International Journal of Occupational Safety and Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

Heavy Mining Vehicle Controls and Skidding Accidents

Christopher Hubbard[a], Syed Abid Naqvi[a] & Mike Capra[a]
[a] School of Public Health, Queensland University of Technology, Kelvin Grove, QLD, Australia
Published online: 08 Jan 2015.

INTERNATIONAL JOURNAL OF
OCCUPATIONAL SAFETY AND ERGONOMICS 2001, VOL. 7, NO. 2, 211–221

Heavy Mining Vehicle Controls and Skidding Accidents

Christopher Hubbard
Syed Abid Naqvi
Mike Capra

School of Public Health, Queensland University of Technology, Kelvin Grove, QLD, Australia

This paper examines various control locations in heavy mining vehicles. Three trucks have been tested on a skid pad in both clockwise and anticlockwise directions. The skid lengths were measured after each trial. The primary focus of the study was the positioning of various controls and their relevance to various skid lengths. Some additional measures such as NASA-TLX scales were also used to make subjective evaluations. The results are presented in this paper. The findings clearly indicate the relevance of control locations to actual skid lengths. The poorly located controls resulted in greater skid lengths. This is an important finding as skid lengths are related to greater reaction times in a skidding situation and hence greater risk of accidents on relevant trucks. Such accidents can incur large repair bills for damaged equipment whereas more importantly, jeopardizing the life and safety of heavy mining vehicle drivers.

jackknife trailer brake skidding haul trucks controls

1. INTRODUCTION

For the transportation of bulk material from mine sites to a processing plant, large articulated haul trucks, capable of weighing in excess of 250 tonnes are required. In particular areas of Australia, where climatic conditions produce extreme amounts of rainfall these vehicles becoming increasingly more difficult to control.

Correspondence and requests for reprints should be sent to Syed Abid Naqvi, Occupational Health Clinics for Ontario Workers (Toronto) Inc., 15 Gervais Drive, Suite 308, Don Mills, ON, M3C 1Y8, Canada. E-mail: <snaqvi@ohcow.on.ca>.

The haul roads these vehicles travel on can become extremely slippery and these vehicles become prone to skidding around corners, which can cause the occurrence of jackknifes.

Jackknifing occurs in heavy articulated mine vehicles when the trailer exhibits uncontrolled movements with respect to the prime-mover and swings at an acute angle to the normal axis of the prime-mover and the trailer. Due to a lack of prior research in the area of jackknifing haul trucks, and specifically to how certain controls may impact on the drivers' manoeuvrability, along with a recorded 29 jackknives at one mine in the past 4 years, are the rationale behind undertaking such an investigation.

To avoid a jackknife from occurring, once a haul truck has entered a skid, three actions are required by the drivers. They are

1. acceleration of the prime-mover;
2. attempt to steer out of the situation, the opposing direction in which the trailer is moving around; and
3. application of the trailer brake lever (located on the right side of the steering column).

From these actions it can be viewed that there are three groups of controls that have the most potential to impact on the affective manoeuvring of a skidding haul truck. These are the steering wheel, the accelerator and brake pedals, and the trailer brake lever.

1.1. The Steering Wheel

Goodwin and Kendall (1995) outlined that the two major factors associated with the steering wheel in automobiles are the dimensions of the wheel itself and the angle the wheel makes with the horizontal plane. Table 1

TABLE 1. Various Recommended Steering Wheel Sizes, Which Will Facilitate Optimal Control of an Automobile

Author	Year of Publication	Wheel Diameter (mm)	Rim Thickness (mm)
Weiman	1993	180–530	20–50
Van Cott and Kinkade	1972	375–450	8.75–37.5
Konz	1990	180–530	20–50
Clark and Corlett	1984	< 500	N/A

Notes. N/A—not applicable.

outlines some recommendations given by a number of authors, in relation to optimal sizes of automobile steering wheels.

The angle the steering wheel column makes with the horizontal plane is the second of the factors involved. Simpson (1991) and Van Cott and Kinkade (1972) recommend an angle of between 40 and 60° to the horizontal plane as being the optimal range for the wheel to be set at.

1.2. Trailer Brake Lever

Van Cott and Kinkade (1972), who recommend a distance of no more than 62.5 mm between the steering wheel and the top of any lever located on the steering wheel column, supply a value to which comparisons can be made.

1.3. Foot Controls

Extensive literature has been published in the area of design, selection, and location of foot controls, addressing adequacies and inadequacies in automobile cabins. The issues of movement time, accidental activation, and whether to incorporate coplanar pedal or vertically separated pedals have been extensively researched. The vast majority of these studies have concluded that there should be a minimum horizontal separation between brake and accelerator pedal of 50 mm, with the desired separation of 100 mm, and a vertical separation of 50.8 mm (Adams, 1989; Clark & Corlett, 1984; Konz, 1990; Simpson, 1991; Weiman, 1993).

How these three controls impact on the optimal control of articulate haul trucks will be further investigated.

2. METHODOLOGY

2.1. Initial Informal Interviews

An informal interview with a number of drivers—along with an analysis of the driving manual each of the drivers is supplied with—was performed in order to identify the actions required to activate each of the controls, and the potential problems associated with these actions.

2.2. Static Assessment

Static measurements of the components, highlighted during the informal interviews, were taken from three different haul trucks that were utilised throughout the study. Information pertaining to the vehicles chosen can be found in Table 2.

Each of the measurements was then correlated against existing literature, to identify if compliance with ergonomic guidelines was reached.

The static measurement categories obtained from each of the three haul trucks incorporated in the investigation are as follows:

1. steering wheel diameter (mm),
2. steering wheel rim thickness (mm),
3. steering wheel angle to the horizontal plane,
4. lateral separation between the brake and accelerator pedals (mm),
5. vertical separation between the brake and accelerator pedals (mm),
6. trailer brake lever length (mm),
7. distance separating the trailer brake lever and the steering wheel (mm).

Figure 1 shows a picture of the trucks used in the study.

Figure 1. Trucks used in the study.

2.3. Dynamic Assessment

A dynamic aspect was incorporated into this investigation, to detect if any of the controls aided or inhibited a variety of drivers, whilst the haul trucks were in a skidding situation.

2.4. Study Population

The participants were all current operators of haul trucks. Three females and 5 males were chosen in order for the study population to be a close representation of the overall driver population.

2.5. Truck Selection

Table 2 outlines relevant information pertaining to each of the three haul trucks utilised throughout the investigation.

TABLE 2. Information Relating to the Three Articulated Haul Trucks Utilised Throughout the Investigation

Truck Type	Years in Production	Empty Weight (tonne)	Loaded Weight (tonne)
A	> 20	95	245
B	20	100	250
C	5	120	270

2.6. Skid Testing

Large circular expanses of land, where jackknife training exercise are held, was the site at which the skid testing was undertaken. The surface of the skid pad, identical to that of the haul roads, was watered down, to allow the drivers of the vehicles to instigate a skid with more ease.

Each participant was instructed to initiate a skid in the first haul truck, once around the skid pad. Markers were placed on the perimeter of the pad, indicating where the skids should be initiated. The direction, or rotation, of the skid initially performed was noted. Each driver was instructed to drive the haul truck as fast as they felt comfortable, however attempting to maintain a similar speed for each of the vehicles.

Once each participant had completed the initial skid, and regained control prior to a jackknife occurring, they were instructed to cease the vehicle progress. The skidding of the haul trucks left a distinct mark on the surface of the skid pad, and therefore each skid length was measured with a measuring wheel, and recorded. Each participant then repeated the skid, in the same rotation, in the same haul truck. This repetition was performed in order to obtain an average.

Upon completion of the second skid, each participant then executed two more skids, in the same haul truck, however in the opposing rotation to the initial two. This aspect was introduced into the investigation, in order to identify if locating the trailer brake lever on only one side of the steering wheel column would affect optimal control for the drivers, in one direction more than the other. Both skid lengths in the opposing direction were measured and averaged.

Once all four skids were completed in the first of the three haul trucks, the participants were then instructed to park the vehicle to the side of the skid pad. Each of the participants was then given the opportunity to emphasise any factors that they felt had impacted on their ability to regain control of the skidding haul truck. They were noted, and correlation between these comments and the driver's performances was evaluated.

All participants following their completion of the four skids in each haul truck also completed a subjective rating tool, the NASA-TLX Rating Scale (Hill et al., 1992), a seven-step analysis of a task. The scale is a multi-dimensional questionnaire, which asks the participant to rate, out of 100, six areas which relate to how adequate the fit is between the driver and the system, or in this case the driver and the haul truck, for this specific task. The six areas involved are mental demand, physical demand, temporal demand, performance, effort, and frustration. Each participant completed one scale for each vehicle.

The maximum heart rates of each participant were also obtained via the use of a polar heart rate monitor, for each skid in each rotation. The physiological results were averaged for each driver, in each vehicle, for each rotation.

An identical procedure was performed for all haul trucks, and all 8 participants. A total of 96 simulated skids were performed, 48 clockwise and 48 anticlockwise. Each participant performed 12 skids.

The only controlled variation incorporated in the study was the order in which each participant skidded the vehicles. In order to eliminate the possibility of results becoming biased due to the participants becoming increasingly more comfortable with the task as the study progressed, each participant skidded the vehicles in an alternative order.

2.7. Analysis

An analysis of variance statistics was performed on the results obtained from the skid lengths, and all information obtained from the individual participant. This was completed in an attempt to identify if any significant relationship is present in the results and the variables under investigation.

3. RESULTS

3.1. Static Measurements

Table 3 summarises the static measurements acquired from each of the haul trucks incorporated in the study.

TABLE 3. Static Measurements Taken From the Three Haul Trucks

	Truck Type		
Measurements	**A**	**B**	**C**
Steering wheel diameter (mm)	400	410	440
Steering wheel rim thickness (mm)	26	25	23
Steering wheel angle (degrees)	54	60	52
Lateral separation between the two pedals (mm)	51	52	65
Vertical separation between the two pedals (mm)	nil	20	nil
Trailer brake lever length (mm)	170	210	150
Distance between trailer brake and steering wheel (mm)	120	85	31

From the values presented in Table 3, it is clear that all measurements, in relation to the steering wheel, for the three haul trucks fall within the ranges outlined in previous ergonomic publications. In relation to the pedal separations all three vehicles have complied with the minimum lateral separation guidelines, however none have met the guidelines for the adequate vertical separation distance.

From the results, the location of the trailer brake lever on the three haul trucks is the most significant factor out of the three controls under investigation. Only Truck C, with a separation of 31 mm is inside the recommendation of 62.5 mm given in literature (Van Cott & Kinkade, 1972). Truck B is also deficient in the fact that there is an additional lever placed in between the trailer brake lever and the steering wheel. This may add some confusion to the drivers when involved in an emergency situation, such as a jackknife.

3.2. Skid Lengths

From Figure 2 it is clear that Truck C has recorded the shortest skid lengths in both directions. Truck A has the longest skid lengths in both directions, slightly longer than those recorded for Truck B. The statistical analysis, significance level .7059, indicates that the difference between trucks is insignificant with respect to skid lengths.

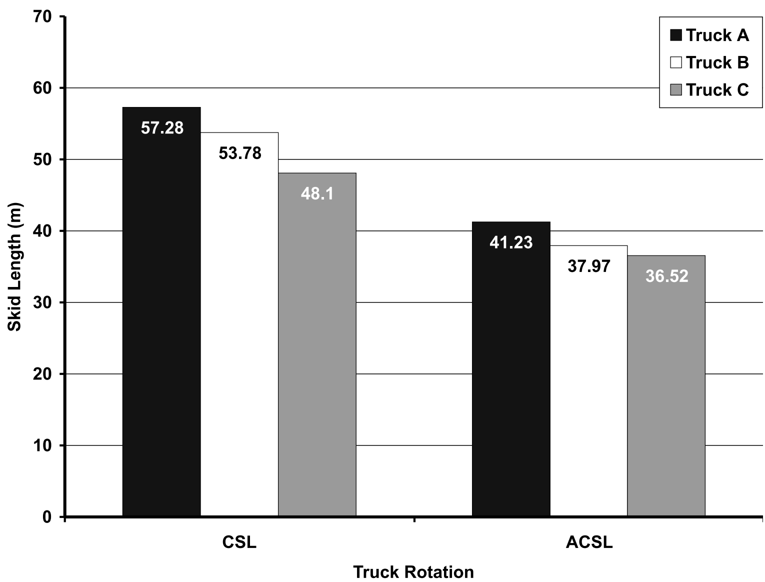

Figure 2. Combined average Clockwise Skid Lengths (CSL) and Anticlockwise Skid Lengths (ACSL) for all three haul trucks.

The results obtained from the differing rotation used in the skid testing do however show some significant findings. The average skids performed in the clockwise direction were recorded at 14.51 m longer than those recorded in the anticlockwise direction. The significance level of .0392, given by ANOVA (Analysis of Variance), reveals that on average, the skids performed in the clockwise direction are statistically greater in length than those performed in the anticlockwise direction.

The heart rate results highlighted that there was no relationship present between the vehicles under investigation and the heart rates recorded, with a significance level of .9993. This trend was also evident when the relationship between the rotations used and the heart rate results were examined.

When the overall averages of the response obtained from the NASA-TLX scale (Hill et al., 1992) were examined, each section highlighted that Truck C was clearly the most preferred by the drivers during a skidding situation. On average it was 11.41 points clear of the remaining two. With only 2.61 points separating Trucks A and B there is not a clear distinction between the two present.

The longer the skid lengths are, the greater the possibility of a jackknife resulting, and in turn the more likely damage to both machinery and drivers alike will result.

4. DISCUSSION AND CONCLUSION

4.1. Truck Rotation

With a significance level of .0392 between the skid lengths in the opposing directions, there is a strong indication that there is a contrast between the truck rotations utilised during this investigation.

The most likely explanation for this variation is in relation to the positioning of the trailer brake lever. The lever, in all three haul trucks, is positioned on only one side of the steering wheel column, the right hand side. This results in problems for drivers during skids that occur in the clockwise direction.

In order to avoid a jackknife, when a haul truck is involved in skid around a clockwise corner, the driver is required to rotate the wheel to the left hand side, the opposing direction to the oncoming trailer. This action, along with activating the trailer brake and accelerating the prime mover, will increase the possibility of avoiding contact.

However because the steering wheel is being rotated to the left, an anticlockwise rotation, the hands of the driver are being positioned away from the location of the trailer brake lever. Therefore it takes a longer period of time for the operator of the vehicle to locate and activate the trailer brake lever. This in turn increases the length of the skid and the likelihood that contact between the prime mover and the trailer will result.

When a driver is involved in a skid around an anticlockwise corner, the opposite rotation op the steering rotation is required. The driver rotates the steering wheel in a clockwise fashion, to the right, placing the hands closer to the trailer brake lever, allowing for easier location and activation, and resulting in a reduction in time to slow the momentum of the trailer.

This principle is highly evident in both Trucks A and B, which have both been identified, from previous literature, as having the most inadequate positioning of the trailer brake lever. Both of these haul trucks have the lever positioned much further down the steering wheel column in comparison to Truck C. When comparisons of the three haul trucks are made, between the variations in skid lengths for the two rotations, it is clear that the trailer brake lever plays a large role in a driver avoiding a jackknife.

This point is further enforced by the results outlined by the Temporal Demand (one of the six dimensions of the scale) section of the NASA-TLX (Hill et al., 1992). It identifies Truck C as clearly being superior in the time it takes for the drivers to utilise the controls.

The variation between rotation for Truck C was recorded at 11.58 m. With Truck A's variation being recorded at 15.81 m and Truck C's variation being 16.05 m, it is evident that locating the trailer brake lever, during a skid around a clockwise corner, becomes increasingly more difficult if it is placed low and on the right hand side of the steering wheel column.

This substantially increases the distance it takes the haul truck to brake, and increases the likelihood of a resultant jackknife.

The principal explanation behind the improved assistance given to the participants, by Truck C, when involved in as skid, is due to its relative youth in comparison to the remaining two trucks. Over the past 20 years there has been a vast improvement in haul truck ergonomics, as can been seen through this investigation, but it is still lacking in some areas. One of these areas highlighted in this study, is the positioning of the trailer brake lever and how it impacts on the affective control of a skidding haul truck.

Further research is required in evaluating the validity of alternative forms of trailer brakes, or the validity of incorporating two trailer brake levers, one on either side of the steering wheel column.

REFERENCES

Adams, J.A. (1989). *Human factors engineering*. New York, NY, USA: MacMillian Press.

Clarke, T.S., & Corlett, E.N. (1984), *The ergonomics of workspace and machines: A design manual*. London, UK: Taylor & Francis.

Goodwin, S., & Kendall, L. (1995). *Identification of ergonomic issues within the road transport industry*. Brisbane, Australia: Division of Workplace Health and Safety.

Hill, S.G., Iaveuhia, H.P., Byers, J.C., Bittner, A.C., Zakland, A., & Christ, R. (1992). Comparison of four subjective workload rating scales. *Human Factors, 34*(4), 429–440.

Konz, S. (1990). *Work design: Industrial ergonomics*. Worthington, OH, USA: Publishing Horizons.

Simpson, G. (1991). *Ergonomics in mining*. Sydney, NSW, Australia: Mining Risk Management Service.

Van Cott, H.P, & Kinkade, R.C. (Eds). (1972). *Human engineering guide to equipment design* (Rev. ed.). Washington, DC, USA: U.S. Government Printing Office.

Weiman, J. (1993), *Handbook of ergonomics and design factors table*. Englewood Cliffs, NJ, USA: Prentice Hall.