for the operator to implement separation if a fatal collision was to occur within the 17-year period.

The results of all the case studies will be examined and discussed within the following section.

5. DISCUSSION

The discussion will examine and discuss the outputs and is reflective of Stage 4 and Stage 5 of the Framework Outputs.

This stage will consist of process output documentation and the development of a mine specific Framework Output Report (FOR), which will provide a summary of the processes and findings for decision making.

5.1 CASE STUDY 1 – BASE CASE

The Risk Based Framework for HV and LV has identified the following for consideration:

- Applying the mine size with the statistical probability of an incident and fatal collision occurring at the site has determined that the mine is likely to have an incident occurring between 5-8 years. Furthermore, a fatal collision is likely to occur between 170-350 years at the mine.
- The construction and maintenance costs to develop the HV-LV separation and mitigate fatal collisions would be in the vicinity of $11.1M, and the economic benefits if a fatal collision occurred in year 1 would be $23.8M.
- The financial benefits of HV-LV separation reduce over time utilising a discount rate of 5% and a fatal collision occurring up to year 18. After this timeframe, the value of the benefits becomes less than the cost of construction. The BCR over time is depicted in Figure 5-1 below.

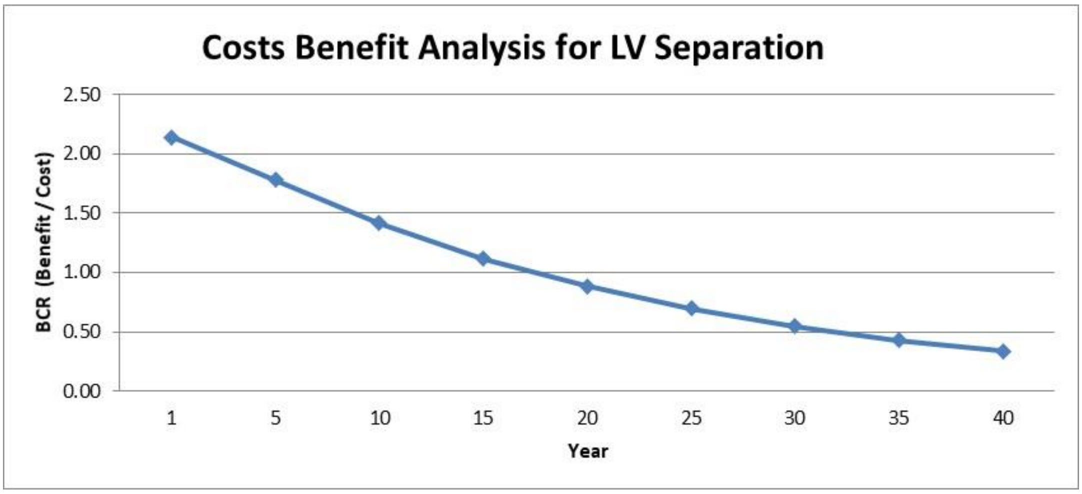

Figure 5-1: Benefit / cost ratio over time (years)

- Examining the DCF over a period of 40 years, the value in production to achieve a BCR of 1 (equal benefits to construction) is less than one day of current production value for the mine.
- Given the probability of an incident occurring within the next 8 years, the scenario of an incident developing into a fatal collision, and the DCF still containing a positive BCR up to year 18, where the costs are in excess of the benefits. The recommendation and in the interest of providing a safe working environment would be to implement the HV-LV separation.

5.2 CASE STUDY 2 – INCREASE IN ROAD NETWORK LENGTH

Increasing the length of the road network identified the following elements that altered from the base case scenario:

- No change to the statistical probability of an incident and fatal collision occurring at the mine site was identified from the base case study, as the number of people employed at the mines were not increased. However, in practice this may not be the case with larger mines requiring larger workforces.
- The productivity and efficiency of the mine benefits were increased due to the increased road lengths with a value of $4.2M in comparison to $2M for the base cases for the first year, pre applying a discount rate.

- The construction and maintenance costs to develop the HV-LV separation also increased to \$13.3M from \$11.1M for the base case for the first year. The total benefits resulted in \$25.9M for the first year with the increase in productivity providing the benefit increase.
- The financial benefits of HV-LV separation reduce over time, utilising a discount rate of 5% and a fatal collision occurring up to year 16; where the value of the benefits becomes less than the cost of construction.

5.3 CASE STUDY 3 – DECREASE IN HV VOLUMES

Decreasing the HV traffic volumes identified the following elements that altered from the base case study scenario:

- The productivity and efficiency of the mine benefits were altered because of the decrease in HV traffic volumes with a value of \$1.3M in comparison to \$2M for the base cases for the first year, pre applying a discount rate.
- The financial benefits of HV-LV separation reduce over time, utilising a discount rate of 5% and a fatal collision occurring up to year 17. This is where the value of the benefits becomes less than the cost of construction.

5.4 CASE STUDY 4 – DECREASE IN LV VOLUMES

Decreasing the LV traffic volumes identified the following elements that altered from the base case scenario:

- The productivity and efficiency of the mine benefits was altered because of the decrease in HV traffic volumes, with a value of \$1.4M in comparison to \$2M for the base cases for the first year, pre applying a discount rate.
- The financial benefits of HV-LV separation reduce over time, utilising a discount rate of 5% and a fatal collision occurring up to year 17. This is where the value of the benefits becomes less than the cost of construction.

5.5 STAGE 5: DECISION MAKING

The decision-making process for the case study would present the results outlined in the previous stage to the company board members and stakeholders to determine if capital expenditure is suitable, or further design applicable.

5.6 KEY FINDINGS

The results indicate that in all case studies the financial benefits outweighed the costs of HV-LV implementation if a fatal collision occurred within year 1 and generally up until year 16 – 18. The relationship between all the case studies is shown graphically in Figure 5-2 below.

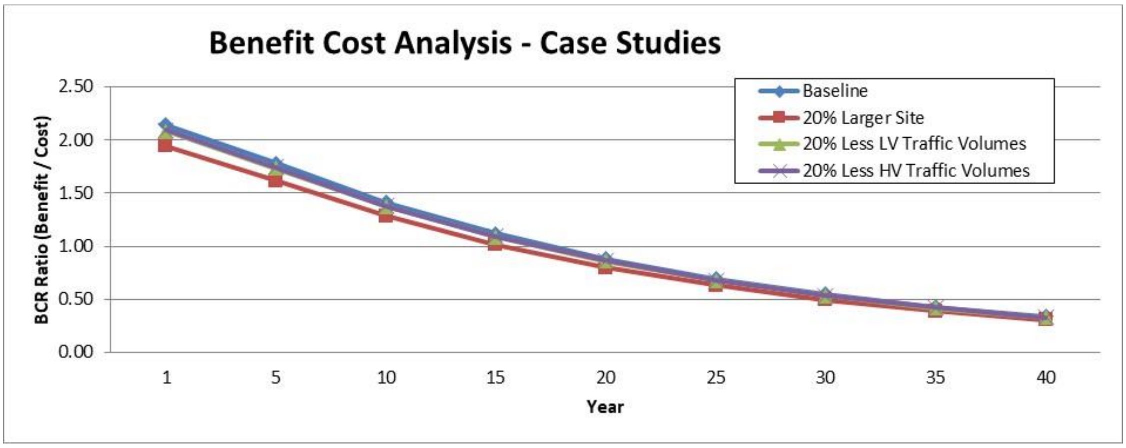

Figure 5-2: All case studies - Benefit / cost ratio over time (years)

Figure 5-2 above shows the increase in the mine size provided the most benefit in terms of BCR value, which provided substantially higher productivity outputs from the traffic modelling results, although this was partially offset with an increase in construction and maintenance costs.

The economic analysis also investigated the payback period for the mining company to achieve a BCR of 1 utilising a 1 day loss of current production value. The analysis showed that for all case studies the mining company only had to sacrifice 1 day of current production value to achieve a BCR of 1 for the 40 years of discounted cash flow analysis undertaken. This indicates that the mine has suitable production which could be sacrificed for the capital construction costs to make the BCR feasible for the 40 years.

A sensitivity analysis on different discount rates was also undertaken to examine how it impacted the year when a BCR of 1 was achieved. A discount rate of 5% was utilised that was based on a 'feasibility study' as outlined within the literature review. Altering discount rates from 3% to 7% for Case Study 1 were examined as shown in Figure 5-3 below.

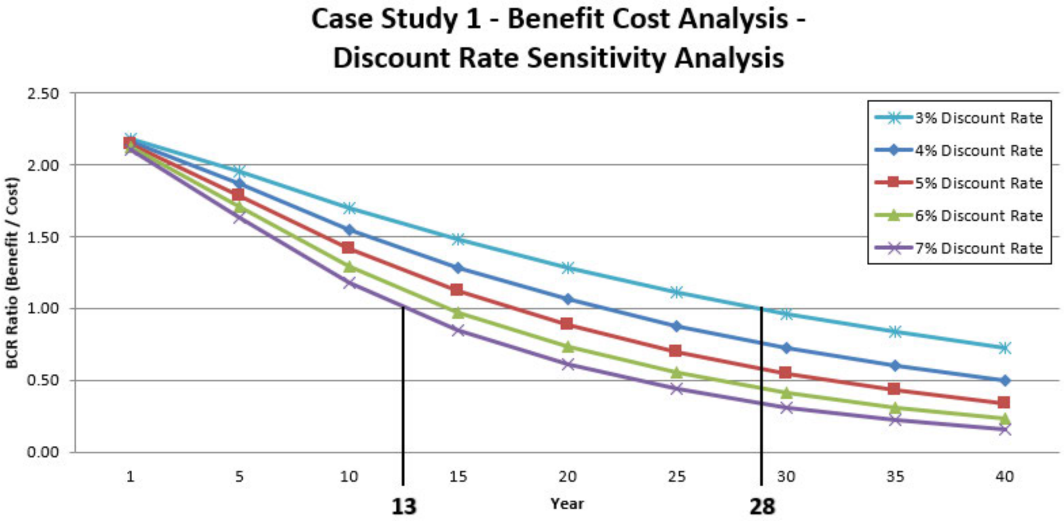

Figure 5-3: Case Study 1 - Benefit / cost ratio over time (years) – Discount rate sensitivity analysis

Figure 5-3 showed that the discount rate utilised for the discounted cash flow analysis had a significant impact to the BCR over the duration. The years of operation for a BCR of 1 were achieved at year 13 when utilising a discount rate of 7%, compared to 28 years when utilising a discount rate of 3%. Therefore, the lower the discount rate utilised; a longer duration of operation occurs before the costs outweigh the benefits.

The different inputs to the traffic model have created altered results for the speed of the vehicles and therefore productivity. The variations in LV speed across the network were the most prominent. The speed of the LV for each case study as well as for the shared and separated road networks are shown in Figure 5-4 below.

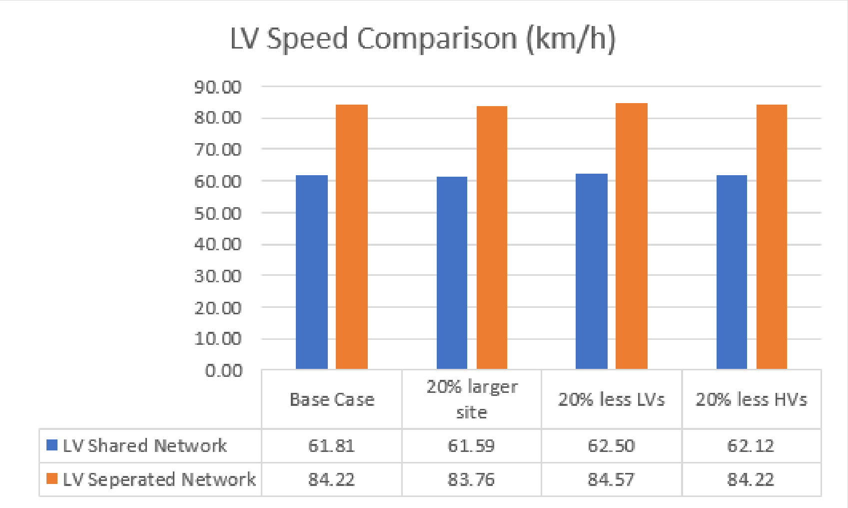

Figure 5-4: LV speed - Case study comparison

The above figure shows that the LV speed on the shared network was approximately 25% slower than the separated network's speed. This is due to the slower HV vehicle reaching a maximum speed of approximately 60km/hr, limiting the maximum speed of the LVs 80km/hr as mine safety prevents LV overtaking. LVs overtaking of HV is not allowed due to safety concerns of vehicle interaction and poor HV visibility. This limitation on overtaking was noticeable in the visual vehicle simulations where bunching of LVs occurred behind a HV on the shared network.

The HVs had marginally increased speeds of approximately 2% with the separated network, which is a result of lesser density of the vehicles within the network. The speed of the HV for each case study as well as for the shared and separated road networks are shown in Figure 5-5 below.

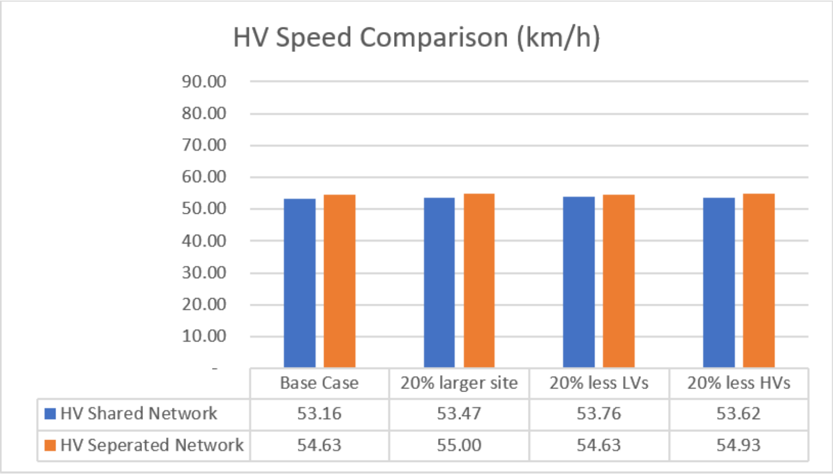

Figure 5-5: HV speed - Case study comparison

The productivity of the vehicles provided by separation was an important input into the discounted cash flow analysis. LV productivity was calculated based on the comparison of travel times for a LV for separated and shared road networks. Most of the time saved is directly related to the LVs travelling at greater speeds when not impeded by HV operating speeds. Notably, the productivity hours were calculated with a LV single occupant. Therefore, the results would double for two passengers and further increase for more passengers as the productivity is calculated on payable operator working hours. Figure 5-6 shows the LV productivity for the different case studies.

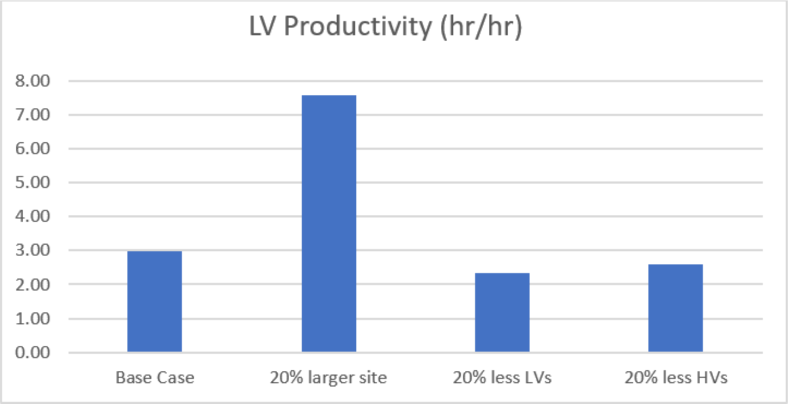

Figure 5-6: LV productivity - Case study comparison

The larger the site, the more increased productivity was evident, and the reduction in either LV or HV traffic volumes decreased the productivity by approximately the equivalent percentage. This shows that inputs such as mine size, LV and HV traffic volumes can alter the productivity outcomes significantly.

HV operator productivity is shown in Figure 5-7 below. The savings are not as significant when compared to the LV. Increased speeds were identified due to minor reductions in delay and queuing across the network.

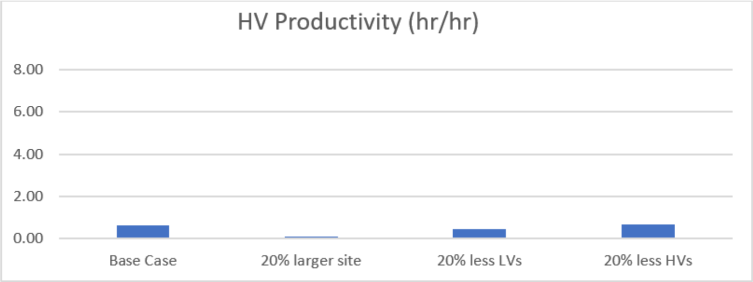

Figure 5-7: HV productivity - Case study comparison

Overall, the traffic simulation software showed the financial benefits of providing separated road networks for the light vehicles and haul vehicles. The most noticeable benefit was due to the increase in vehicle speeds. While improvements were identified in queueing, delay, and density, the benefits from these were only marginal in comparison to the benefits from speed improvement. Undertaking the sensitivity analysis has shown that the results from the different models can vary depending on the size of the mine and the traffic volumes utilising the road networks.

The sensitivity analysis has examined items such as mine sizes, discount cash flows, traffic volumes, however other factors may be considered dependent on the type and location of mine. Factors such as productivity alterations, labour costs, construction costs and commodity price fluctuations could be considered.

5.7 STAKEHOLDER ENGAGEMENT AND CONSULTATION

Stakeholder engagement was undertaken with the mining community through the presentation of a paper “Using Traffic Modelling in the Optimisation of Surface Mine Layouts” (Birkbeck S, 2021) at the International Conference on Energy and Mining Engineering in April 2021. The interest in the traffic modelling results were evident from the discussion generated by the presentation within the conference.

Consultation has been undertaken with mining companies when seeking data to undertake the research. Interest was expressed from numerous companies in relation to the research as a tool to better understand the risk, however the companies did not have the available resources for data correlation.

6. CONCLUSION

In conclusion the research has identified that fatal collisions do occur within the Australian mining industry, particular within surface mining operations, and regulatory bodies have been recommending the separation of light vehicle and haul vehicles.

The research delivered a risk-based framework for HV and LV interaction within surface mines. Overall, it is anticipated that incorporating a financial assessment process into the risk management process will provide guidance for mining companies to determine if mitigating the risk of HV and LV interaction is a suitable investment.

The research determined how separating the HV and LV vehicles with additional road networks will impact the productivity and efficiency of the mine with the use of traffic modelling software. The traffic models tested the future unbuilt road networks to develop an understanding of the positive impacts including the increased speed, and reduced vehicle density.

The positive results showed the incorporation of haul vehicle and light vehicles separation should be incorporated, however inputs from differing mines may provide differing results and recommendations.

6.1 FUTURE RESEARCH

The research has successfully developed a risk-based framework, however future research within the risk management, technology and traffic modelling fields may be applicable in the following years.

Traffic modelling of the separate road networks has provided insight into how it can affect a company’s profitability with minimal expenditure at feasibility stages, prior to major capital expenditure of the construction works. While the research utilised

Aimsun as the traffic modelling software, future research in developing mining specific traffic modelling packages is advisable.

The use of traffic modelling may also provide an awareness of how the carbon emissions impact of the mining vehicles are affecting the environment. This can be undertaken by including the fuel usage and environmental emissions of the vehicles into traffic modelling software packages. These environmental measuring tools are currently utilised within the infrastructure industry and would be beneficial for the mining industry and achieving Australia’s emission targets.

The development of traffic modelling software for specific use in mining vehicles would also provide more accurate results for different areas of the mine site. As a mine site can have different operational parameters such as speed, gradient and traffic volume. Areas such as pit ramps have higher gradients, lower speeds, and lower traffic volumes. Comparing to the main haul roads which are generally lower gradients, higher speeds, and higher traffic volumes. Therefore, further research could be undertaken to ensure vehicle operation is consistent within the model to different operational parameters of a mine site.

Similarly, the different areas of the mine would have different construction costs for implementation of vehicle separation. For instance, the cost to establish a new light vehicle road adjacent a haul road within a pit ramp would incur significant costs in excavation within deep pits. However, the cost of an additional light vehicle road adjacent the main haul road would have incurred significantly less costs. Also, the construction costs may be substantially different dependent on where the mine site is located. Other construction costing considerations for the framework would include who is undertaking the construction. Major mining companies have the available plant to self-perform the construction and can be undertaken at much cheaper unit rates when compared to construction contractors. Therefore, further research may be applicable for construction costing, and utilising the framework for different areas of the mine site to potentially achieve partial vehicle separation.

The risk-based framework developed may also have other applications within the mining industry. Mines encounter numerous hazards within the materials handling and vehicle maintenance operations. These hazards could be evaluated using the similar life cycle quantitative approach to determine if it is financially feasible to eliminate the risk.

It is a fact that fatal collisions have reduced over the years with the introduction of new technology and the application of more rigorous safety regulations. Further advances in technology, such as the introduction of autonomous vehicles and the new vehicle location systems, certainly have a role to play in improving safety. However, none of these technologies are likely to completely eliminate the possibility of LV/HV collisions. In the future, operators' trust in the technology improvements may change this understanding of risk control. Future research may be required focusing on technology improvements and how achieving a reliance upon autonomous vehicles as the trusted elimination method.

If current technology can provide a solution to remove the HV operators from the mine, it may require more research to remove the LV operators as they are prone to the fatal collisions. The LV operators provide maintenance, planning, inspections, engineering, as well as drill and blast support to the mining operations. Further research may be applicable with each to these fields to ascertain if their presence can be removed from the site through technology advancement or procedural innovations. Advancements may include inspections with unmanned aerial vehicles, autonomous drill and blast fleets and autonomous road maintenance. Procedural innovations may be applicable to reduce the interaction through periods of haul road usage only allowed for LVs.

Company reputation was identified as a contributor to financial loss for mining companies due to poor safety performance, including HV/LV collisions. The literature review identified larger stock exchange listed companies would be financially impacted due to company reputation. While the research has undertaken a literature review of this subject, future research could be undertaken on this subject and in particular the impact to stock prices when an incident is reported within media broadcasts and developed into the Discount Cash Flow analysis.

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APPENDIX A

HV LV Collision Reports

- Western Australia Collision
- New South Wales Collision

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

Mines Safety Significant Incident Report No. 152

Haul truck and light vehicle collision

Incident

An unloaded Caterpillar 789C haul truck and light vehicle collided at a controlled mine intersection. The right side front and rear wheels of the haul truck ran over and crushed the cab of the light vehicle. The light vehicle driver sustained fatal injuries. Cutting equipment was used to free the light vehicle driver.

The incident was re-enacted with an exemplar truck and light vehicle, based on information derived from the interviewing of witnesses and the road marks visible after the collision. It appears that the combination of the alignment of the (terminating) haul road as it intersects the main (through) haul road and the converging speeds of both vehicles may have placed the light vehicle behind the right side 'A' pillar of the haul truck's roll over protection structure (ROPS), where it may not have been clearly visible to the haul truck driver. Similarly, the light vehicle driver's view of the haul truck as he approached the intersection may have been obscured by the light vehicle's internal rear vision mirror.

Immediate causes and contributory factors

- The intersection was not designed and constructed at a 90° angle.
- The slight uphill grade from the terminating road to the intersection.
- The curvature of the main haul road.
- Both drivers' fields of view were restricted at the intersection due to poor sight approach lines and distances, windrow height and vegetation on the windrows.
- The speed at which the haul truck entered the intersection.
- Possible restriction of the haul truck driver's field of vision due to the cabin ROPS frame structure and the fact that the light vehicle was approaching from the right (blind) side of the haul truck.
- Possible restriction of the light vehicle driver's field of vision due to the rear vision mirror, which may have obscured a clear view of the haul truck approaching the intersection.
- A lack of auditing, risk assessments and maintenance of the intersection.

Comments and preventative actions

- Perform regular documented traffic management audits and risk assessments on all intersections to identify potential collision hazards.
- Develop a site traffic management plan.
- Where determined by a risk assessment or where sight distances at intersections are less than prescribed in Australian Standard AS 1742.2:1994 *Manual of uniform traffic control devices – Traffic control devices for general use*, 'STOP' signs should utilised instead of 'GIVE WAY' signs at intersections.
- Ensure traffic signage is regularly maintained and not obscured by vegetation, poles or other signage.
- Ensure vegetation is regularly removed or trimmed from windrows on approaches to intersections.
- Ensure windrows are tapered down to 0.75 m near intersections to increase visibility.

- Ensure terminating roads are positioned at 90° to through roads to allow for maximum sight distances.
- Intersections should be placed in safe locations away from vertical or horizontal alignment changes.
- Approaches to intersections should be constructed at a flat (0%) grade for a minimum distance of the length of the longest vehicle using the intersection.
- Consider lowering speed limits on through roads at intersections that are deemed to be high risk as a result of formal risk assessment.
- Install median bunding to ensure right angle entry to roads and to slow speeds of turning vehicles (bunding should be set 2 m back from through road to allow good visibility).
- Consider separation of light and heavy vehicles by means of separate mine access roads for light vehicle use only.
- Ensure daily inspections of haul roads and intersections are carried out by a competent person.
- Ensure that operators are informed of road and traffic management changes at the work site when they have returned from time off.
- All vehicle types should be examined for potential blind spots and attempts should be made to eliminate or reduce them.
- Ensure that all vehicle operators are aware of residual vehicle blind spots.
- Consider fitting both heavy and light vehicles with proximity detection devices.

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STATE MINING ENGINEER

26 February 2009