Vehicle Operation Safety Monitoring Using Context Based Metrics: A Case Study

James Ward, Stewart Worrall, Gabriel Agamennoni and Eduardo Nebot

Abstract

This paper presents results of the deployment of vehicle safety systems developed by the Intelligent Vehicles and Safety Systems Group at the Australian Centre for Field Robotics. The technology was deployed within an active mine site in Australia undergoing standard open-cut mining operations. Data were collected from the vehicles and analysed in order to assess the overall safety and performance of the vehicle operations within the mine. Metrics calculated include distributions of vehicle paths along stretches of road for driving line analysis, and statistics around vehicle events such as overspeed and proximity to other vehicles.

1. Introduction

The Intelligent Vehicles and Safety Systems Group at the Australian Centre for Field Robotics has been developing and deploying systems to monitor vehicle operations and interactions. In this paper we explore some of the data that has been collected from an active mine site where mining trucks were fitted with the system.

One method of monitoring safety is to record all accidents and near misses during operations. This has a number of drawbacks, not least of which is that this provides a very sparse dataset on which to do any meaningful analysis and on which to base policy. Metrics that are precursors to accidents provide a much more robust approach to the problem of vehicle operation safety. The literature describes multiple approaches to the computation of metrics and indicators that are correlated with levels of safety [1, 2, 3, 6]. We seek to extend the work on metrics by exploring what other metrics can be derived from a rich dataset detailing operations and interactions of vehicles on a large scale.

It should be noted that the data that were used to create this paper were historical, which means that conclusions drawn cannot be acted upon and verified. Nonetheless, we feel that discussion of our results within the ITS community is valuable as it will lead to improvements in the approach to solving the safety problem, and forms the basis for further research where more direct actions and their consequences can be observed. This workshop paper is deliberately exploratory in nature in order to stimulate such discussion.

2. System Overview

The safety monitoring system has two major components that are necessary to generate the dataset for analysis. The first component is the in-vehicle system including sensors and multiple redundant radios which are fit to each vehicle. The sensors are used to determine the vehicle position and other state information, and the radios are used to broadcast this information to other vehicles in the vicinity. This broadcast is made on a peer-to-peer basis and is not relayed to third party vehicles as is the case in Vehicular Ad-hoc Networks (VANETs) such as those described in [5]. A graphical and audio interface is provided to the operator to improve his situation awareness by providing information about the surrounding environment and any risks that are detected. Fig. 1 shows an example of an interface mounted in the vehicle cabin. A thorough explanation of this approach is presented in [7] and [8]. A similar approach is used in an urban setting in [4].

The second component to the safety system is the fixed infrastructure and database which facilitates the collection and storage of the vehicle state information. Each vehicle stores its own state information together with information about interactions with vehicles that it has encountered. As each vehicle passes a fixed data collection point(s) the data are opportunistically downloaded and stored in a central database. It is from this database that the analysis in this paper was derived.

The database stores position, speed and state information (e.g. reversing state) for each vehicle. It also records communications between vehicles including which radio module was used. Finally, breaches of any rules that drivers must obey in the mine, such as speed or traffic proximity limits, are also logged. This
is a rich dataset for exploring the safety of vehicle operations in the mine.

3. Trip Cycles

In order to make analysis of the data more meaningful, it is desirable to group the logged positions by trip. To achieve this, the positions are processed in two steps.

Firstly, positions that fall within the boundaries of a defined area are identified. When these positions are ordered chronologically they can be grouped into times when the vehicle was in a particular area. We call these periods dwell periods.

Secondly, between each dwell the vehicle is assumed to travel on a road connecting the areas in question. The positions between the times of each dwell are fitted to one of the roads connecting the two areas. This is done on the basis of smallest value of the summed displacements between recorded positions and each road. The road on which the vehicle travelled and the summed displacement for this trip is stored for later use.

The total displacement of a given trip is calculated as:

\[ d_{\text{total}} = \sum_{x_i \in T} d(x_i, R) \]  

(1)

where \( d_{\text{total}} \) is the total displacement, \( x_i \) is a GPS location, \( R \) is the road used for the trip, \( d(x_i, T) \) is a function to determine the shortest distance between a point and a road, and \( T \) is the set of GPS points recorded for a given trip.

4. Map Monitoring

With our system drivers are presented with a map of the immediate area so that potential conflicts can be displayed with reference to the area in which the vehicle is operating. In mining operations it is usual for the layout of roads to change frequently as new areas are opened up and old areas closed down. A map that does not accurately reflect the current state of the roads is distracting for the driver and does not allow the presence of other vehicles to be accurately conveyed in the appropriate context. The data collected from the vehicles can be used to identify vehicles travelling on paths that do not form part of the stored road map. This is used to flag areas of the map that need updating.

Fig. 2 shows GPS information logged by the vehicles overlayed on part of the existing map. It appears that a new road has been created between the eastern Dump Area and DOM 1 Pit.

It is not convenient to allocate a person to constantly study the GPS position plots and identify map areas in need of improvement. Using the trip information calculated in Section 3, a table of the average displacement of trips between two areas can be generated. Trips between area pairs with high displacements from existing roads indicate regions of the map that need attention. It is a simple matter to set a threshold (generally expressed as a percentage of the trip distance) and provide an automatic alert to the personnel responsible for map maintenance when this is exceeded.

An example of such a calculation is shown in Table 1. It appears that trips between the Dump Area and DOM 1 Pit are not taking the known roads and should be investigated. This agrees with the GPS position plot of 2.
From | To | Fractional Trip Displacement (%) | Road ID | SD of Fractional Trip Displacement (%) | Number of trips |
--- | --- | --- | --- | --- | --- |
Dump Area | DOM 1 Pit | 33.2 | 50 | 20.7 | 10 |
DOM 1 Pit | Dump Area | 17.3 | 48 | 20.7 | 211 |
DOM 1 Pit | Intersection | 12.5 | 45 | 14.1 | 61 |
DOM 1 Pit | Intersection | 12.5 | 74 | 10.5 | 7 |
Intersection | DOM 1 Pit | 10.1 | 40 | 5.7 | 112 |
Ramp | DOM 1 Pit | 5.3 | 20 | 5.7 | 52 |
DOM 1 Pit | Ramp | 4.3 | 56 | 5.5 | 220 |
DOM 1 Pit | Intersection | 2.7 | 69 | 5.4 | 465 |
Ramp | DOM 1 Pit | 1.9 | 12 | 5.3 | 8 |
DOM 1 Pit | Ramp | 1.6 | 60 | 4.6 | 374 |

Table 1: Displacement of trip path compared to road path between given areas. Expressed as a fraction of the road length.

Table 2: Standard deviation of displacement of trip path compared to road path between given areas. Expressed as a fraction of the road length.

5. Driving Line Analysis

A simple metric that can be used to identify behaviours that warrant further investigation is the distribution of vehicle tracks on particular roads. Table 2 shows the standard deviation of displacement of the vehicle trajectory from the defined road normal driving line, where the displacement is expressed as a percentage of road length. There is a step increase from roads where the standard deviation is less than 6 % to those where it is greater than 10 %.

Fig. 3 has the four roads with the largest standard deviation of vehicle tracks plotted in red. Whilst wide driving line deviation distribution is always worth investigating, it is most likely to be of more value when investigating longer stretches of highlighted roads. The highlighted road between the two dump areas in the centre of Fig. 3 is the longest. High levels of deviation distribution could be due to poor definition of the road which leaves the particular driving line chosen to the judgement of the driver, or it could be indicative of poor road condition encouraging drivers to pick a clean line down the road. A sudden change to the road such as an obstruction would also lead to an increase in the standard deviation of track displacement. The exact cause for the broad distribution of track deviation cannot be gleaned directly from the data, but it does provide a good indicator of where to focus investigation of possible unsafe conditions in the mine.

6. Event Metrics

The systems installed in the vehicles are able to log the time, location and type of event that is triggered by a rule violation. In this deployment the two events that were logged were overspeed events and when drivers travel too close to a vehicle in front. Details of these events can be analysed in a number of different ways to create useful metrics.

6.1. Geospatial Plots

Plotting events on a map gives an excellent high-level overview of possible safety concerns within the mine.

Fig. 4a shows overspeed events. It is possible at a glance to identify areas of the mine that should be targeted for remedial action. This may include better signage, monitoring, awareness training or redesign of the road itself to discourage speeding. It is interesting to note that it is possible to infer the types of areas from the distribution of the overspeed events on the map without any prior knowledge. Vehicles in this mine drive on the left side of the road and it can be seen that overspeed violations tend to occur in one direction on each road. Speeding is more likely in an unloaded vehicle, thus overspeed events tend to occur on the roads exiting from dump areas. One can infer dumping and loading
sites quite accurately by looking at speed distributions on the connecting roads.

Fig. 4b illustrates the events where a vehicle followed too close to another vehicle, which is 50 meters of separation as defined in the mine site driving rules. Investigating these areas is called for as it may be indicative of regions with poor sight lines or regions in which vehicles naturally operate close to one another, such as queuing for loading. Proximity violations may not be a cause for concern per se, but a positive assessment of the safety implications must be made. In this way, highlighting these areas is beneficial.

6.2. Event Distribution

Event distribution can provide useful metrics to assess the safety of vehicle operations.

Time based analysis of events can help those responsible for vehicle operation safety to assess whether measures are having a positive impact on safety levels. Fig. 5 shows proximity events over a period of time. The graph shows that in the most recent period the number of violations is lower than in the previous month but that the average length of violations is higher. This may mean that drivers are becoming better at avoiding proximity rule violations when driving on roads, and the average time of violation is being driven up by long periods in close proximity to other vehicles in areas such as loading zones or dumps.

Further investigation by breaking down violations by area can help to tease this information out. Fig. 6 shows a week’s proximity rule violations grouped by area. The number of events in the pit (the area where trucks are loaded) is relatively high and could explain why the average duration of violations had increased in Fig. 5 when the number of violations had fallen. Nonetheless, a large number of instances of vehicles operating in close proximity does increase the potential for conflict and ways to reduce this number should be considered.

In the same way that violations could be examined on the basis of area type, it is also useful to look at violation events grouped by vehicle type. Fig. 7 shows over-speed events by vehicle type. Such a plot can highlight whether a particular class of vehicle is over-represented in potential conflicts. Perhaps the design of the vehicle makes violations more likely, or perhaps remedial training should be focused on the drivers of that vehicle type. Of course, on a given mine site the numbers of vehicles in each class will not be the same so Fig. 8 shows the
(a) Speed violations. Green dots are below the speed limit, yellow is 0-10% above the speed limit, orange is 10-20% above the speed limit, red is greater than 20% above the speed limit.

(b) Proximity violations. Red dots show two trucks within 50 metres of one another.

Figure 4: Excerpts of map showing rule violations.
Figure 6: A week’s proximity violations broken down by mine area.

Figure 7: A week’s speed limit violations broken down by vehicle type.

same data on a per vehicle (i.e. normalised) basis.

7. Conclusion

This paper introduced a system for monitoring, transmitting and logging vehicle state information which has been developed and deployed in a real mining fleet application. Such a system creates large amounts of detailed information about vehicle operations and interactions, a set of which is presented in this paper. Analysis of this data allows metrics that reflect the safety of vehicle operations to be generated and explored.

Acknowledgements

This work is supported by Australian Research Council Linkage Project LP120100700.

References


Figure 8: A week’s speed limit violations broken down by vehicle type and averaged over each vehicle.