Safety In Mines Research Advisory Committee

# SIMRAC

**DRAFT**

# Final Project Report

Title: THE INFLUENCE OF ERGONOMIC DESIGN OF TRACKLESS MINING MACHINES ON THE HEALTH AND SAFETY OF THE OPERATORS, DRIVERS AND WORKERS

Annexures:

1. The ergonomics of trackless vehicles in South African Mines (A design handbook)
2. HSEC Ergonomics Index for underground trackless vehicles
3. HSEC risk assessment procedure for underground trackless vehicles
4. HSEC sightline risk assessment procedure for underground trackless vehicles
5. Retrofit to improve the ergonomics of trackless vehicles

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# Executive Summary

The project has produced information and methodologies for use by designers, mine managers and engineers to improve the health and safety associated with the use of trackless vehicles in mines. The project deliverables focus on assisting: designers optimising new vehicle ergonomics; mines specifying the ergonomics of new vehicles; and mines improving the ergonomics standards of their current vehicles by detailed risk assessment methodologies and cost-effective retrofit modifications.

The deliverables include: a design handbook addressing 12 ergonomic features of trackless vehicles; an index for assessing the standard of the ergonomics of trackless vehicles; a comprehensive risk assessment procedure and a specific sightline risk assessment procedure. Training is also an important part of improving the health and safety associated with trackless vehicles and a demonstrator using virtual reality was produced to help improve the safety of mineworkers working close to trackless vehicles. Both features of the vehicle and the mine layout can be modelled to reflect conditions at specific mines.

Before these could be developed, basic research was needed to: identify hazards associated with vehicle use; review International Standards; and develop an assessment methodology for studying the vehicles in South African mines.

# Acknowledgements

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# 1 Introduction

The risks to both health and safety from driving and working close to trackless vehicles underground have been known for some time. For example, a detailed description was provided of the introduction of trackless vehicles to a UK mine (Illsley and White, 1987). This included details of changes which were done to the roadways and junctions. The problems of driver error were detailed. Damage to cabs, mudguards, engine covers, conditioner boxes and tyres also occurred. However, these problems reduced as drivers became more experienced, but changes were still required to the designs of vehicles to improve aspects of health and safety.

It is important that these risks are put into perspective. Numerous benefits of using trackless vehicles were detailed. One was safety. Compared to rope haulage, trackless vehicles eliminated the need to transfer loads from one system to another and to negotiate points. Less men were also at risk when they were used to deliver supplies and loads compared to other haulage and transport systems. Nevertheless, trackless vehicles introduced new risks to both drivers and pedestrians.

An early assessment of these risks was conducted by the Bureau of Mines in the United States (Ankenbruck et al, 1975) in relation to underground coal mine haulage systems. The research identified the following significant types of accidents for underground trackless vehicles.

***Table 1.1***
***Extracts of significant types of accidents by Bureau of Mines***

| Accident Type | No of Serious Accidents (>40 man-days) | Total No of Accidents | Total Lost-Time (Man-days) |
|---|---|---|---|
| Personnel stuck or squeezed when caught by trailing cable | 2 | 7 | 6187 |
| Personnel stuck or run over by vehicle | 6 | 6 | 2884 |
| Collision or contact between vehicle and fixed obstacles or equipment | 4 | 17 | 429 |
| Falling material struck miner | 3 | 3 | 233 |
| Riding personnel struck parts of body on top or side obstruction | 1 | 11 | 227 |
| Riding personnel caught between moving parts of vehicle | 2 | 2 | 186 |
| Personnel injured by shock, burn, or explosion of trailing cable | 1 | 7 | 126 |
| Riding personnel injured because of rough ride or sudden stops and starts | 2 | 8 | 116 |

All accidents were subsequently correlated for potential contributing factors in terms of environmental irregularities, planning, equipment or design faults, and unsafe acts or human faults. In Table 1.2, information has been extracted specifically for trackless vehicles (ie tracked and belt systems have been excluded). The potential contributing factors were shown alongside the number of accidents.

***Table 1.2***
***Summary of contributing factors to trackless vehicle accidents***

| Major Deficiency | Contributing Factor | No of Accidents |
|---|---|---|
| **Environmental Irregularities**: Physical conditions in the mine that may affect safety directly or indirectly | Uneven sidling (sic) wet floor | 49 |
| | Insufficient illumination | 42 |
| | Restricted overhead clearance | 28 |
| | Noise resulting in poor communications | 6 |
| **Planning**: Problem areas that are related to overall mine systems | Defective equipment (maintenance) - brakes, lights, bell, steering, tramming control | 49 |
| | View obstructed by brattice | 34 |
| **Equipment or Design Faults**: Problems related to the design or choice of specific haulage equipment | Poor design or location of controls | 42 |
| | Poor driver visibility | 42 |
| | Insufficient lighting on vehicles | 42 |
| | Inadequate or no panic bars | 28 |
| | Lack of, or poor design of, canopies | 14 |
| **Unsafe Acts or Human Faults**: Errors in judgement, negligence, or breaches of common sense committed by individual miners | Inexperienced or unfamiliar operator | 56 |
| | Excessive speed for circumstances | 42 |
| | Not facing direction of travel | 42 |
| | Headlights not on while tramming | 42 |
| | Not checking equipment pre-shift | 42 |
| | Not observing caution passing through brattice | 42 |
| | Loading coal too high - visibility | 34 |
| | Items protruding from equipment | 23 |
| | Riding in unsafe position, standing | 21 |
| | Poor cable control | 14 |
| | Not shutting down, setting brakes, blocking a parked vehicle | 8 |

| Major Deficiency | Contributing Factor | No of Accidents |
|---|---|---|
| | Not sounding bell at start, before curtains or before turning | 6 |

It is clear, from the above, that aspects of the ergonomics of trackless vehicles contributed to many of the accidents in the study. For example, poor visibility and poor locations of controls were each associated with the causes of 42 accidents in the reporting period. Despite this early recognition, ergonomic features of these vehicles still often fall short of the best standards currently achievable. The result is that the risks to health and safety are greater than necessary.

Some sickness costs in the South Africa mining industry were discussed by Beugger (1993). This noted the high absence, with subsequent frequent replacement of drivers, and indeed pedestrians new to a district. Stress manifesting itself in alcohol abuse was also said to be relevant to risk assessments concerning the use of trackless vehicles.

A report by the UK Health and Safety Executive (HSE, 1992) provided a more detailed summary of accidents involving trackless vehicles and other hazards such as diesel emissions. A comparison is given between accidents involving trackless vehicles and alternative methods of haulage.

In the five year period between April 1986 and March 1991 there were 11 fatal accidents and 282 major injury accidents involving rope haulage, five fatal and 74 major injury accidents involving locomotives and four fatal and 38 major injury accidents primarily attributed to the use of trackless vehicles. Other results show there were five fatal and 58 major injury accidents with some involvement of trackless vehicles.

The breakdown of these trackless vehicle accidents by categories are given in Table 1.3 and Table 1.4.

***Table 1.3***

***Trackless vehicle accidents by category (UK - 1986 to 1991)***

| Category | Fatal | Major Injury | Over 3 Days |
|---|---|---|---|
| Accidents due to the movement of the vehicles | 4 | 27 | 58 |
| Accidents during load transfer | 1 | 15 | 84 |
| Accidents during maintenance | 0 | 14 | 49 |
| Others | 0 | 2 | 38 |
| **TOTALS** | **5** | **58** | **229** |

*Table 1.4*

***Accidents from movement of vehicles (UK - 1986 to 1991)***

| | | **Fatal** | **Major Injury** | **Over 3 Days** |
|---|---|---|---|---|
| ACCIDENTS TO PEDESTRIANS | Run over | 2 | 5 | 4 |
| | Struck by vehicle | 0 | 6 | 7 |
| | Trapped by vehicle | 0 | 5 | 7 |
| COLLISION ACCIDENTS | With roadway supports | 0 | 2 | 12 |
| | With roadway fittings | 0 | 2 | 6 |
| | Driver trapped | 1 | 2 | 3 |
| OTHER ACCIDENTS | Struck by tramp material | 0 | 2 | 5 |
| | Secondary use of vehicle | 0 | 3 | 4 |
| | Other | 1 | 0 | 10 |
| **TOTALS** | | **4** | **27** | **58** |

The UK accident results showed that fifty per cent of all trackless vehicle fatal and major injury accidents involved moving vehicles. Injuries were to drivers and pedestrians alike. Of particular concern was that drivers were often unaware that pedestrians had been killed or injured. Limitations in driver visibility were noted. It was also noted that the transient nature of the work of craftsmen and mine officials made them particularly vulnerable.

Six accidents occurred as a result of persons being struck by shuttle car power cables. A driver was also killed when he became trapped between a roof joist and the cab canopy. No injuries resulted from collision between these vehicles.

Studies in the United States, by the Mine Safety and Health Administration, confirmed the importance of ergonomics. Their findings showed that 36 per cent of the fatalities involving underground coal mobile equipment were related to improperly designed operator compartments (Unger and Rider, 1987).

It is also apparent that many poor ergonomic features may be indirectly associated with other accidents. For example, 56 accidents were identified as being caused by inexperienced or unfamiliar operators. Such problems are more likely to occur if there are poor features such as no standardisation of controls between different vehicle manufacturers, or indeed between different models of vehicles by the same manufacturer. This is supported by studies on a number of trackless vehicles in the UK which showed poor standardisation of factors such as: whether bucket controls on LHDs are positioned for left or right handed operation; or whether brakes should be operated by the right or left foot (Kingsley et al, 1980). Such major differences increase the difficulties drivers experience when they transfer from one vehicle type to another, or if the vehicle they regularly drive differs from that on which they received their training.

An Australian survey looked at accident statistics in relation the use of large surface mining vehicles (Harris and Rendalls, 1993). It stated that 25 per cent involved machinery and of these, 32 per cent were a consequence of seating, the remainder occurring during the access/exit procedure. Back injury and pain were said to be common problems caused by poor seating. Dismounting from these large surface machines was said to involve the greatest risk. Such problems may also be present with some underground vehicles.

Four recent accidents involving trackless vehicle in South African mines were investigated.

Accident one was a fatality to a fitter who was crushed between a shuttle car and the sidewall. The fitter was walking around the vehicle to check that the service jacks had lifted properly. The unpowered vehicle was said to have moved under no power trapping the fitter. It was noted that there were six different standards on the mine for shuttle car cabin layout. The vehicle involved had been modified so that the driver sat sideways in the same position for either direction of travel. The Government Mining Engineer considered that better ergonomic design and standards were essential elements that could help eliminate that type of accident.

Accident two was a fatality involving a cable handler who had received little training. He was apparently run over by a shuttle car, while he was in a sitting position during normal mining operations. Sightlines were a factor in this accident as the driver could not see the deceased. Training the workforce on the risks involved in working close to these vehicles also appeared to be a factor in this accident.

Accident three involved a shuttle car. The deceased was trapped between the vehicle and sidewall. Events leading to this accident were unclear.

Accident four also had little information on the events leading to a fatality as the deceased was found some time after the accident. The deceased was said to have been trapped between the two sections of a LHD at the pivot. Two possibilities were considered. Firstly, the operator may have accidentally operated the controls while mounting or dismounting from the machine. Alternatively, the operator stood on the ground next to the machine and tried to reach to the controls from there to carry out some manoeuvre. Either way, aspects of the design of the vehicle (ie sightlines, control layout, workspace, or control design) appear to have been a factor in this accident.

These accidents involving trackless vehicles in South African mines further support the need for ergonomic standards to be improved in relation to sightlines, control layout and design, vehicle workspace and also aspects of safety training of the workforce. The importance of making vehicles easy to use was also noted in order to reduce mis-operation of these vehicles and to reduce physical and mental fatigue (Okomoto, 1993).

Although other factors such as safety culture, the attitudes of drivers, limitations of the safety management systems and aspects of the mine layout must be taken into consideration (eg Davies, 1995), there are significant benefits to be derived from a detailed application of ergonomics to the design of trackless vehicles used in the coal mines of South Africa.

The objectives of this project were therefore to build on the knowledge gained from previous European and American research to develop a package of deliverables which would enable mines in South Africa to improve the standard of the ergonomics of their existing and new trackless vehicles. The contractual requirements of the project are summarised in Appendix One.

This project was managed by HSEC Ltd in the UK with the assistance of Turgis Technology (PTY) Ltd of South Africa and the AIMS Research Unit of Nottingham University. It began in January 1997 and was completed in June 1998.

# 2 Literature Review

A literature review was undertaken on the ergonomics research undertaken on trackless vehicles in operation in coal mines. The detailed review is given in Appendix Two.

Much of the early research was funded by the European Coal and Steel Community's Ergonomic Action Programme. Most of this research was undertaken by the Institute of Occupational Medicine (IOM) which was associated with the UK National Coal Board (later changed to British Coal). This research focussed on: improved methodologies for assessing the ergonomics of mining equipment in general; developing a designers' handbook specifically for free-steered vehicles (equivalent to trackless vehicles); and in developing an ergonomic index for quantifying the standards of ergonomics for a range of mining machines, including trackless vehicles. Ergonomists at the IOM were also working directly for the Industry by assessing individual vehicles.

Later research in the UK (at British Coal and by the Health and Safety Executive) and in the United States focussed on the considerable problems associated with driver vision from trackless vehicles. Initially this concentrated on the development of methodologies to measure driver sightlines. Later the question of criteria was addressed to enable these measurements to be judged against what drivers actually needed to see.

The behaviour of vehicle drivers and mineworkers close to trackless vehicles was investigated at British Coal in terms of factors which increased all forms of human error and also their hazard awareness and risk perceptions. Hazard awareness also began to be addressed using virtual reality techniques by researchers of the AIMS Unit of Nottingham University.

Research finally began to address the ergonomics associated with the health and safety of maintenance staff working with trackless vehicles, and also methods to determine how the ergonomics standards of existing vehicles could be improved by retrofits.

Several research studies were undertaken, primarily in the United States, into the causation of accidents associated with trackless vehicle operations.

The implications of driving posture and vehicle vibration were also being addressed.

# 3 Methodology

## 3.1 Utilising previous research findings

Previous studies on the ergonomics of trackless vehicles have been funded by the European Coal and Steel Community (ECSC) and British Coal. Deliverables from these projects are within the public domain. Those relevant to this project include:

- an evaluation methodology for underground vehicles originally based around a ten point ergonomic feature checklist but later developed into an index reflecting both the importance and quality of a number of ergonomic features (Mason, 1992 a)

- sightline assessment procedures and sightline criteria for underground machinery (eg Mason et al, 1985) and later for trackless vehicles (unpublished)

- a handbook of ergonomic features of trackless vehicles (also referred to as free-steered vehicles in the UK) (Mason et al, 1990 a)

- a methodology for determining cost-effective retrofit modifications to trackless vehicles to improve health and safety (Rushworth et al, 1993 and 1995)

The current project aimed to start with the above deliverables and adjust them to South African conditions as well as further developing aspects such as better incorporating ergonomics into the risk assessment procedures associated with the use of these vehicles.

## 3.2 Project Aims

The project aimed to provide information & methodologies to improve both new and existing trackless vehicles.

Lasting improvements in health and safety are best achieved through the introduction of trackless vehicles with a good standard of ergonomics. To achieve this, ergonomic criteria need to be determined suitable for the designers of trackless vehicles for the South African mining industry.

Both equipment designers and the mines have key roles in achieving such improvements. Designers obviously need suitable ergonomic criteria on which to base their new designs (see Simpson and Mason, 1983). Mines may also need to better specify their ergonomic requirements in the specifications for new vehicles.

Mines may specify carrying capacity, power source, size and cost when selecting new vehicles. Unless mines also specify their minimum ergonomic requirements, the possibility exists of vehicles with poor ergonomics entering the South African mining industry. Information and procedures therefore need to be provided to assist mines when they specify new vehicles.

It is unrealistic, however, to expect a rapid improvement in the ergonomics of the industry's trackless vehicles through the introduction of new ergonomically designed vehicles. The industry will be using older vehicles for some time. It is therefore necessary to address improving the ergonomics of these older vehicles. Procedures therefore also need to be provided to improve the ergonomics standards of current vehicles by the adoption of cost-effective retrofit modifications.

The deliverables produced by this project therefore form a comprehensive package which will help improve the health and safety associated with the use of trackless vehicles in South African mines.

## 3.3 Information and procedures for mines and designers

In order to achieve the above overall goals a number of deliverables needed developing for use by engineers at mines, those involved in the selection of new vehicles, and also those involved in the design process. These key deliverables are:

### 3.3.1 An ergonomic handbook with data sheets on key aspects of trackless vehicle design

This is intended for use by designers and mine engineers to both assist in the design of new vehicles and improve existing vehicles. Information in the handbook is also of value during risk assessments. Data sheets on 12 ergonomic features are provided in a standard layout addressing: the importance and consequences of not achieving minimum standards in each area; critical issues needing consideration; and ergonomic guidelines on each critical issue. The handbook is presented as a separate report in Annex 1.

### 3.3.2 An ergonomic index for trackless vehicles

This assesses 12 ergonomics factors of trackless vehicles: eg sightlines, workspace, lighting, seating, control design and control location. Scores are obtained on the quality of each factor for a specific vehicle. These are then modified to take account of the relative importance of each factor in terms of the likely health and safety consequences. The end result is an overall score of the quality of the vehicle ergonomics. The Index is described in full in Annex 2.

These numbers provide a useful profile of vehicle ergonomics which can be either used to help select vehicles with good features or be used to determine and monitor minimum standard of ergonomics for these vehicles. The Index can also be used to predict improvements in the scores from hypothetical vehicle improvements. It has been specifically designed to be easily and reliably used by the non-ergonomics specialist.

### 3.3.3 A comprehensive risk assessment procedure

A risk assessment procedure was developed specifically for underground trackless vehicles. It utilises the outcome of an exhaustive search of the literature for hazards associated with trackless vehicles. These are then used to assess the likelihood and severity of foreseeable events. The results identify the significant ergonomic features which contribute to the overall risks, in addition to identifying the highest risks themselves. The procedure is fully described in Annex 3.

### 3.3.4 A specific sightline risk assessment procedure

This is used when the Ergonomic Index or General Risk Assessment identify major problems with vehicle sightlines. The sightline risk assessment recognises that a sightline safety problem can be addressed by improving vision from the vehicle and/or removing the hazard at source by altering either features of the mine or the operating procedures. For example, poor driver vision to see pedestrians close to the vehicle can be addressed by improving driver vision and/or removing people from that roadway.

"Sightline" and "Mine Feature" checklists are used along with a simple scoring system. The methodology can be used interactively to predict improvements from changing aspects of the vehicle and/or the mine features. The most cost-effective safety solutions can therefore be determined. Full details are provided in Annex 4.

### 3.3.5 A methodology for retrofit modifications to existing vehicles

Improving the quality of the ergonomics of existing vehicles requires significant risks to be highlighted and the most cost-effective retrofits modifications to be determined. Beginning with the output of the Ergonomic Index, the General Risk Assessment, or the Sightline Risk Assessment, a retrofit improvement procedure was developed. The procedure addresses the interaction of sightlines and mine features on driver vision and enables selected modifications to be assessed for their predicted improvement in overall standards. By comparing several alternatives, this mechanism enables estimates of the most cost-effective retrofits to be determined. Suggested retrofit are summarised in Annex 5 for each of the 12 ergonomic factors.

### 3.3.6 A safety training demonstrator

There will always be some risk to people working close to trackless vehicles and training is an important means of controlling this risk. A demonstrator was developed showing the benefits of using virtual reality techniques for training people who work with, or close to, trackless vehicles.

This is an interactive training aid which can be used by pedestrians to show the restrictions on drivers' vision and actions which can be taken to reduce the risk. Although it reflects only one of the mine areas examined by the project, the training demonstrator can quickly be changed to fully reflect other mine layouts, other vehicles, and other methods of vehicle operation. Further information is provided in Appendix Three.

## 3.4 Basic research

Before the above deliverables could be developed some initial basic research was needed.

### 3.4.1 Review of International Standards and ergonomic research

A review was undertaken of International Standards on underground trackless vehicles and related surface vehicles. This is summarised in Appendix Four. A detailed literature review was also undertaken on ergonomics research projects conducted in the UK, Australia and in USA on safety of trackless vehicles (see Appendix Two).

### 3.4.2 Hazard taxonomy for trackless vehicle operation

The literature review and experience from studies on trackless vehicles in British Coal mines were used to comply a list of hazards associated with the use of trackless vehicles. Full details of these hazards are provided in Appendix Five.

A basic level presents a number of risk situations arising from each hazard. A more detailed level presents further information on the underlying potential causes of many of these hazardous events. Several of the deliverables of the project address these specific risks. The list was also used to develop part of the underground study methodology.

### 3.4.3 Develop an assessment methodology

A methodology needed to be developed to study the ergonomics of trackless vehicles in South African mines. Since the project started from an advanced position, as a result of previous UK projects, the methodology was developed primarily to address selected areas where the ergonomics of vehicles in South Africa could be expected to differ from those in other countries.

Particular attention was paid to: the anthropometrics of the workforce; the control and workstation design and layout; labelling; and sightline requirements of the drivers. Features of the mine layout and methods of working which could interact with the vehicle ergonomics were also addressed. A questionnaire was developed for drivers to determine the incidence of musculoskeletal discomfort and problems experienced by limited vision from vehicles.

Full details of the final methodology used to collect the data for the project are given in Appendix Six. Details were obtained on:

- initial information of vehicle type, mine, district, operation
- the actual tasks for which the vehicle is used
- the physical measurements of vehicle features
- specific detailed measurements of vehicle sightlines
- any drivers' problems and discomfort using a questionnaire and interview
- any roadway features which could increase the safety risk

The prototype methodology was applied to two vehicles at 'Mine A'. These studies were undertaken jointly by HSEC Ltd of the UK and Turgis Technology of South Africa. Several aspects of the methodology were refined before other vehicles were evaluated by Turgis Technology at 'Mines B and C'. Finally, two more vehicles were jointly evaluated by HSEC and Turgis Technology at 'Mine D'.

### 3.4.4 Develop virtual reality techniques to improve sightlines on current vehicles

Virtual reality techniques were developed by the AIMS Unit of Nottingham University to assess ways to improve driver vision on shuttle cars. The work assessed the risks to pedestrians in locations at junctions and determined how these risks could be reduced by alternative driver locations and simple changes to the vehicles. Software was developed to calculate the volume of space which drivers can see as a vehicle travels through a simulated mine (see Appendix Seven).

# 4 Findings

It was agreed with the Mines that findings from the individual studies would remain confidential to the Mines who cooperated with the project. Nevertheless an overall description of underlying problems with the ergonomics of trackless vehicles can be given.

Seven vehicles were evaluated by the project. Four shuttle cars (different versions of the Joy 10SC22 vehicles) and three LHDs (an example of the Eimco 913, the Tamrock Voest Alpine Toro, and the Wagner ST 3.5S) have been studied in detail at the four mines.

## 4.1 Results from the Ergonomic Index

An overview of the ergonomic standards of trackless vehicles in use in South Africa can be seen by a comparison of summary findings from the 4 shuttle cars. This provides an indication of the size of the design improvement which could be achieved by the adoption of the recommendations of the project.

Table 4.1 shows part of the scores from the ergonomic index. These are the scores for the quality of each of twelve ergonomic features. The best score is +5 and the worst score is -5. Essentially, any negative score should be considered with some urgency for improvement. Low positive scores should also be considered. Where the scores are different for each of the two driving positions, the worst case score is shown.

***Table 4.1***
***Quality scores for shuttle cars***

| [redacted] | | | | |
|---|---|---|---|---|
| Driver sightlines | N/A* | -1.3 | -1.3 | -2.5 |
| Workspace | -5 | -3.3 | 0 | 0 |
| Driver protection | -2.9 | +0.7 | 0 | -2.1 |
| Access & egress to cab | +2 | +4.1 | +2.5 | +2.5 |
| Control & display location | -0.5 | -0.8 | 1.2 | -0.5 |
| Control design | +3.6 | +3.8 | +4.1 | +4.1 |
| Display (gauge) design | -1 | -1.7 | -1.7 | -1.7 |
| Labels and instructions | 0 | -0.9 | -3.8 | -3.8 |
| Seating | -4 | -5 | +2.9 | -4.2 |
| Lighting | +0.6 | +0.6 | +0.7 | 0 |
| Environment (noise & heat) | +3.3 | +5 | +5 | +5 |
| Warning systems (horns etc) | +4.2 | +1.7 | -2 | +1 |

* The sightline assessment methodology used on this pilot study was modified for the main studies. As a result an equivalent score was not available for this vehicle.

Each of the twelve ergonomic features has different levels of importance in terms of the resulting health and safety consequences that poor features would cause. For example, poor driver sightlines will have a greater overall impact than poor quality of labelling. 'Importance scores' have therefore been set by a panel of experts to reflect the potential contribution of each to the health and safety of trackless vehicles. These range from 5 to 25.

The product of the 'quality' of each ergonomic feature for a given vehicle and the relative 'importance' score for that feature results in the Ergonomic Index score. These are given in Table 4.2. The greater the magnitude of negative scores the worse the ergonomic feature.

Where the scores for the reverse seating positions are different from those for the forward seating position, the worst case scores are shown.

***Table 4.2***
***Ergonomics index scores for shuttle cars***
(Importance x Quality Scores)

| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
|---|---|---|---|---|
| Driver sightlines | N/A* | - 31 | - 31 | - 63 |
| Workspace | - 50 | - 50 | 0 | 0 |
| Driver protection | - 52 | +13 | 0 | +39 |
| Access & egress to cab | +30 | +61 | +38 | +38 |
| Control & display location | - 6 | - 11 | +17 | - 8 |
| Control design | +44 | +45 | +49 | +49 |
| Display (gauge) design | - 10 | - 17 | - 17 | - 17 |
| Labels and instructions | 0 | - 4 | - 19 | - 19 |
| Seating | - 40 | - 50 | +29 | - 42 |
| Lighting | +7 | +8 | +9 | 0 |
| Environment (noise & heat) | +23 | +35 | +35 | +35 |
| Warning systems (horns etc) | +42 | +20 | - 24 | - 12 |

* The sightline assessment methodology used on this pilot study was modified for the main studies. As a result an equivalent score was not available for this vehicle.

The equivalent results are shown in Tables 4.3 and 4.4 for the three LHD vehciles. These vehicles are not shown in the order described above. Table 4.3 shows part of the scores from the ergonomic index.

***Table 4.3***
***Quality Scores for LHDs***

| [redacted] | [redacted] | [redacted] | [redacted] |
|---|---|---|---|
| Driver sightlines | - 1.3 | - 0.6 | N/A |
| Workspace | 0 | 0 | - 2.5 |
| Driver protection | - 1.3 | +0.6 | - 2.5 |

| | | | |
|---|---|---|---|
| Access & egress to cab | +1.5 | +2.5 | +1.8 |
| Control & display location | +0.8 | +3.1 | +2.6 |
| Control design | +1.2 | +4.4 | +2.6 |
| Display (gauge) design | +1.3 | +0.3 | - 3.6 |
| Labels and instructions | +1.5 | - 5.0 | - 4.2 |
| Seating | +2.5 | +3.1 | 0 |
| Lighting | - 2.9 | - 1.5 | - 1.1 |
| Environment (noise & heat) | +1.3 | +5.0 | +1.7 |
| Warning systems (horns etc) | +3.3 | +5.0 | +3.8 |

The product of the 'quality' and the 'importance' score are given in Table 4.4.

***Table 4.4***
***Ergonomics Index Scores for LHD's***
(Importance x Quality Scores)

| | | | |
|---|---|---|---|
| Driver sightlines | - 31 | - 16 | N/A |
| Workspace | 0 | 0 | - 25 |
| Driver protection | - 23 | +11 | - 45 |
| Access & egress to cab | +23 | +38 | +27 |
| Control & display location | +11 | +47 | +32 |
| Control design | +15 | +53 | +31 |
| Display (gauge) design | +13 | +3 | - 36 |
| Labels and instructions | +8 | - 25 | - 13 |
| Seating | +25 | +31 | 0 |
| Lighting | - 34 | - 17 | - 13 |
| Environment (noise & heat) | +9 | +35 | +12 |
| Warning systems (horns etc) | +40 | +60 | +38 |

## 4.2 Summary of results for sight line risk assessment

The following results are derived from the detailed sightline risk assessment developed for the project and described in Annex 4. The larger the score the higher the risks associated with each indicated hazard.

### 4.2.1 Shuttle Car Sightlines

Scores for sightlines from reverse cab shown in brackets.

***Table 4.5***
***Quality Scores for shuttle cars***

| Hazard | Shuttle Car 1 | Shuttle Car 2 | Shuttle Car 3 | Shuttle Car 4 |
|---|---|---|---|---|
| Unexpected vehicle movement injuring people nearby | 238 (238) | 374 (396) | N/A | 182 (234) |
| Vehicle striking and injuring people when travelling in a straight roadway | 168 (224) | 264 (264) | N/A | 130 (182) |
| Vehicle striking and injuring people when negotiating corners | 238 (238) | 374 (242) | N/A | 156 (208) |
| Tyres damaged on objects or objects thrown up by tyres - possibly striking people nearby | 252 (252) | 396 (396) | N/A | 130 (234) |
| Driver struck by objects projecting into cab | 140 (140) | 132 (44) | N/A | 26 (26) |
| Driver struck or crushed against roadway sides when leaning out to see better | 188 (204) | 257 (191) | N/A | 121 (147) |
| Driver struck or crushed against roof | 168 (224) | 176 (88) | N/A | 78 (78) |
| People struck by vehicle reversing or slewing | 21 (21) | 9 (9) | N/A | 306 (306) |

### 4.2.2 LHD sightlines

***Table 4.6***
***Quality Scores for LHD's***

| Hazard | LHD 1 | LHD 2 | LHD 3 |
|---|---|---|---|
| Unexpected vehicle movement injuring people nearby | 352 | 221 | 247 |
| Vehicle striking and injuring people when travelling in a straight roadway | 352 | 182 | 232 |
| Vehicle striking and injuring people when negotiating corners | 286 | 182 | 203 |
| Tyres damaged on objects or objects thrown up by tyres - possibly striking people nearby | 396 | 234 | 261 |
| Driver struck by objects projecting into cab | 44 | 26 | 29 |

| | | | |
|---|---|---|---|
| Driver struck or crushed against roadway sides when leaning out to see better | 227 | 135 | 160 |
| Driver struck or crushed against roof | 176 | 78 | 116 |
| Driver vision obscured by load being carried - subsequent injuries to people nearby | 143 | 30 | 132 |
| Load being loaded/unloaded tips on uneven floor - injuring people nearby | 143 | 14 | 87 |
| Driver vision obscured by load being carried - vehicle collides with objects causing subsequent injuries to people nearby | 127 | 35 | 154 |
| Load being carried topples from vehicle injuring people nearby | 108 | 13 | 59 |
| People struck by vehicle reversing or slewing | 7 | 272 | N/A |

## 4.3 Use of virtual reality techniques

Virtual reality techniques were used to predict the improvements in driver vision on shuttle cars from retrofit modifications to increase the height of the eye point and/or moving the cab outwards from the vehicles. The results are summarised in Appendix Seven.

The best vision when manoeuvring around a bend is found when the vehicles are being driven forwards with the cab located on the inside of the bend. Even in this situation, only about 45% of those areas around the vehicle can be seen at the position of the best vision as the vehicle turns the bend. The worst vision is found with the cabs at the rear (ie when reversing) when typically the best vision is only around 2%.

These vision measures were found to increase by up to 30% when the eye point was raised by 30 cm and when the cabs were moved outwards by 50 cm. However, for most combinations of cab location and type of corner the improvements were much less.

# 5 Discussion

The project has produced a package of deliverables designed for different groups of people and to address different problems associated with the safety of trackless vehicles. The package has been aimed at designers of new vehicles and mine operators who may wish to improve their ergonomic specifications for buying vehicles, conduct risk assessments and improve the ergonomics of their current fleet.

The two risk assessment procedures which are provided are not prescriptive in nature and so do not impose values derived from other countries which may have limited relevance to the South African climate. They do, however, ensure the risk assessors benefit from the comprehensive list of hazards which were identified from an international review. The relevance of each will be for the assessor to decide.

## 5.1 Vehicles and mine systems

It is recognised that certain problems for drivers, passengers and pedestrians can be addressed by either making improvements in the vehicle ergonomics or by changing aspects of the roadway features or methods of vehicle operation. For example, a problem of high risk of pedestrians being run over can be addressed by improving sightlines; by improving the illumination on the vehicles; by enforcing the wearing of high visibility clothing; by improving roadway illumination at junctions and other areas of high risk; or by removing pedestrians from the vehicle routes. By the same token, problems with drivers' backs could be addressed by better seating or by ensuring the roadways have a smooth surface and that violent shocks are avoided as vehicles drive over pot holes or other large surface irregularities.

It is therefore apparent that the design of the vehicles should not solely be targeted. The health and safety factors associated with even the best vehicle can be compromised if it is used in a mine which places extreme demands of the vehicle. Consequently, although much of the deliverables are aimed at improving the ergonomics of new and existing trackless vehicles, attention is also given to indicating where other improvements can be achieved through non-vehicle routes.

## 5.2 Using the deliverables

The suggested use of the package depends to a large extent on what is wanted to be achieved. For example, the comprehensive risk assessment and ergonomics index can be used interchangeably in many circumstances; however, each has benefits and disadvantages. It is therefore recommended that the following steps are adopted for: (i) current users who wish to assess the safety of their vehicles and/or improve safety by retrofit improvements (ii) those buying new vehicles or producing specifications for new vehicles; and (iii) designers of new vehicles.

These are summarised below for each 'class' of user. It is recommended that readers only look at the section most relevant to their needs.

### 5.2.1 Recommended path for current users of trackless vehicles

Two risk assessment procedures have been developed to enable trackless vehicle users to evaluate the health and safety risks and, where significant risks are found, to undertake a range of retrofit modifications to the vehicles to reduce these risks.

The general risk assessment methodology is first used (see Annex 3). A basic list of hazards is initially presented for drivers, passengers and pedestrians and for the vehicle operations of (i) setting off, normal driving, stopping and parking, (ii) entering and leaving the driver and passenger compartments, and (iii) loading and unloading materials.

Where this general risk assessment identifies driver sightlines as a major problem, there are advantages in undertaking the more detailed sightline risk assessment, described in Annex 4.

It is recognised that certain problems for drivers, passengers and pedestrians can be addressed by either making improvements in the vehicle ergonomics or by changing aspects of the roadway features or methods of vehicle operation. For example, a problem of high risk of pedestrians being run over can be addressed by improving sightlines and illumination on the vehicles, or by removing pedestrians from the vehicle routes.

The sightline risk assessment therefore combines a more detailed assessment of the vehicle sightlines with a simple assessment of the mine features which can interact to create health and safety problems for vehicle users. The scoring method combines both vehicle and mine features to give an overall indication of risk. Benefits from improving vehicle features and/or mine features can then be synthesised to develop an overall cost-effective strategy for reducing risks. Where the results show improvement to vehicles to be an effective route to reducing the risks associated with vehicle sightlines, guidance is provided in the handbook provided in Annex 1 and also further suggestions for retrofit modifications provided in Annex 5.

Finally, it is recommended that the user repeats the original risk assessments and reappraises changes in both likelihood and severity of the listed hazards to compare the original and modified risk scores. Alternatively, the user could apply the ergonomics index in before and after conditions to assess the benefits which vehicle changes have made.

The virtual reality simulations demonstrated that the gains in sightlines from raising the eye height and extending the cab outwards are disappointing. While it is recommended that they be adopted where feasible they will not, by themselves, satisfactorily remove the risks to mineworkers in the vicinity of trackless vehicles. Alternative means are required to reduce the risks to personnel near these vehicles.

### 5.2.2 Recommend path of buyers of new trackless vehicles

It is recommended that 'buyers' of trackless vehicles use the deliverables to produce a detailed specification of their ergonomic requirements and then use a system to evaluate new vehicles to ensure their minimum requirements have been met.

Problems can arise where specifications are ill-defined. For example, a requirement may simply be that visibility for the drivers of the vehicle should be good. A manufacturer may consider driver vision to be good whereas drivers or safety experts may consider it inadequate. Specifications therefore need to be set at practical levels and need to be measurable.

It is recommended that buyers use the ergonomic index provided in Annex 2 to generate their minimum specifications. This can be done in a number of ways. Buyers can scan the individual requirements under each of the 12 ergonomic topics and list those they identify as essential to their needs. Alternatively, buyers can use the whole index as a specification and set the designers/manufacturers with the task of demonstrating the vehicle achieves a set minimum per cent pass score. A minimum score could be set for each of the 12 topics. Alternatively a minimum score could be set for the whole vehicle.

The ergonomic index therefore provides the buyer with a variety of ways of generating minimum ergonomic specifications to suit the Company requirements. As the ergonomic index uses the same 12 point structure as the data sheets in the handbook, the detailed design information to achieve each requirement is easily accessible.

### 5.2.3 Recommended path for designers of trackless vehicles

The information contained in the handbook (Annex 1) should ensure a very high standard of ergonomics in vehicle design. The full benefits will, however, be compromised where certain design parameters have already been imposed on designers (for example, decisions have been made on driver position, vehicle height/width). Designers can still access relevant data sheets, such as control layout, design, lighting, access systems etc., to produce vehicles with improved ergonomics.

Key ergonomic requirements are produced on 12 ergonomic data sheets. Each sheet begins with bulleted information on the importance of that ergonomic topic to the overall ergonomic design of the vehicle and provides examples of the likely consequences which can arise if basic ergonomic requirements are not provided. Each sheet will then briefly introduce key issues within the topic which must be considered.

The data sheets provide comprehensive ergonomic data in a form suitable for designers. Wherever possible, 'minimum' ergonomic requirements are presented. This avoids placing undue restrictions onto designers who already have the difficult task of creating machines which fulfill a range of engineering, performance, and cost requirements in addition to machines with good ergonomics.

There may be instances where a designer cannot satisfy all the ergonomics requirements in the data sheets. In such circumstances, the designer needs an indication of the quality of the ergonomics of the whole vehicle. This would enable a designer to test the overall effects of various ergonomics trade-offs to determine which give the overall best achievable standard of ergonomics.

Such a measure would also enable the designer to develop a 'bench mark' of the minimum ergonomics quality which will produced by that manufacturer. In this way, it would be possible during the design stage to identify that a prototype vehicle was unacceptable and that radical changes to its ergonomics was necessary before the vehicle was manufactured.

The ergonomic index (Annex 2) enables the designer to fulfill these requirements. An advantage of the index is that actual changes to the vehicles do not need to be made in order to identify the resulting improvements. The index can predict the overall effects of a number of ideas. The idea with the best overall effect can therefore be easily identified.

Where the engineering costs of achieving some of these ideas are known, the index can form the basis of a cost-effective analysis so that the financial resource can be best spent to achieve the overall biggest improvement in ergonomics quality.

## 5.3 Training

The training needs of trackless vehicle drivers were determined along with those for other mineworkers to make all mineworkers trackless vehicle orientated (Mapp, 1983). The analysis extended beyond driving skills to include the requirement to further educate drivers and officials into the need to pay scrupulous attention to the maintenance of the machines, both on a shift basis and as regards the regular routine servicing which the maintenance schedules demanded.

The language difficulties in South Africa place especial importance on the use of pictographs as a means of communicating complex information and instructions. A recent study by Wogalter and Sojourner (1997) also identified the importance of training focussing on the understanding of such difficult pictorial information. A significant increase in pictorial comprehension and post-training comprehension was found following this training.

Training is also an important part of improving the health and safety associated with trackless vehicles. The demonstrator using virtual reality enables mine workers to see how their own safety relies on their own vigilance and how, in many situations, they have a much better view of the vehicle than the driver would have of them. The demonstrator and its envisaged use in a training course is described in Appendix Three.

The demonstrator was shown to a number people with experience in mining in South Africa and the responses from a feedback questionnaire were positive.

If judged a useful complement to a mine's existing training programme, both the vehicle and the mine layout can be easily modelled to reflect actual vehicles and roadway layout at that mine.

# 6 Conclusions

The health and safety of operators, drivers and workers can be improved by better ergonomic standards of trackless vehicles in use in South African mines.

## 6.1 Project deliverables

The project aimed to produce a package of practical deliverables which can be used to assist designers of new vehicles achieve optimum ergonomics but more importantly can assist mines to both select vehicles with improved ergonomic features and help mines improve the ergonomics of their existing vehicles through cost-effective retrofit modifications. The methodologies are fully interactive and designed to be used by mine personnel with no experience of ergonomics. Some training may, however, be needed in their use.

The ergonomic handbook was produced for use by mine engineers and designers alike to be used when designing or specifying new trackless vehicles and when improving the designs of existing vehicles. It can also form a reference during risk assessments.

The ergonomic index was specifically developed for trackless vehicles. It enables a non-ergonomics specialist to undertake detailed and comprehensive assessments of vehicles. The results can be used to select vehicles with the best ergonomic features. The scores can also be used as bench marks of minimum standards of ergonomics. The index can be used to quantify the benefits from a variety of potential modifications. Where the costs of these modifications are known, the index forms the basis of a procedure to rank the cost-effectiveness of a range of alternative design modifications.

The general trackless vehicle risk assessment procedure uses a detailed list of hazards drawn from the literature. Checklists and additional reference sources are used to obtain measures of risk. These are then cross-referenced to obtain a ranking of the ergonomic features of the vehicle which most contribute to these risks and hence where retrofit improvements are likely to be most cost-effective. An additional document has been produced listing retrofit suggestions beyond those covered in the handbook.

The detailed sightline risk assessment provides a powerful, yet simple, procedure which again capitalises on a detailed list of hazards drawn from the literature and incorporates both vehicle design and aspects of the mine layout to determine risk. An important benefit of this approach is that mine engineers can determine whether the risks are best addressed though changes to the vehicles or changes in the mine layout or methods of using the vehicles.

Training also plays an important role in improving the health and safety of trackless vehicle operation. A demonstrator was produced using virtual reality techniques to help convey the risks associated with working near these vehicles and to enable mineworkers to 'see for themselves' how risks can be reduced. The demonstrator is suitable for use on most personal computers and can be easily modified to reflect specific mine layouts and actual vehicles used in a mine.

## 6.2 Using the package of deliverables

Mines can use information contained in this package to quantify and improve the ergonomics specifications of new vehicles. Mines can also use the information to improve the standard of ergonomics on existing vehicles.

The package primarily focusses on design aspects of trackless vehicles, however, they take into consideration aspects of the mine which interact and create added risk. The package also addresses the importance of training for those mineworkers who have to work with, or close to, trackless vehicles.

The package is purely advisory, however the individual deliverables can be used to determine a minimum standards of ergonomics quality for the industry (either by individual mines, Mine Houses, or by vehicle manufacturers).

The package is designed to be used alongside conventional risk assessments although two comprehensive risk assessment methodologies are presented specifically for trackless vehicles.

## 6.3 Recommended further research

The project has identified a number of areas which would benefit from further research. These are presented below in a style similar to previous SIMRAC project outlines. Six proposals are offered for consideration for further research.

### 6.3.1 Proposal 1

**Title of research topic**

The influence of ergonomic design of opencast mining machines on the health and safety of the operators, drivers and workers

**Primary output/s of research**

Equivalent to COL 416 but directed to opencast machines

**Potential impact of research**

Reduction in health and safety risks in opencast mining operations

**Scope of research: Focus areas**

All aspects of ergonomic including: sightlines, noise, vibration, seating, training, hazard awareness and risk perception

**Potential for application**

General applicability to users and designers of opencast mining machinery.

### 6.3.2 Proposal 2

**Title of research topic**

Improving the health and safety of trackless vehicle maintenance

**Primary output/s of research**

Guidelines and risk assessment methodology

**Potential impact of research**

Reduced health and safety risks for vehicle maintenance staff

**Scope of research: Focus areas**

Maintenance workers have additional health and safety risks to other mineworkers. Accidents statistics frequency show that a high proportion of injuries occur during maintenance. Some European research has been undertaken into ways of reducing the risks to trackless vehicle maintenance staff and for reducing the general risks for mining maintenance staff.

This work could be used to developed guidance and procedures to suit the specific problems of the South African coal mining industry.

**Potential for application**

The deliverables would have value to training, planning of maintenance, selection of maintenance facilities and influencing vehicle designs to become 'maintenance friendly'.

### 6.3.3 Proposal 3

**Title of research topic**

Field trials of a virtual reality training package for trackless vehicle drivers and mineworkers.

**Primary output/s of research**

Recommendations on improving training methods to highlight the risks associated with use of these vehicles in mines.

**Potential impact of research**

Reduction in accidents to personnel from trackless vehicles

**Scope of research: Focus areas**

Development of the initial demonstrator to add secondary tasks for the mineworker to compete for vigilance when in the proximity of trackless vehicles.

Develop the demonstrator to increase the hazard awareness and risk perceptions of trackless vehicle drivers.

Trail the modified demonstrator at a number of mines.

Utilise feedback to develop a full training package with all training material necessary for use at any mine.

**Potential for application**

Once developed at a sample of mines, the virtual reality training package would be suitable for use at training centres of all mines having access to personal computers.

### 6.3.4 Proposal 4

**Title of research topic**

Technological routes to reducing the sightline risks to trackless vehicles.

**Primary output/s of research**

Review of technological options which reduce the risk to people working with trackless vehicles. A demonstrator project is not appropriate until after options have been identified which are practical in the mine environment.

**Potential impact of research**

Modifications available to improve driver sightlines are unlikely to eliminate the risks to people working near these vehicles. Applications of new technology are likely to result in improved safety if they can be made to be suitable to mine conditions.

**Scope of research: Focus areas**

Assessment of the benefits of close circuit televison to improve vision.

Assessment of the practicality of using radio sensors carried by mineworkers to automatically stop trackless vehicles if they come into close proximity to the vehicles.

Review of other engineering developments.

**Potential for application**

If shown to be feasible, the technology could be developed for new vehicles and retrofitting on existing vehicles.

### 6.3.5 Proposal 5

**Title of research topic**

Training mine staff in the use of the ergonomic index and vehicle risk assessment procedures

**Primary output/s of research**

Widespread training on use of assessment procedures

Feedback to modify procedure instructions were necessary

Collection of results to form a data base - see Proposal 6

**Potential impact of research**

Full benefits to health and safety from project COL 416 being achieved at all mines by reliable and accurate application of deliverables.

**Scope of research: Focus areas**

Usability of procedures and identification of any additional training material.

Publicising and managing the data base.

**Potential for application**

Engineers and safety personnel at all mines involved in risk assessment.

### 6.3.6 Proposal 6

**Title of research topic**

Drafting of ergonomic standards for underground trackless vehicles in South African mines.

**Primary output/s of research**

Procedures could be developed and introduced to collect and publish a central data base of results from the application of the ergonomic index and the sightline risk assessments.

A multi-industry work group could be formed to use this data base and work with the ergonomist to develop and agree a minimum ergonomic standard for trackless vehicles in South African mines.

**Potential impact of research**

The data base could be accessed by mine staff to help select trackless vehicles with improved standards of ergonomics.

Manufacturers may improve the ergonomics of their vehicles in the knowledge that this data base is being used to select new vehicles.

Longer term benefits would results from the introduction of minimum ergonomic standards for new vehicles entering the industry.

**Scope of research: Focus areas**

Publicise the assessment tools developed by COL 416.

Provide support and training where necessary (see Proposal 5).

Produce a central collation and distribution centre for the data base information.

When data base material is available, a team selected by SIMRAC to form to work with the ergonomist to agree on minimum acceptable criteria for key factors.

Establish ergonomic standard.

**Potential for application**

All mines selecting new vehicles. All mines modifying existing vehicles.

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# Appendix One

## Primary and enabling outputs of the project

The project undertook to fulfill a number of objectives. These have all be achieved.

The primary output from the project were:

1 Identification of ergonomic factors impacting on safety and health of trackless machine operators, drivers and workers. This has been achieved from a review of the International literature on the ergonomics of underground trackless vehicles and the hazards associated with their use in mines. Studies were used to determine those issues were ergonomic criteria needed to be altered to suit the conditions in mines in South Africa.

2 Recommendations for the improvement of the ergonomics of trackless machines used in South African coal mines. This has been achieved in a number of ways. The Handbook provides a comprehensive source of recommendations on key aspects of vehicle ergonomics. This is supported by two risk assessment procedures which identify those aspects of a vehicle where improvements are most warranted. Further recommendations are also provided to assist with improving vehicle ergonomics by retrofit modifications.

These primary outputs, and the ergonomic index, form the basis for the Industry to set a standard and basic specification for the ergonomics and design of machines.

The project aimed to develop the following other deliverables:

3 A handbook of essential safety and health requirements for the ergonomics of trackless vehicles. This is given in Annex One of the project. It discusses and provides detailed recommendations on 12 ergonomic issues relating to the health and safety of people who drive and work close to trackless vehicles.

4 A methodology for the ergonomic assessment of trackless vehicles underground for use by the non-specialist. The project identified the need for three methodologies.

   The basic methodology is the HSEC Ergonomic Index. This is given in Annex Two. Twelve checklists are used to assess a vehicle. The scores can be used to determine whether the vehicle meets minimum standards (scores agreed by the mine), which aspects of the vehicle needs to be improved (referencing to the Handbook for criteria), and to predict the magnitude of the improvements that would result from a number of modifications in advance of changes being made.

   The HSEC General Risk Assessment procedure can also be used to assess the ergonomics of a vehicle. Based on a detailed hazard taxonomy taken from the International literature, the risks to drivers, passengers and pedestrians can be assessed. This procedure also enables a detailed assessment to be undertaken of those aspects of vehicle design which most add to the overall risk. Reference is then made to the Handbook for detailed criteria to reduce these risks. This procedure is given in Annex Three.

   The HSEC Sightline Risk Assessment procedure can be used where poor sightlines are known to be a significant problem. There are often practical difficulties in providing ideal sightlines for drivers. This procedure therefore recognises and takes into consideration the influence of the mine layout and methods of working when assessing the overall risk. For example, problems that the driver could have in not seeing pedestrians in the roadway could be eliminated if the mine adopted procedures to prevent pedestrians from entering those parts of the mine. This procedures therefore identifies the risks for a number of known hazards and then enables engineers to determine the best combinations of changes to the vehicle and/or the mine features to eliminate or reduce these risks.

5 Indication of the suitability of virtual reality software techniques for machine assessment. The AIMS Unit of Nottingham University developed procedures for evaluating the influence of restricted sightlines when negotiating corners. The influence of different driver positions were assessed. Unfortunately the results showed that little benefit could be gained from these modifications.

6 Indication of the suitability of virtual reality techniques for the training of drivers and operators. The studies underground identified the highest risks were to people working in the roadways used by trackless vehicles. The training demonstrator was therefore developed which could form part of the training for mineworkers to highlight the risks to them and the actions they should take to minimise these risks. The demonstrator can also be used be drivers. Recommendations are made to further refine this training tool.

In order to achieve these outputs a number of enabling outputs were produced.

7 It was not possible to obtain an accurate list of the types of trackless vehicles in use in South African coal mines, however, those in use were identical or similar to those used in other Countries. The recommendations were therefore not directed to specific models of specific vehicles. Generic recommendations are given and procedures developed to enable any vehicle to be assessed and improved.

8 An assessment was undertaken of the ergonomic factors used internationally for trackless vehicle assessments. This is summarised in Appendix One.

9 The relevant international standards were reviewed and this is summarised in Appendix Two. No South African standards were found, although some mine companies had their own internal standards.

10 The assessment methodology was piloted in the first mine. This was modified and further studies were undertaken at three further mines. In all, 4 shuttle cars and 3 LHD vehicles were assessed in detail.

11 The ergonomic requirements for the health and safety of drivers and operators were determined from these studies and the literature reviews.

12 The HSEC Sightline Risk Assessment was developed to primarily form the basis of reducing the risk from vehicle vision restrictions. However, this procedure is complemented by the general risk assessment procedures, the ergonomic index, the handbook and the further recommendations for retrofit improvements.

# Appendix Two

## Literature review on ergonomics

The review covered the following information sources.

## 2.1 Ergonomic assessments of trackless vehicles in the UK

Since trackless vehicles began to be introduced into the National Coal Board, ergonomists at its Institute of Occupational Medicine regularly undertook ergonomic evaluations and reported any concerns to engineers in the Industry. These were primarily Eimco and Gullick Dobson battery and diesel vehicles. The first evaluations were conducted in 1977.

These early assessments were based around a 'ten point plan' framework of headings addressing: driver sightlines, workspace, control design, display design, control and display location, seating, access, lighting, labels, and the working environment. Although some ergonomic criteria could be transferred from those derived for other machinery, some basic research was required. In particular, research funded by the Ergonomics Action Programme of the European Coal and Steel Community, was directed at better identifying the visual needs of drivers and ways to assess vehicle sightlines (Mason et al, 1985).

Later assessments used an ergonomic index. This 'operability index' was first reported in the journal Applied Ergonomics (see Mason 1992 a and 1992 b). Ergonomic vehicle assessments using the Index included assessments of the Eimco 612C loader, and both diesel and electric versions of the Explorer models (Mason 1991, 1992 c, and 1993).

The operability index used the concepts of importance and quality for each of the following ergonomic factors (NB figures in brackets are the importance weightings for FSVs): driver sightlines (25), workspace (10), driver protection (18), access/egress facilities (15), control/display location (12), control design (12), display design (10), labels and instructions (3), seating (10), machine lighting (12), environment (7) and warning systems (10). Checklists were developed for each factor listing the specific requirements and pass/fail criteria. These checklists enable a quality score to be produced for each. The combined measure of importance and quality provide the end scores against which different vehicles can be compared.

In order to assist both vehicle designers and the Industry better specify its ergonomic requirements, a design handbook was produced specifically for free-steered vehicles in 1980. This was originally produced as part of an European Coal and Steel Community Ergonomics Action Programme project looking at both underground locomotives and free-steered vehicles (Kingsley et al, 1980). Upgraded versions of this report were also later produced (Mason and Simpson, 1990a).

The design handbook had detailed sections covering aspects such as: sightline criteria and measurements, seating, control location zones, canopy design and lighting.

Growing interest was also being directed to the ergonomics of the routine maintenance of trackless vehicles. A more detailed index addressing routine maintenance was developed and the prototype applied to an Eimco 912 LHD vehicle and a Gullick Dobson MP150 in 1988 (Mason, 1988 a and 1988 b). This index was termed the Bretby Maintainability Index (Mason, 1990 b).

No equivalent comprehensive ergonomic assessments of trackless vehicles could be found in other countries although several studies by the United States Bureau of Mines addressed specific aspects of these vehicles such as sightlines.

## 2.2 Health implications from driving trackless vehicles

With the exception of shuttle cars, the majority of trackless vehicles used underground required drivers to sit sideways in the vehicle. The result is that drivers need to adopt postures where the spine is rotated to enable them to look either side. The effects from twisted postures and whole-body vibration during driving were researched by Wilstrom (1993). Different postures, speeds and vehicles were studied. Vibration levels and degree of twist were recorded and these were shown to correlate with Borg's CR-10 scale and EMG-activity. Discomfort was localised to the lumbar and neck-shoulder regions. Rotation of the neck gave big effects on both discomfort and EMG-level.

Three classes of postures were used:

P1 Forward facing, both hands on wheel, optional placement of feet - driving forwards

P2 Head turned to left, trunk not rotated, both hands on steering wheel, optional placement of feet - driving backwards viewing mirror

P3 Driver sitting turned somewhat to the left on the seat, head and trunk turned to the left, looking in rear view window, right hand on steering wheel and left arm over backrest of seat, optional placement of feet, driving backwards

Different speeds were considered. Drivers would normally choose to drive vehicles at a higher speed than the underground speed limits. These self-selected driving speeds appeared to give greater discomfort in the first 2 postures but about the same as the fixed speeds in the third (twisted) posture. There was little difference between the machines studied. It could therefore be concluded that the suspension/seating may be very similar or that their effects were limited.

Any long term health implications to drivers tended not to be readily apparent in the early years following the introduction of trackless vehicles. Later findings have been reported in Section 1; however, these refer primarily to the consequences of accidents and not long term exposure to factors such as vibration and poor postures.

## 2.3 Hazard analysis methods

An early report by the Bureau of Mines (Ankenbruck et al, 1975) reported the result of 35 surveys of underground coal mines. Interviews and observational methods were used. Hazards were identified and accident data assessed against these to determine how each hazard could have contributed to the accidents. Preventative measures were determined which might alleviate the hazard. These were presented in Table 1-2 of the report. Factors contributing to hazards are listed in Table 1-1 and these have been added to the master taxonomy used in this report. Data from this study is reported in the introduction section of this report. A comprehensive list of observed hazardous conditions and unsafe acts were given

The authors recommended that further research was needed to: develop standardised cabs; develop canopy concepts for low coal haulage machines; and assess the pros/cons of full cabs and the need for two egress routes.

In recent years there has been a sudden growth in the numbers of methodologies which can be used to assess risk. These have been applied to trackless vehicles. A paper by Boyle (Boyle,

1997) threw doubt on aspects of most published methodologies. For example, it proposed that the cumulative risk of low, medium and serious risks need to be calculated. Frequently only the most severe are processed to yield risk and this must result in an underestimate of the actual risks. The implications of inconsistent terminology was discussed as was the similarity of the hazard identification stage and the preliminary risk assessment stage. The essence of these conclusions were taken into consideration in the current project.

Researchers at Nottingham University had developed virtual reality techniques to address aspects of risk assessments of trackless vehicles (McClarnon et al, 1995). The initial work utilised 'dynamic risk regions' around trackless vehicles along with awareness zones for pedestrians. The size of the risk region would increase with vehicle speed and the size and shape of the awareness zone would change with job demands and orientation of the pedestrian. The package was initially targeted as a training aid.

Sanders, in an undated publication by the U.S. Bureau of Mines, determined what needed to be seen and what could be seen from underground mining equipment. This work was reported under U. S. Bureau of Mines contract J0387213. A task analysis approach was used to determine the needs for shuttle cars, continuous miners and scoops. 64 visual attention areas were determined for shuttle cars. A procedure called HERMI was described which uses cameras and lights to assess the sightlines to these VAAs. Unfortunately the report does not describe the VAAs for shuttle cars. The approach identified the eye point at which each of the pieces of information, if received, can be seen by the operator. Although thorough, this approach was time consuming. Other approaches were to be more practical.

Ergonomics in the UK mining industry developed a range of sightline measurements from which the most suitable could be determined depending upon the vehicle type and the location (Mason et al, 1985). For example, methods suitable for vehicles on the surface standing in the middle of a level surface would not suit conditions underground where a vehicle would be in the confines of a roadway on uneven ground.

Ergonomists in the UK Health & Safety Executive were developing sightline measurement techniques using computers to plot restricted vision (HSE, 1992).

A limitations with both these areas of work was that insufficient criteria had been derived for areas on, and around vehicles, which drivers need to see to operate these vehicles efficiently and safely. The sightline criteria derived by the Bureau were not easily transferable to the methods of working and types of vehicles used in the UK. Clearly further work was still needed.

Unger and Rider (1987) reported a computer-aided analysis of human factors aspects of mining crewstations undertaken by the U.S. Bureau of Mines. A CAD system was being developed to assess reach, visibility and illumination. Fifty four visual attention locations (VALs) were said to be derived from studies. A second paper by the same authors gives the locations for shuttle cars. It stated that the Bureau planned to use it for accident investigations and also for use by original equipment manufacturers and mining companies for the initial design work on new machines and to evaluate proposed modifications to existing machines. Insufficient information was provided to determine the relative priorities of these VALs and these may not transfer directly to the South African vehicles and methods of working.

A useful approach to assessing risk was developed in Australia in relation to producing design guidelines for remote controls of mining equipment (Tenniswood et al, 1993). The project aimed to develop an Australian Standard to guide the mining industry into making acceptable decisions on specification, selection and usage of remote control systems for mining equipment. The draft

Standard provided a framework to assess the risks associated with the use of remote control units and has relevance to trackless vehicles.

Safety risk was defined in terms of 3 elements:

Action risk (A) — that is whether the machine motions being controlled are fast and could possibly represent a serious safety hazard

Period of action (P) — that is the duration of the machine function being controlled and its frequency of occurrence

Exposure of people (E) — that is how many people are usually in the immediate vicinity of the machine being controlled

Each of these received a score of 1,2 or 3 and the product of APE was the safety risk. APE hazard scores were given for a range of machines, with continuous miners, load haul dump, and shovel machines being assessed as high risk. Shuttle cars were assessed as medium risk. Individual risks appear to have stemmed from loading/unloading, travelling (both loaded and unloaded), tramming and steering/slewing.

Personal damage from mobile mining machinery was summarised (McDonald, 1993) as:

- A division of personal damage into permanent, temporary and inconvenience
- Damaging energy exchanges divided into single, repeated and continuous
- Measurement of damage to people by impairment giving effective days of living destroyed
- Pain in its chronic form as a major source of impairment and the development of pain behaviour
- A theory of pain which shows that other factors increase or decrease the perceived pain
- Physical, mental, emotional and spiritual models of man and that emotional health and fitness influences impairment
- Long term back damage involving mechanical failure of discs
- Disc damage from a combination of single, repeated and continuous overloads from falls, manual handling, sitting, vibration, jarring and smoking

## 2.4 Strategies for improving vehicle ergonomics

Part 1.1 described the initial work of ergonomists in the mining industries. The initial emphasis was on helping both designers and mine staff improve the designs of new vehicles entering the industry. However, it became particularly evident in the mid-eighties that the run down of some industries had significantly reduced the numbers of new vehicles entering the industry. Vehicles from closed mines were being refurbished and transferred to new mines.

It was therefore apparent that further improvements in ergonomics would best be achieved if procedures were devised to enable existing vehicles to be cost-effectively modified to improve the standards of ergonomics.

Within the UK mining industry, one of the first systematic attempts to improve the ergonomics of mining machinery was directed to modifying trackless vehicles to make them easier and safer to conduct routine maintenance (Mason, 1988 a and b). This work was the first application of the Bretby Maintainability Index (Mason, 1990 b). The Index and its application to trackless vehicles is described in Mason and Rushworth (1989).

Similar benefits for the drivers of trackless vehicles from retrofit modifications were later reported (Rushworth et al, 1995 and Rushworth, 1996). This described a detailed approach which was developed, changes made to a vehicle and likely effectiveness of these retrofits. The approach was based around a risk assessment and used a modified operability ergonomic index (see Mason 1992 a). The approach essentially provided a score of the percentage maximum achievable. The improvement in this score after the retrofits have been added (or proposed), along with estimates of the costs of the modifications, give some measure of the cost-effectiveness of improvements. This process is comprehensive but may take too long to complete for its routine application.

# Appendix Three

## Virtual reality demonstrator for improved safety training

### 3.1 Background

Virtual reality techniques are being increasingly applied to training situations. Many are being directed to training certain 'life-skills' for those with learning difficulties. For example: shopping in supermarkets, dealing with money, crossing the road, and safety in the home. Virtual reality is also being applied to industry situations such as giving training in emergency egress routes, and maintenance operations. The training demonstrator developed by the project was aimed at improving the awareness of hazards and perceptions of risk for those people who work in close proximity to trackless vehicles.

The AIMS Unit of Nottingham University had developed some techniques for showing hazard areas around underground and surface mining machinery (McClarnon et al, 1995). This essentially consisted of a cuboid around each moving vehicle which changed size depending upon the speed and direction of the vehicle. These volumes interacted with those of other vehicles and obstacles in the paths of vehicles and changed colour to reflect the magnitude of the hazard. For example, very high hazards were shown in red.

The AIMS Unit also used virtual reality and computer graphics to reproduce accidents to pedestrians in roadways from trackless vehicles, and other accidents, to highlight risk in the safety of the classroom.

### 3.2 Objectives of the project demonstrator

Accident data and the results of both the underground studies and the risk assessments undertaken by the project highlighted the safety problems for pedestrians working in close proximity to trackless vehicles.

Mineworkers need to be fully aware of the restricted vision that trackless vehicle drivers often have of people near vehicles. The demonstrator is therefore developed to show how drivers' vision is influenced by:

- the direction of travel,
- the nature of the corner (turning left of right), and
- the affect of the load being carried by the shuttle car

The onus, therefore, has to be placed on mineworkers being especially vigilant when working or walking in roadways used by these vehicles. This is developed to show:

- how to watch for the lights from the vehicles - which will be seen before the vehicle itself is seen, and
- how to use the cap lamp to increase the chances of drivers seeing you

## 3.3 Discussion

### 3.3.1 Interactive facility

The demonstrator uses two views. One is that of the miner. The other is that of the shuttle car driver.

The miner can move freely about the mine and stop or stoop at any position. The miner can look in any direction. The miner has a cap lamp and the light of the cap lamp shines on the roadway sides depending on the miner's location.

The shuttle car driver can also look in any direction from the two seats on the shuttle car. The vehicle is fitted with two spot lights and the illumination from these show up on the roadway as the vehicle travels and turns corners.

It should be borne in mind that the movements in the virtual world may appear slow or jerky on some computers. This is purely as a result of the computer being used. Slow processor speed, poor performance of the video card and small RAM will produce these effects. The recommended minimum specification for a PC for using the demonstrator is therefore a P150 processor with a 4 MB graphics accelerator card. The recommended specification is a P200 (or better) processor with an 8 MB graphics accelerator card.

### 3.3.2 Showing risk

A novel approach has been developed to allow the mineworkers to 'see' the risks to themselves through all combinations of vehicle direction, speed, type of corner and their own position in the roadway. This is based on a moving bar chart which shows the cumulative risk to the individual along with (optional) five contributing elements: (1) the speed of the vehicle, (2) the direction of the vehicle relative to the miner; (3) the distance from the vehicle to the miner; (4) the visibility of the miners from the driving seat and (5) the direction the miner is looking. For example, a miner can be near a vehicle but the risks could be low if the miner is looking at it and if the vehicle is stopped or moving very slow. The risks could be high if the vehicle is far away but the miner is not looking in that direction and if the driver's vision is poor towards the position the miner is standing.

The demonstrator currently uses equal importance for each factor, although further work would be needed to refine this (see later). The cumulative risk bar changes colour depending upon the calculated risk. Red shows the highest risk.

#### 3.3.2.1 Training demonstrations

The demonstrator has flexibility to be used in a variety of ways depending upon the experience of the mineworkers undergoing training. A typical method is outlined below:

1 Small groups of mineworkers would sit around a PC with a training instructor. The instructor would explain the two views shown on the screen and show the mineworkers how to move the vehicle and the pedestrian in the virtual world. This is undertaken using a mouse or the keyboard direction arrows.

2 Mineworkers would initially 'see for themselves' the limited view of trackless vehicle drivers operating shuttle cars in the loaded and unloaded condition when manoeuvring around left and right handed junctions with the vehicle (a shuttle car) travelling in either direction.

Although the demonstrator can have the vehicle freely moving about a mine, this initial stage would be restricted to the vehicle moving around a pre-set route around a small section of a mine layout.

3 Mineworkers would then move their attention to the view of the virtual mineworker shown on the second part of the screen. They would familiarise themselves with moving the miner about in the roadway and in turning to look in any direction.

4 Mineworkers need to consider whether it is safest for them to walk in the centre of the roadway or to the sides when in the proximity of trackless vehicles. They can adopt a number of positions and see for themselves where they can best see the vehicle and where the risks are the lowest.

5 At critical increments around a left or right hand junction the mineworkers would simultaneously look at both portions of the screen to see how a miner detects a vehicle. Mineworkers can see the lighting changing on the walls near junctions where vehicles are approaching. They would also look at what the driver is likely to see (possibly the light from the cap lamp and direct vision if the vehicle sightlines permit). Mineworkers can run this in slow motion both forwards and backwards and change the position of the virtual mineworker to determine the effect of different positions in the roadway.

6 The training instructor would lead discussions to draw the following conclusions:

- that drivers have generally poor ability to see them when turning corners where the driver sits on the outside of the bend
- that the load, and often low seating position, adds to the drivers' difficulties
- that even when the driver has the ability to see them, or part of them, that the driver may be looking elsewhere for a period of time to judge clearances between the roadway and vehicle
- KEY POINT ONE: Don't rely on the driver being able to see you.
- that mineworkers can see a vehicle coming before the driver can see the miner
- that it is often possible to see a vehicle coming by looking at the light beam in front of it before you can actually see the vehicle
- KEY POINT TWO: Miners must keep alert when in roadways used by trackless vehicles. When talking keep face-to face so that one person is facing each direction and be aware of the need to look for changes in illuminations which could signal the arrival of a trackless vehicle
- that there are safer parts of the roadways to walk in and that it is possible to draw attention to a driver by waving the cap lamp about on the roadway visible to the driver, however, don't rely on this method for your safety

### 3.3.2.2 Further research

This demonstrator can later be developed to better address:

#### 3.3.2.3 Developing the Risk Matrix

The algorithm used to show the cumulative risk has been initially produced with 'equal importance' from: the speed and direction of the vehicle relative to the miner; the vision of the driver to the miner; the direction the miner is looking relative to the vehicle; and the distance of the miner to the vehicle. These weightings can be modified in the demonstrator.

Detailed studies would be necessary to provide a more accurate method of combining the individual factors to form an overall indicator of risk to the miners. Furthermore, it is likely that the individual factors would not have a linear relationship to risk. Although, the risk indicator is a useful starting point in its present form, it is recommended that further research be directed to this area.

#### 3.3.2.4 Increasing the content of the demonstrator

The demonstrator could be developed for driver training to enable drivers to 'steer' vehicles freely around a representation of any mine with miners walking about and working at fixed locations or at locations decided at random.

The training demonstrator for mineworkers could be improved with additional miners being added such that they could be discussing work and not facing vehicles. Miners could be given additional tasks, such as watching for general hazards in the virtual roadways, which could introduce a distraction to the vehicles moving about the mine.

Different trackless vehicles could be added to the demonstrator, for example, different types of Load Haul Dumps.

The effects of wearing reflective strips on helmets and clothing could be added. Track markings in roadways could also be added.

## 3.4 Conclusions

The demonstrator appears to be an effective means of addressing critical aspects of safety associated with working in the proximity of trackless vehicles. Initial feedback from people with experience of mining in South Africa supports this view.

It is recommended that this demonstrator be further developed to more accurately show cumulative risk and add additional tasks for the mineworkers to more realistically introduce factors which could distract mineworkers' attention and thereby increase risk.

It is also recommended that the demonstrator is developed to address the training needs of the vehicle drivers.

# Appendix Four

## Ergonomic Standards

### 4.1 Review of European standards

A literature review was undertaken on Standards relating to underground trackless vehicles. Where appropriate detailed recommendations have been incorporated into the ergonomic design handbook and parts of the assessment methodologies.

For each Standard, relevant information has been collated under the following headings used for the handbook and other parts of the methodologies developed by the project:

Driver Sightlines & Vision
Workspace
Driver Protection
Access & Egress Systems
Control & Display Provision and Location
Control Design
Display Design
Labels & Instructions
Seating
Machine Lighting
Environment
Warning Systems

Comments are shown in italics. These often identify conflicting requirements or aspects of ergonomics which are not fully appropriate to trackless vehicles.

The most appropriate European Standard for trackless vehicles is the Standard, 'Machines for underground mines - safety' - Part 1 - rubber tyred vehicles. This was developed as a standard conforming with the essential Health and Safety Requirements of the Machinery Directive 89/392/EEC. It was drawn up by CEN Technical Committee CEN/TC 196, Working Group 2; the current draft is dated May 1996 and the Standard is no. prEN 1889-1..

## 4.1.1 Machinery for Underground Mines - Mobile Machines Working Underground - Safety - Part 1: Rubber Tyred Vehicles

Extracts from this draft standard are summarised under the structure of the ergonomic features used in the handbook and in the ergonomic index. For ease of reading these are cross-referenced to the original sections in the relevant standard documents.

### Driver Sightlines & Driver Vision

| | |
|---|---|
| 5.12.1.1 | The driving position located to give good vision. Where necessary optical aids should be provided. Manufacturers shall provide information on field of view in accordance with ISO 5006-1:1991 |
| 5.12.4.2 | Windscreen wipers, washers, demisters etc provided if conditions dictate. |

### Workspace

| | |
|---|---|
| 5.12.5.1 | Drivers' space shall conform to EN 23411:1988 and prEN 547-4 as far as practicable. Specific information given for modifications where space is limited. |

### Driver Protection

| | |
|---|---|
| 5.12.1.2/3 | Design shall prevent body of driver projecting outside the envelop of cap and coming into contact with moving parts of vehicle. An insulated roof shall be provided if vehicle used under live conductors. |
| 5.12.1.4 | Cab or canopy to be fitted if conditions dictate. |
| 5.12.2.1 | Cab designed to minimise injury to driver from accidental contact with roof/sides and collision with other vehicles. |
| 5.12.5.2 | Roof, inner walls and working space in cab shall not present sharp edges or corners liable to injure the driver. |
| 5.14.4 | Diesel vehicles shall be equipped with fire extinguishing system cable of operation from safe and easily accessible position (normally in the cab and on side of vehicle) - need not apply to vehicles used in non-gassy mines with engine power less than 65 kW. |

### Access & Egress into Cabs

| | |
|---|---|
| 5.12.3.1 | Access to cab shall meet ISO 2867:1980 as far as possible |
| 5.12.3.2 | Emergency exit from cab shall be provided on a different side |
| 5.12.3.3 | Devices provided to retain doors open or shut |

### Control & Display Provision & Location

| | |
|---|---|
| 5.11.1.4 | Where brakes use reservoirs, a pressure gauge should be provided and located in drivers' view. The minimum acceptable pressure should be indicated or warning devices provided |

### Control Design

| | |
|---|---|
| 5.11.1.11 | Remote control shall be designed to stop a machine if control, power supply, or command signal is interrupted (also 5.18.5). |
| 5.18.5 | Resetting only possible by intentional action by driver. |
| 5.18.3 | Starting a remotely operated/unmanned automatically operated vehicle shall only be possible from a control on the vehicle, or from a position have sufficient visibility (TV monitoring system OK). Before starting a visual and/or audible warning actuated indicating remote control mode. |
| 5.18.4 | Remote/unmanned vehicles shall be fitted with an emergency stop switch conforming to EN 418 on remote control/monitoring control panel. and additional stop switches on the vehicle in accessible positions. |

| | |
|---|---|
| 5.11.1.12 | Brake pedal operating forces shall conform to ISO 3450 |
| 5.12.6.1 | Controls designed and laid out to prEN 894 Parts 1 & 3 to make them easy to use, minimise confusion due to stereotypes. On vehicles with more than one driving position the controls shall be located similarly in each position. |
| 5.12.6.3 | Controls whose accidental operation could be hazardous shall be located and designed to prevent accidental operation. |
| 5.12.6.4 | Means to prevent unauthorised persons starting vehicle and starting engine shall not cause hazardous movement. |
| 5.12.6.5 | All controls to return to neutral position on release expect those continuously or automatically activated or have a functional detent. |

**Display Design**

| | |
|---|---|
| 5.12.7.1 | Displays necessary for safe driving located in zones in figs 2 & 3 of prEN 50099-1. Repeated in vehicles with more than one driving position. |
| 5.12.7.3 | On vehicles with windscreens displays shall be illuminated |
| 5.12.7.4 | All vehicles to be fitted with service hours/kilometer recorder. Note - it may be necessary to provide a speed indicator to ensure compliance with legislation. |

**Labels & Instructions**

| | |
|---|---|
| 5.1.7 | Danger zones marked in accordance with IOS 3864 |
| 5.6.5.7 | Warning signs indicating presence of external live conductors |
| 5.12.6.2 | Control and display labels indelible and to ISO 6405:1982 and ISO 3864:1984. Wording in user language. |
| 5.18.6 | Remotely operated and/or unmanned vehicles equipped with warning signs indicating remote/automatic operation. |

**Seating**

| | |
|---|---|
| 5.12.5.3 | Seat shall give good and stable posture and be easily adaptable to drivers of different weight and height (ref ISO/CD 11112) and minimise vibration transmitted to the driver. |

**Machine Lighting**

| | |
|---|---|
| 5.9.1 | At least two white headlights - giving sufficient illumination to enable driver to control vehicle in all its driving modes/operating conditions - where necessary dipped beams provided to prevent dazzle. Adjustable headlight mountings. |
| 5.9.2 | Two red reflectors (20 sq cm or more) & two red lights (5 watts or greater) *or*<br>Two red triangular reflectors of 0.15 m side length or reflecting film of at least equivalent area<br>*but*<br>National legislation may require use of red lights at the rear |
| 5.9.3 | Easily cleaned light glass/lenses and reflectors |
| 5.9.4 | For vehicles normally operating in only one direction: at least one reversing light<br>For vehicles normally operating in both directions: duplicate lighting & auto selected to direction of travel<br>*but*<br>Selection can be manual if only short distances are travelled in each direction<br>Can have additional lights fitted<br>Independent working lights can be fitted |

**Environment**

| | |
|---|---|
| 5.7.2 | Diesel exhaust gases directed to avoid penetration into drivers and passenger areas |

**Warning Systems**

5.10.1 Manual operated audible warnings designed and tested in accordance with EN 457 shall be operable from each cab. Additional visual warnings should be considered in high noise areas.

5.10.2 Automatic audible or visual signals provided when reversing. Changing from white to red lights are sufficient.

5.11.1.5 A warning should be provided to show the driver if the parking brake is partially/fully on. Alternatively a means should be provided to prevent vehicle being driven in this state.

5.11.1.10 Warning provided for drivers where oil-immersed brakes are used and a risk of high temperatures exists.

### 4.1.1.1 BS EN 457: 1992, Safety of Machinery - Auditory Danger Signals - General Requirements, Design and Warning

**Warning Systems**

Auditory signals should satisfy a physical standard or a listening check.

A-weighted sound level of a signal should be more than or equal to 15 dB above ambient levels and greater than or equal to 65 dB. Alternatively, the signal should be greater than or equal to 10 dB in one octave or more, or greater than or equal to 13 dB in one third octave band or more.

Warning signals should be discriminable in at least two parameters of level, temporal or combinations of frequencies. They should also be unambiguous.

alternatively:

Ten or more people (or all people present at the workplace) should all be able to hear warning signals - using PPE if applicable - in a series of 5 tests with signals presentation being unannounced and in the most unfavourable conditions.

### 4.1.1.2 prEN 50099 - 1: 1992. Safety of Machinery - Indicating Marking and Actuating Principles - Part 1: Visual, Audible & Tactile Signals

**Control & Display Provision and Location**

Visual zones are provided on page 12. *(Note - these are wrong for flashing light type warnings which are most effective in peripheral vision).*

**Control Design**

Emergency stop/off actuators shall be red.

**Display Design**

Colour codes should be adopted: red - danger/emergency; yellow - caution/abnormal; green - safe/normal; blue - mandatory significance

**Labels & Instructions**

Active and passive signals should take account of potential for sensory deficiencies - eg. colour defective vision, deafness, or the effects of ppe

**Warning Systems**

Audible signals should exceed background noise by a minimum of 10 dBA. *(Note - this contradicts EN 457 which specifies 15 dB)*

Sound signals given for different message categories of danger, caution, information and all clear.

### 4.1.1.3 BS 5538: 1982 & 1SO 3411 - 1982 & EN 23411. Minimum Operator Space Envelope for Earth Moving Machinery

**Workspace**

Anthropometric data for 5th, 50th, 95th male percentiles are provided for drivers of earth moving machines. These make allowance for shoes/boots and the thickness of working clothes. Arctic clothing is assumed in separate data.

Even on narrow machines the space envelopes should not be less than 750 mm width.

Minimum internal distance from centre line of seat to side of enclosure is 375 mm.

### 4.1.1.4 BS 6912 Part 15: 1995 & ISO 2867: 1994. Safety of Earth-Moving Machinery: Part 15. Specification for Access Systems

**Access & Egress Systems**

4.1 Alternative exit needed if operator platform 3 m or more above ground level and preferably if platform is 2 m or more above ground level. *[Note - the need for a second means of egress is not related to height - simply to the chances of being trapped]*

4.2/3 Minimise snagging & tripping risks

4.4 Minimise contact with extremes of hot/cold, electricity hazards, moving parts and sharp corners

4.5 Access to accommodate to 95th percentile [ie 5 percent can't get in]

4.6 The access method/route should be obvious

4.7 Three point contact should be possible during access/egress

4.9 Alternative exit shall be provided and clearly indicated if not obvious *[NB this contradicts 4.1 for cabs under 2 m from floor]*

5.2 Maximum gap in tread to protect stepping through

5.5 All surfaces to be slip resistant

5.6 Handrails shall be free of roughness and sharp corners which could injure

6 Step design preferably wide enough for both feet; location co-ordinated with hand holds; shields provided where necessary to prevent feet protruding through to moving parts; slip resistant; minimisation of accumulation of debris; located for natural foot placement;

For ladders, stairways, handrails, platforms, walkways etc not applicable to underground vehicles

11 Minimum openings for front access enclosure: 450 mm width - tapered at head height and 250 mm width at and below knee height. Basic requirements are, however, 680 mm wide and 1300 mm high

#### 4.1.1.5 prEN 547 - 1: 1991. Safety of Machinery - Human Body Dimensions

Part 1: Openings for Whole Body Access - not applicable to FSVs

Part 2: Principles for Determining the dimensions for Access Openings

**Routine Maintenance**

Access for maintenance operations - *(Note, these do not allow for sightlines or allow for components to be transported through the opening, the use of tools, the size of the component, and therefore are not good enough)*

*(Note: space requirements are usually dictated by the size of the large person and reach by a small person BUT in 4.3, width was dictated by a small women's dimensions! Similarly pages 21 & 22 read as if lower arm access has to be at elbow height whereas full reach is at shoulder height. Note, the former could also be at this height)*

#### 4.1.1.6 prEN 12464. Lighting Application - Lighting of Workplaces

**Machine Lighting**

This is not directly relevant to underground trackless vehicles but it is of interest. At traffic zones inside buildings, an average of 100 lux specified but avoiding glare to drivers and pedestrians. At public car parks (indoor), ramps at night and parking areas - 50 lux is recommended.

At outdoor work places such as slow site roads - 10 lux is recommended. At open cast mining/quarries - 30 lux is recommended.

#### 4.1.1.7 British Coal - Issued with Engineering Circular (90) 25. (a) Minimum Requirements Specification for Diesel Powered Free Steered Vehicles, and (b) Minimum Requirements Specification for Battery Powered FSVs

**Driver Sightlines & Vision**

Seat positioned to afford good vision in both directions (a & b)

**Driver Protection**

Substantial canopy to protect driver (a & b)
Single portable extinguisher mounted for easy reach (a)
Two 9 kg dry powder extinguishers - one within drivers' reach (b)

**Control & Display Provision and Location**

Main isolator operable from driving position (b)
Controls positioned to discourage operation from outside of cab (b)

**Control Design**

Park brake hand operated detent 'ON' with direct action to release (a & b)
Steering wheels only (a & b)
With two cabs only controls in driving cab can be energised (a & b)
With two cabs - if vision only possible in one direction - reversing prevented (a & b)
Prevention of unauthorised starting/operation (a & b)
Overspeed device (b)

**Display Design**

All gauges sized and colour coded for go/no go limits (a & b)

*The following must be monitored: (a)*

Starter pressure, brake accumulator pressure, brake line pressure, engine oil pressure, safety circuit pressure/status, engine coolant temp, engine gas temp, hydraulic oil temp, engine speed, hours run, transmission pressure, transmission temperature, vehicle speed, and where applicable, load movement

The following must be monitored: (b)

Battery condition, brake accumulator pressures, brake line pressure, hydraulic oil temp, motor current, hours run, vehicle speed, and where applicable, load movement

Device to monitor battery to frame leakage - flashing/steady red in alarm (b)

**Labels & Instructions**

All controls marking with function and direction of operation (a & b)

All gauges labelled (a & b)

All major components marked with lifting points and weights for transportation (a & b)

**Machine Lighting**

Two headlights at each end - to include red tail filaments - auto switching from drive direction (a & b)

Headlight range 60 m and not obscured by loads/attachments (?) (b)

**Warning Systems**

Robust audible warning fitted (a & b)

### 4.1.1.8 BS 6911 PART 5: 1992, ISO 5006-1:1991. Testing Earth-Moving Machinery Part 5. Determination of Operator's Field of View

**Driver Sightlines & Vision**

Vehicles in set position regarding heights of moveable components above floor level and vehicle located at the centre of a 12 m and 19 m circle.

Three bulb spacings are used to represent binocular vision, and various degrees of body/head assist. In the ahead position the test is made with binocular vision and the widest bulb spacings. For rear vision this is restricted only to binocular vision as body assist would be difficult due to the turning posture of the trunk. (Note the centre of vision would not necessarily be at the test point). For sideways/ahead vision full body assist is allowed. For the sideways/rear vision partial assist is allowed.

The closest two bulbs (2 x 65 mm representing 50 per cent eye separation) are initially used and areas on the 12 m radius not visible noted. If these occur in any of the ahead sectors then the test is repeated with the widest bulb spacing. If these occur in the sideways/rear sectors the intermediate bulb positions are used. For the rear sector only the closest two bulbs are allowed.

If maskings are recorder in the "sector of vision" and "visual field" (ie ahead and to the rear) at 12 m then the test is repeated at 19 m. The maximum bulb separation (2 x 202.5 mm) is used for the ahead vision (to cater for body turn?) but only the closest two bulbs are used for the rear position.

Masked vision is recorded at 12 m and 19 m in the ahead and rear directions but only at 12 m in the side directions.

*This is a reasonable method. The use of 50th per cent eye height should be questioned as it is the smaller 5th per cent which is critical. There is some room for debate as a smaller operator may adjust the seat higher and this could approximate to the average 50th per cent eye height. Caution is needed, however, as this could result in the small driver not being able to rear pedals and other controls.*

*The effect of any vehicle articulation is not addressed nor is the test procedure directed to look at the vehicle with its intended load. Loads can vary to some extent however the objective on an earth moving vehicle is to carry earth. The maximum volume of such a load could therefore be reasonably accurately predicted and taken into account. For vehicles carrying other loads the adoption of a standardised load may be more difficult to address in such a standard.*

*This does not address vision upwards. Vehicles to hit overhead cables/pipework etc and so this could have been addressed. It would however be difficult to do this using the method as a 12 m circle above the vehicle would be needed.*

### 4.1.1.9 BS 6912: PART 12: 1993, ISO 5006-2: 1993. Safety of Earth-Moving Machinery. Part 12. Evaluation of Operator's Field of View

**Driver Sightlines & Vision**

The premise of this standard is that a person would not necessarily be seen if the masking chord length at the perimeter of the 12 m arc was 700 mm or greater. Furthermore, it is stated that unless the spacings between two adjacent masked areas is 1300 mm or more then it may still not be possible to reliably detect a person in this zone. In these case the adjacent masked areas would be combined to reveal a larger solid masked area.

*A problem with this logic is that a masked area of the perimeter of a 12 m radius shows the parts not visible at floor level. Unless a person is lying on the floor this is insufficient to suggest a problem in seeing a person stood erect or even stooping/kneeling. Other studies have shown that as long as the upper body/head are visible then the person will be reliably detected.*

The test method relies on part of ISO 5006-1.

Three visibility categories are referred to: I, II and III. The definition of each is dictated by the 4 vision zones which are confusingly called: sector of vision (ahead), visual field (to the rear), field of vision (forwards to the sides), and field of view (rear to the sides).

For the forwards direction:

Visibility Category I: (12 m radius and binocular vision) no more than 2 maskings in the ahead zone with a masked chord of 700 mm or less.

Visibility Category II: (12 m radius and wide bulb separation) the above masking conditions are met.

Visibility Category III: (12 m radius and wide bulb separation) no more than 2 maskings with masked chord of 700 mm or less AND 2 maskings with masked chord of 1300 mm or less.

For the forwards/side directions:

Visibility Category I: (12 m radius and binocular vision) no more than 1 masking with masked chord of 700 mm or less AND no more than 1 masking with masked chord of 1300 mm or less in each left and right fields of vision.

Visibility Category II: (12 m radius and wide bulb separation) the above masking conditions are met.

Visibility Category III: (12 m radius and wide bulb separation) if more than one of the maskings in Cat II have a chord length of 5500 mm or less. I suspect this should say "no more than one" ...

For the rear/side directions:

Visibility Category I: (12 m radius and binocular vision) no more than 2 maskings with masked chords of 700 mm or less in either left or right areas

Visibility Category II: (12 m radius and intermediate bulb separation) no more than 1 masking with masked chord of 700 mm or less AND 1 masking with a masked chord of 1300 mm or less in either left or right areas

Visibility Category III: (12 m radius and intermediate bulb separation) no more than one masking with masked chord of 700 mm or less AND one with masked chord of 5000 mm or less in either left or right areas

For rear vision

Visibility Category I: (12 m radius and binocular vision) no more than 2 maskings with masked chords of 700 mm or less AND 1 masking with masked chord of 1300 mm or less

Visibility Category II: (19 m radius and binocular vision) no more than 2 maskings with masked chord length of 1100 mm or less and 1 masking with measured chord of 2060 or less

Visibility Category III: (12 m radius and binocular vision) no more than 2 maskings with a masked chord of 700 mm or less AND 1 masking with measured chord of 5000 mm or less

#### 4.1.1.10 BS 6912: PART 13: 1993, ISO 5006-3: 1993. Safety of Earth-Moving Machinery. Part 13. Acceptance Criteria for Operators' Field of View

**Driver Sightlines & Vision**

This capitalises on the measurement methods described in BS 1611 and the categorisation of driver vision in BS 1612 Part 12. No logic is given, however, acceptable criteria for each of the 6 vision zones are given for a range of machine types. In some case it is acceptable for vision to be worse than class III.

Of the sample of vehicles, the Loader - Wheel (< 24 ton & > 24 ton) are vaguely equivalent to LHDs but the cabs are fwd facing.

### 4.1.1.11 BS 6912: PART 3: 1990, ISO 9533: 1989. Safety of Earth-Moving Machinery. Part 3. Sound Test Method for Machine-Mounted Forwards and Reverse Warning Alarm

**Warning Systems**

*This is a basic test with machines in the open.* Base machine sound levels are recorded with the engines at maximum governed engine speed under no load conditions. Measures are taken at eight positions around the machine and at the operator ear. Measurements are taken around a 260 mm radius circle at 1.2 m above floor or at 635 mm above seat squab. With the engine at idle speed the sound level is measured with the alarm sounding.

Criteria:
For reverse alarms, the A-weighted sound levels at any test location with alarm on shall be equal or greater than the base machine levels.

The A-weighted alarm at the drivers' ear shall be no more than 3 dB above the base level at the driver ear.

The forward alarm A-weighted level shall be at least 10 dB more than base level at a location 7 m in front of the machine.

### 4.1.1.12 BS 6912: PART 5: 1992, ISO 2860: 1992. Safety of Earth-Moving Machinery. Part 5. Recommendations for Minimum Access Dimensions

**Routine Maintenance**

Minimum dimensions given for hand, head, body, arm, two-handed access for the purposes of inspection, adjustment and maintenance. Larger openings are said to be needed in specific instances depending upon the nature of the task, size and mass of the parts etc. Dimension said to accommodate the 95$^{th}$ per cent operator as defined in ISO 3411.

Hand Access:
The figures for single hand access derive from anthropometric data. *In fact Pheasant (1997) gives the 95$^{th}$ per cent man's hand width as 114 mm. This standard specifies a minimum aperture width of 110 mm. Depth is slightly greater than Pheasant's 95$^{th}$ & hand depth at 65 mm compared to Pheasant's 58 mm.*

*These data are quite rightly said to reflect the minimum access and it is acknowledged that larger apertures will be needed for some tasks. Larger apertures will more often than not be required. The problem then is how large should they be. Mason et al (1986) provides much more detailed information to help designers in these instances with dimensions for simple screw driver and wrench usage. This standard should provide information for these simple maintenance tasks. Obviously some jobs will be "one-offs" and require special attention, however, routine and simple tasks should have been reflected in these standards.*

Head Access:
The dimensions given appear to cater well for the larger head. *One weakness of this data is that head access will probably be needed to inspect a component. If such components are located on the face of this access volume then the distance from eye to component would be so small that the person would be unable to focus on it.*

Reach Access: (Arm Access)
*Comments similar to hand access in terms of logic in providing dimensions which would be too small for most jobs which the standard states it is intended to address. Furthermore, the dimensions prevent the persons from seeing what he is touching in many instances.*

Reach Access: (Two Handed Access)
*This makes allowance for the width of an object being handled but not the height. It is confusing in that it labels the height of the aperture as the width of opening!*

*The aperture reflects the size of the component being handled, however, Military Handbook 759 makes the point that the aperture has two purposes. One is for effective hand movement within the aperture. The second is aperture dimensions to enable components to be passed through. This creates the concept of an aperture opening and an internal volume for work. This standard gives only a single set of data for both. Compared to Mason et al (op cit) the widths recommended in the equation broadly fall in between the min and max provided in the other document. The height of aperture is however smaller.*

*No allowance is made for enabling the operator to see the objects being inspected or maintained.*

*Overall, insufficient attention has been paid to providing data suitable for typical inspection/maintenance tasks on earth-moving vehicles. The dimension reflect more absolute minimum dimensions based on anthropometric dimensions. This will enable most people to physically get their hands/head/body into an aperture - but frequently little more than that. Space for simple and routine jobs appear to have been insufficiently considered.*

### 4.1.1.13 BS 6912: PART 18: 1995, ISO 12508: 1994. Safety of Earth-Moving Machinery. Part 18. Specification for Bluntness of Edges at the Operator Station and in Maintenance Areas

**Driver Protection**

External corners such as on cab or service doors and pointed objects shall have a minimum radius of 4 mm.

Edges of parts shall be rounded or chamfered to a minimum dimension of 0.3 mm.

**Access & Egress Systems**

Grab handles and edges/corners of hand-holds should have a minimum radius of 5 mm.

**Routine Maintenance**

In maintenance areas the edges of parts shall be rounded or chamfered to a minimum dimension of 0.3 mm.

**Passenger Compartment**

In passenger areas the edges of parts shall be rounded or chamfered to a minimum dimension of 0.3 mm. Refer to access & egress systems for hand holds.

### 4.1.1.14 BS 6912: PART 19: 1996, ISO 11112: 1995. Safety of Earth-Moving Machinery. Part 19. Specification for Dimensions and Requirements for Operators' Seat

**Seating**

Specifications given for dimensions and adjustment ranges and armrests where fitted. The standard enables dimensions to be changed but only when the changes can be shown to be more suitable to a population group.

Dimensions are referenced to "the seat index point (SIP)". This is not the seat reference point (SRP) normally used by ergonomists. I am not sure what it is but it may be an initial reference for a sprung seat - I doubt this as the full seat moves and therefore the relationship between the squab/backrest etc. remain constant.

There is insufficient dimensions provided to assess simple features of a seat. For example, no information is provided on the dimension between SIP and backrest or height of SIP above the squab. This may be implicit in the definition of SIP.

There are no recommendations for seat height or how to locate a seat relative to pedals. There are no recommendations for squab padding (thickness or hardness).

The "inside" dimensions of the bucket (ie the flat surface in contact with the buttocks/thighs/back is not given. Only the outer dimensions for the raised lateral supports are given.

### 4.1.1.15 BS 6912: PART 20: 1996, ISO 10968: 1995. Safety of Earth-Moving Machinery. Part 20. Specification for Operator's Controls

**Driver Protection**

Appropriate controls should be deactivated, guarded or arranged to they cannot be activated unintentionally especially when drivers are getting into/out of the vehicles.

**Control & Display Provision and Location**

The standard identifies: steering, clutch/inch pedal, gear selection, speed, travelling, brakes, and rotary/slewing motion as primary controls. For "equipment" this also includes: raising/lowering operations, boom extending/retraction operations, backwards-forwards motions, attachment operations and rotary/slewing operations. These should be located in zones given in ISO 3411 and ISO 6682.

Secondary controls are infrequently used but are needed for proper function of the machine (parking brake and lighting are given as examples). There is no recommendation on the location of these controls.

*Ignored are controls which may be infrequently used but which need to be operated speedily and reliability (eg emergency controls). These need also to be located in the primary zones.*

The distance between control levers, adjacent pedals, handles, knobs shall allow operation without unintentional actuations of adjacent controls. For hand or finger operated controls with forces up to 150 N (34 lbs) at least 25 mm clearance should be available in each control position to any adjacent parts. Overlap is permitted to enable simultaneous operation of controls.

*Interestingly there does not appear to be any consistency in control location between different vehicle types. For example, some vehicles with steering wheels have ancillary controls for the left hand while other recommended layouts specify the same functions on the right side.*

**Control Design**

The surface of any frequently used pedals shall be fitted with slip-resistant material.

Normal stereotypes shall apply unless combining or customary usage dictate otherwise. The stereotypes (control/machine movement relationship) should be the same in multi-cab vehicles. Several stereotypes are given in Annex One of the Standard.

Controls should return to neutral on release unless the control of the machine requires detent controls.

For remote control, there should be no hazardous movement on start-up or stop of power supply or engine. There should be no unintended movements from interference.

*Control forces are provided for hand and foot controls. Compared with military data these figures represent quite high levels. Assuming "toe operated" pedals are equivalent to those operated by ankle flexion. The standard gives the maximum at 90 N whereas the Military Specification gives about 44 N. Such differences are apparent for operation of the brake lever (upwards). The standard gives 400 N. This reflects other values but this can only be achieved if the lever is pulled upwards towards the shoulder. It would be inappropriate for an upwards pull at arms length.*

# European Standards Relating to Trackless Vehicles

The following European Standards are presented in order of their BS (British Standard) number. Where equivalent ISO (International Standards Organisation) exists, this is shown in brackets.

**BS EN 292Part 2 1991**. Safety of machinery - Basic concepts and general principles for design

**BS EN 292-2/A1 1995.** Safety of machinery - Basic concepts and general principles for design. Part 2: technical principles and specifications

**BS EN 294 1992.** Safety of machinery - Safety distances to prevent danger zones being reached by the upper limbs

**BS EN 349 1993.** Safety of machinery - Minimum gaps to avoid crushing of part of the human body

**BS EN 418 1992.** Safety of machinery - Emergency stop equipment, functional aspects - Principles for design

**BS EN 474-1 1994.** Earth moving machinery - Safety - Part 1: General requirements (possibly also Parts 2 to 5)

**BS EN 563 1994**. Safety of machinery - Temperatures of touchable surfaces - Ergonomics data to establish temperature limit values for hot surfaces

**BS EN 614-1 1995.** Safety of machinery - Ergonomic design principles - Part 1: terminology and general principles

**BS EN 626-1 1994.** Safety of machinery - Reduction of risks to health from hazardous substances emitted by machinery - Part 1: principles and specifications for machinery manufacturers

**BS EN 791 1995.** Drill rigs - Safety

**BS EN 1037 1995.** Safety of machinery - Prevention of unexpected start-up

**BS EN ISO 6682 1995.** Earth-moving machinery - Zones of comfort and reach for controls. (ISO 6682:1986, including amendment 1:1989)

**BS 6911: Part 5: 1992 (ISO 5006-1): 1991.** Testing earth-moving machinery. Part 5. Determination of operator's field of view

**BS 6912: Part 3: 1990 (ISO 9533: 1989).** Safety of earth-moving machinery. Part 3. Sound test method for machine-mounted forward and reverse warning alarm

**BS 6912: Part 5: 1992 (ISO 2860: 1991).** Safety of earth-moving machinery. Part 5. Recommendations for minimum access dimensions

**BS 6912: Part 12: 1993 (ISO 5006-2).** Safety of earth-moving machinery. Part 12. Evaluation of operator's field of view

**BS6912: Part 13: 1993 (ISO 5006-3).** Safety of earth-moving machinery. Part 13. Acceptance criteria for operator's field of view

**BS 6912: Part 18: 1995 (ISO 12508: 1994).** Safety of earth-moving machinery. Part 18. Specification for bluntness of edges at the operator station and in maintenance areas

**BS 6912: Part 19: 1996 (ISO 11112: 1995).** Safety of earth-moving machinery. Part 19. Specification for dimensions and requirements for operator's seat

**BS 6912: Part 20: 1996 (ISO 10968).** Safety of earth-moving machinery. Part 20. Specification for operator's controls

# Appendix Five

## Summary version and detailed hazard taxonomy for trackless vehicle operation

Three checklists are presented. The first is a top level overview. This is shown in 3.1. The second presents the same information but with more detailed supporting information on potential causal factors. This is shown in 3.2.

A third presents an overview in terms of elements of the tasks. This is shown in 3.3.

## 5.1 Top level vehicle hazard taxonomy

### 5.1.1 Start-up, driving off, vehicle in motion, stopping, parking

**Hazards for the driver (only)**

- Musculoskeletal injuries from priming engine start system
- Musculoskeletal injuries from operating stiff controls
- Musculoskeletal injuries from awkward operating postures
- Driver struck by objects entering cab space
- Driver struck, crushed or trapped against roadway
- Driver struck, crushed or trapped by canopy against object
- Driver struck, crushed or trapped by roof
- Sudden vehicle movement causing driver to strike object in cab
- Driver injured by falling from, or in, cab

**Hazards for passengers (only)**

- Passengers struck by object thrown up by vehicle
- Passengers struck by objects entering passenger area
- Passengers crushed, trapped against roadway
- Passengers thrown about/fall in cabin
- Passengers struck roof
- Passengers travelling on vehicle unapproved for manriding

**Hazards for driver and passenger**

- Contact with hot vehicle surfaces
- Whole body vibration
- Dust, exhaust, noxious fumes
- Heat stress from high ambient temperatures
- Hearing loss from high noise levels
- Not being able to exit cab due to obstruction (incl emergency egress/fire)

**Hazards for pedestrians/other miners**

- Nearby people startled by engine noise on start-up
- Vehicle strikes nearby people
- People injured by electrical cable
- People nearby stuck by falling loads
- People injured on sharp objects on side of vehicle
- People injured by protruding loads or sharp ends of load binders
- People injured by load binders unexpectedly snapping
- People injured by contact with hot vehicle surfaces
- People injured by exposure to hazardous substances on vehicle
- People injured by exposure to hazardous substances used with vehicle

**Hazards for services/items in roadway**

Vehicle strikes critical services, objects or supports in the roadway
Safety consequence through services being disrupted

#### 5.1.1.1 Pre-shift driver checks

**Hazards for the driver (only)**

Unexpected vehicle movement or moving component striking driver
Driver slips/falls from vehicles while performing checks
Electrocution injury
Burns injury
Injury through contact with hazardous substances
Injury through being struck with high pressure water jet (cleaning)
Musculoskeletal injury from lifting heavy/awkward items
Musculoskeletal injury from applying high forces to tools/components
Struck by falling objects

**Hazards for driver, passengers and other miners**

Consequences of pre-shift checks not being performed

#### 5.1.1.2 Entering/ leaving the cab - passenger compartment

**Hazards for the passengers (only)**

Injured from getting on or off moving vehicle
Injured from not boarding/alighting in orderly manner

**Hazards for both driver and passengers**

Strike body on sharp/protruding components
Snag clothing/belt equipment when climbing in/out
Musculoskeletal injuries through adopting awkward postures
Falling and slipping when climbing in/out

**Hazards for pedestrians**

Injured from unexpected vehicle movement

#### 5.1.1.3 Loading & unloading materials

**Hazards for the driver (only)**

Musculoskeletal injuries from lifting/stacking/securing/releasing load
Lacerations from handling loads
Injuries from load falling from vehicle when unsecured

**Hazards for pedestrians**

Injuries from load movement by vehicle striking objects to be loaded
Slip/trip injuries in load area from items on floor
Load tipping when unloaded onto uneven floor
Load tipping by sudden movement during unloading operation

#### 5.1.1.4 Routine maintenance operations (by maintenance crews)

**Hazards for the maintenance worker (only)**

Maintenance staff injured from contact with moving components
Injuries from unexpected vehicle movement or moving component
Injuries from exposure to hazardous chemicals/chemical burns
Burns/scolds
Contact with rotating fan blades
Tyres bursting/exploding

Musculoskeletal injury from lifting heavy/awkward items
Musculoskeletal injury from applying high forces to tools/components
Slipping and falling off vehicle
Injury through being struck with high pressure water jet (cleaning)
Electrocution injury
Struck by falling objects

**Hazards for driver, passengers and other miners**
Consequences of routine maintenance not being undertaken
Consequences of errors made in routine maintenance

#### 5.1.1.5 Other potential hazards

**Hazards for general mine workers**
Injured by vehicle on fire, smoke or fumes
Injured when fire fighting

This is supported by a more comprehensive version.

### 5.1.2 Detailed trackless vehicle hazard taxonomy

#### 5.1.2.1 Start-up, driving off, vehicle in motion, stopping, parking

**Hazards for the driver (only)**
Musculoskeletal injuries from priming engine start system
Musculoskeletal injuries from operating stiff controls
Musculoskeletal injuries from awkward operating postures
- insufficient headroom
- sideways seated postures with head turned
- leaning to gain better vision
- badly located controls
- badly designed controls
- poor seating
    - *sharp edges on top of back rest*
    - *insufficient adjustment*
    - *insufficient lateral support*
    - *insufficient thigh support*
    - *problems accommodating belt worn equipment*

Driver struck by objects entering cab space
- falls of ground

Driver struck, crushed or trapped against roadway
- uneven, sloping or wet floor conditions

Driver struck, crushed or trapped by canopy against object
Driver struck, crushed or trapped by roof
- restricted overhead clearances
- sudden change in overhead clearance
    - *lack of signs warning of clearance problems*
- hanging roof bolts

Sudden vehicle movement causing driver to strike object in cab
- low headroom under canopy
- sharp objects in cab
- collision with other vehicle
    - *poor or ineffective traffic control*

- collision with object in roadway
  - unexpected bump in roadway
Driver injured by falling from, or in, cab

**Hazards for passengers (only)**

Passengers struck by object thrown up by vehicle
Passengers struck by objects entering passenger area
- falls of ground
- moving supplies and men together

Passengers crushed, trapped against roadway
Passengers thrown about/fall in cabin
- failure to remain seated with vehicle in motion
- vehicle in collision with other vehicle or object in roadway
- rough roadway conditions
- sharp edges in cabin
- alcohol or drug abuse

Passengers struck roof
- restricted overhead clearances
- sudden change of overhead clearance

Passengers travelling on vehicle unapproved for manriding

**Hazards for driver and passenger**

Contact with hot vehicle surfaces
Whole body vibration
Dust, exhaust, noxious fumes
Heat stress from high ambient temperatures
Hearing loss from high noise levels
Not being able to exit cab due to obstruction (incl emergency egress/fire)

**Hazards for pedestrians/other miners**

Nearby people startled by engine noise on start-up
Vehicle strikes nearby people
- driver fails to see people in time
  - *view obstructed by brattice etc in roadway*
  - *view obstructed by vehicle load*
  - *view obstructed by vehicle sightlines*
    *Canopy design, headlights, mudguards, covers, instruments, other items on top of vehicle*
  - *dirty vehicle headlights*
  - *inefficient/misaligned headlights*
  - *glare from roadway lights or oncoming vehicles*
  - *poor illumination at junctions/transfer points*
  - *airborne dust*
  - *poor visibility of miners (no reflective clothing etc)*
- fails to stop in time/brake failure/skidding
  - *excessive debris or spillage in roadway*
  - *overloaded vehicle*
- pedestrians fail to hear vehicles
  - *ineffective, or damaged warning devices*
  - *masking of warning by background noise levels*
- pedestrians fail to see vehicles
  - *poor visual acuity*
  - *pedestrians facing other way*
  - *pedestrians attention occupied on other task*
- poor driver behaviour
  - *failure to give warnings when setting off*

- *driving too fast*
- *driving too close to people*
- *operation by inexperienced drivers*

  *lack of safety signs and good labelling; lack of standardised control features, high sickness/absence*
- *failure to stop and let pedestrians by*
- *alcohol or drug abuse*

- unexpected vehicle movement
  - *slide sideways on cross gradient*
  - *wet roadways*
  - *excessive debris or spillage in roadway*

    *poor draining, poor roadway maintenance*
  - *overloaded vehicle*
- run-away vehicle
  - *failure to apply parking brake when leaving vehicle*
  - *failure to position vehicle to run into sides if brakes fail*
  - *lack of, or inefficient, emergency stop device*
  - *leaving vehicle unattended with engine running etc*
- lack of safe working or walking areas
- insufficient or obstructed side clearances
- sharp objects or protruding objects in reach of pedestrians
- lack of safety signs in roadways
- lack of pedestrian control procedures
- poor pedestrian training
  - *turnover leading to many unfamiliar with districts*
- use of defective vehicles

People injured by electrical cable
- slip/tripping hazard
- electrocution hazard
- crush/trap injuries
  - *poor cable control*
  - *poor cable maintenance/inspection*

People nearby stuck by falling loads
- poor vehicle design features to secure loads to
- poor availability of securing materials
- poor procedures for securing loads
- poor training in securing methods

People injured on sharp objects on side of vehicle
People injured by protruding loads or sharp ends of load binders
People injured by load binders unexpectedly snapping
People injured by contact with hot vehicle surfaces
People injured by exposure to hazardous substances on vehicle
People injured by exposure to hazardous substances used with vehicle

**Hazards for services/items in roadway**

Vehicle strikes critical services, objects or supports in the roadway
- poor visibility through small size and contrast
- poor sightlines from vehicles
  - *view obstructed by brattice etc*
  - *view obstructed by vehicle sightlines*

    *Canopy design, headlights, mudguards, covers, instruments, other items on top of vehicle*
  - *dirty vehicle headlights*
  - *inefficient/misaligned headlights*
  - *glare from roadway lights or oncoming vehicles*

- *poor visibility of miners (no reflective clothing etc)*
- poor siting of equipment in roadways
  *high pressure water ranges, electrical cables, communication cables/terminals, roadway supports, conveyors, stone dust and water barriers, monorails, ventilation baggings, fire fighting equipment*
- fails to stop in time/brake failure/skidding
  - *excessive debris or spillage in roadway*
  - *failure to see instruments indicating brake fault*
- poor driver behaviour
  - *driving too fast*
  - *operation by inexperienced drivers*
    *lack of safety signs and good labelling; lack of standardised control features*
- unexpected vehicle movement
  - *slide sideways on cross gradient*
  - *excessive debris or spillage in roadway*
- use of defective vehicles
- run-away vehicle
  - *failure to apply parking brake when leaving vehicle*
  - *failure to position vehicle to run into sides if brakes fail*
  - *lack of, or inefficient, emergency stop device*
- design prone to damage by vehicle contact

Safety consequence through services being disrupted

#### 5.1.2.2 Pre-shift driver checks

**Hazards for the driver (only)**

Unexpected vehicle movement or moving component strikes driver
Driver slips/falls from vehicles while performing checks
Electrocution injury
Burns injury
- contact with ignited vapour
- hot components and fluids
- exploding dust
- steam

Injury through contact with hazardous substances
- failure to wear eye, ear, head, hand protection
- failure to provide appropriate personal protection equipment
  *thinners, hydraulic fluid, diesel fuel, paraffin, acetylene, engine oil, grease, plastic pipe, rope, oxygen, rodol, transmission fluid*

Injury through being struck with high pressure water jet (cleaning)
- stuck by flailing high pressure water hose

Musculoskeletal injury from lifting heavy/awkward items
Musculoskeletal injury from applying high forces to tools/components
Struck by falling objects

**Hazards for driver, passengers and other miners**

Consequences of pre-shift checks not being performed

#### 5.1.2.3 Entering/leaving the cab - passenger compartment

**Hazards for the passengers (only)**

Injured from getting on or off moving vehicle

- poor passenger control

Injured from not boarding/alighting in orderly manner

- poor passenger control

**Hazards for both driver and passengers**

Strike body on sharp/protruding components

Snag clothing/belt equipment when climbing in/out

Musculoskeletal injuries through adopting awkward postures

- restricted access space

Falling and slipping when climbing in/out

**Hazards for pedestrians**

Injured from unexpected vehicle movement

- accidental operation of controls when entering/leaving cab

### 5.1.2.4 Loading & unloading materials

**Hazards for the driver (only)**

Musculoskeletal injuries from lifting/stacking/securing/releasing load

- poor inbye unloading facilities, eg power hoists

Lacerations from handling loads

Injuries from load falling from vehicle when unsecured

**Hazards for pedestrians**

Injuries from load movement by vehicle striking objects to be loaded

Slip/trip injuries in load area from items on floor

Load tipping when unloaded onto uneven floor

Load tipping by sudden movement during unloading operation

### 5.1.2.5 Routine maintenance operations (by maintenance crews)

**Hazards for the maintenance worker (only)**

Maintenance staff injured from contact with moving components

Injuries from unexpected vehicle movement or moving component

Injuries from exposure to hazardous chemicals/chemical burns

- failure to wear eye, ear, head, hand protection
- failure to provide appropriate personal protection equipment

  *thinners, hydraulic fluid, diesel fuel, paraffin, acetylene, engine oil, grease, plastic pipe, rope, oxygen, rodol, transmission fluid*

Burns/scolds

- accidental release of radiator caps
- contact with exhaust system
- contact with ignited vapour
- hot components and fluids
- exploding dust
- steam

Contact with rotating fan blades

Tyres bursting/exploding

Musculoskeletal injury from lifting heavy/awkward items

- handling canopies
- handling cover plates
- handling wheels

Musculoskeletal injury from applying high forces to tools/components

Slipping and falling off vehicle

- removing or replacing covers
- accessing components from top of vehicle

- checking vehicles

Injury through being struck with high pressure water jet (cleaning)

- stuck by flailing high pressure water hose

Electrocution injury

Struck by falling objects

**Hazards for driver, passengers and other miners**

Consequences of routine maintenance not being undertaken

Consequences of errors made in routine maintenance

#### 5.1.2.6 Other potential hazards

**Hazards for general mine workers**

Injured by vehicle on fire, smoke or fumes

Injured when fire fighting

### 5.1.3 Hazard checklist based on task element

#### 5.1.3.1 Pre-shift service checks

- Injured being struck or crushed by unexpected vehicle movement or by moving parts of the vehicle
- Injured through falling or slipping
- Lacerations, abrasions, and impact injuries
- Injuries from electrocution
- Musculoskeletal injuries from heavy lifting
- Musculoskeletal injuries from applying heavy forces
- Burns through contact with ignited vapours, hot components and fluids, exploding dust, steam and noxious chemicals etc.
- Injured through contact with hazardous substances
- Injuries from being struck by jet of high pressure fluid
- Stuck by flailing high pressure water hose (cleaning)
- Struck by falling objects

Note: Subsequent injuries could arise from service checks not being conducted properly.

#### 5.1.3.2 Entering and leaving vehicle cab

- Pedestrians injured through unexpected vehicle movement from accidental operation of controls by driver entering cab
- Falling and slipping

- Injured by striking against components inside cab
- Musculoskeletal injuries from awkward stooping/twisting
- Injured through PPE snagging on items in cab/access route

#### 5.1.3.3 Start up engine

- People nearby startled by unexpected engine noise
- People nearby injured by unexpected machine movement
- Maintenance staff injured through contact with unexpected moving components/energy source
- Musculoskeletal injuries from priming engine start system

#### 5.1.3.4 Driving off

- Vehicle strikes pedestrians and/or maintenance staff
- Vehicle strikes/damages roadway supports
- Vehicle strikes/damages objects in roadway
- Pedestrians struck by objects thrown up in roadway by vehicle
- Driver struck by objects entering cab space
- Driver struck, crushed or trapped by canopy against objects when leaning out of cab
- Driver injured by sudden movement causing to strike against component in cab
- Load shed striking people nearby

#### 5.1.3.5 In motion

The list of hazards should be considered separately for: various conditions of roadway, direction of travel, left and right turns and with vehicle laden and unladen.

- Vehicle strikes people in roadway
- Vehicle strikes critical services in roadway (water, electricity, communications, fire fighting equipment etc.)
- People struck by objects thrown up by tyres
- Driver struck by objects entering the cab
- Driver struck, crushed or trapped by canopy against objects when leaning out of cab
- Driver injured by sudden movement causing to strike against component in cab

- Load shed striking people nearby
- Driver injured falling from/in cab
- Musculoskeletal injures from adopting awkward operating postures and/or frequent changes in operating postures
- Musculoskeletal injures from application of high forces to controls
- Driver injured being thrown against object in cab
- Contact with hot surfaces
- Whole body vibration
- Dust, exhaust and/or noxious fumes
- High ambient temperatures - heat stress
- High noise levels - noise dosage

Risks from not being able to leave cab if vehicle stops/breaksdown near obstacles which inhibit the egress route need to be considered at different points in the roadways.

#### 5.1.3.6 Stopping

- Vehicle strikes people due to inadequate braking performance
- Vehicle strikes objects in roadway or support due to inadequate braking performance
- Sudden stopping causes driver to strike objects within cab
- People struck by falling loads

#### 5.1.3.7 Loading operations

- Vehicle striking objects to be loaded - movement causing injuries
- Slip/trip injuries in area from items on floor
- Musculoskeletal injuries from lifting/stacking load
- Musculoskeletal injuries from securing load with load binders
- Lacerations from handling loads

#### 5.1.3.8 Unloading operations

- Musculoskeletal injuries from releasing load binders
- Injuries from load falling from vehicle when unsecured
- Musculoskeletal injures from unloading heavy items

- Lacerations from handling loads
- Load tipping when unloaded on uneven floor
- Load tipping by sudden movement during unloading operation

#### 5.1.3.9 Parking vehicle

- Vehicle runaway injuring people/driver
- Vehicle runaway damaging key services and supports
- People injured on sharp objects on machine
- People injured by protruding loads or sharp ends of load binders
- People injured by load binders snapping
- Contact with hot surfaces
- Contact with hazardous substances

#### 5.1.3.10 Other periods/general

- Injured when fire fighting
- Consequences of not being able to extinguish fire on vehicle
- Being trapped in vehicle and unable to tackle fire

# Appendix Six

## Underground study methodology

## 6.1 Background

A methodology needed to be developed to study the ergonomics of trackless vehicles in South African mines. Since the project started from an advanced position as a result of previous UK projects, the methodology was developed primarily to address selected areas where the ergonomics of vehicles in South Africa could be expected to differ from those in other countries.

Particular attention was paid to the anthropometrics of the workforce, control and workstation design and layout, labelling, and the sightline requirements of the drivers. Features of the mine layout and methods of working which interact with the vehicle ergonomics were also addressed. A questionnaire was developed for drivers to determine the incidence of musculoskeletal discomfort and any problems experienced by limited vision.

The prototype methodology was applied to two vehicles at Mine A. These studies were undertaken jointly by HSEC Ltd of the UK and Turgis Technology of South Africa. Several aspects of the methodology were refined before other vehicles were evaluated by Turgis Technology at Mines B and C. Finally, two more vehicles were jointly evaluated by HSEC and Turgis Technology at Mine D.

### 6.1.1 Data Collection Packs

Sections 1 & 2

*Initial data collection on the Mine surface*

Section 3

Vehicle static ergonomic assessments

Section 4

Driver interviews

Section 5

Roadway/junction assessments

## SECTION 1 INITIAL INFORMATION ON VEHICLE TYPE, MINE, DISTRICT AND OPERATION

### Part One: Initial Checklist

| | |
|---|---|
| Vehicle Type | |
| Serial Number | |
| Date of study | |
| Mine | |
| District(s) worked | |
| Main function | |
| Other vehicles used by drivers of this vehicle | |

Details of any modifications to:

| | |
|---|---|
| cabs | |
| canopy | |
| controls | |
| covers | |

Details of any visible damage to vehicle

| |
|---|
| |

**Also**: General Arrangement Drawings with Main Dimensions; Photographs of example of vehicles (especially showing cab view); Max Speed, Acceleration and Braking estimates; Location/Type of Headlights; Turning Circle

## Part 2 Details of the actual tasks for which the vehicle is used

***Interview with Vehicle Controller/Supervisor*** (this can be completed on the surface before the study)

1 Superimpose on a map of the district (if applicable) the normal route(s) used by the vehicle. Indicate on this any significant gradients (including cross gradients), any maximum speeds, any obstacles such as air doors which need to be passed.

2 Comment if the vehicle usually operates in a set sequence of operations, or whether there are several routes/activities.

3 Indicate where on the route(s) the vehicles could be in close proximity to pedestrians.

4 Estimate the number of times a driver would typically get in/out of the cab.

5 Obtain details of other vehicles or routes which these drivers could be expected to use under normal circumstances. In particular, if drivers could change driving to operating other vehicle types in a single shift, obtain details of the other vehicles, typical times spent driving each and the nature of the other operations.

6 Determine the mine rules for safe vehicle operation - eg for driving past pedestrians (eg stop and let them walk past before continuing). Also determine if drivers routinely communicate with the supervisor during vehicle operation and if so, how.

7 Obtain details of accidents at the mine involving trackless vehicles: injuries to drivers and pedestrians, accident black spots, 'causes' of these accidents.

8 Finally, obtain information on the training given to drivers: how long is the training, does it extend to underground training, are drivers trained on the exact vehicle they will use, how was training assessed (skills or time based).

If possible, also obtain photographs of the vehicle - to help with the VR simulations.

## SECTION 3 VEHICLE STATIC ERGONOMIC MEASUREMENTS

### Part One: ASSESS VEHICLE SIGHTLINES

Using sitting eye heights of:

5th Percentile 737 mm
95th Percentile 859 mm

This assessment used separate measurements for conventional trackless vehicles (LHD) and shuttle cars.

### For CONVENTIONAL TRACKLESS VEHICLES

**General Visual Attention Areas (VAAs) associated with:**

**1 Starting engine and moving off safely**

The small driver must be able to see a height of at least 1 metre for the primary zones and 1.3 metres in the secondary zones. These are taken at a distance of 0.5 metres from the profile of the vehicle.

| | Primary Zones | | |
|---|---|---|---|
| Secondary Zones | fully met | >50% met | less than 50% |
| fully met | 1 | 4 | 7 |
| +50% met | 2 | 5 | 8 |
| less than 50% | 3 | 6 | 9 |

**2 Normal driving along straight roadways**

The short driver should be able to see obstacles on the floor and sides of the roadway to a height of 0.5 metre above the highest point of the vehicle between 20 and 30 metres from the driving position(s) in both directions. Where the roof can be less than 1 metre above the maximum vehicle height, the tall driver should be able to see the roof at least 20 metre from the driving position across the full width of the roadway in either direction.

| | fully met | >50% met | less than 50% |
|---|---|---|---|
| Roof - worst direction | 1 | 2 | 3 |
| Sides - worst direction | 1 | 2 | 3 |
| Floor - worst direction | 1 | 2 | 3 |

**3 Manoeuvring or cornering - roof area**

A tall driver must, therefore, be able to see sufficient roof either side of the driving position. This is assessed by measuring/estimating the distance above the canopy (h), and the distance (l) between the front edge of the canopy and the closest point at which the roof can be seen across the full width of the roadway. Calculate the value of l/h

| Rear Zone | Travelling forward (load end) | | |
|---|---|---|---|
| | l/h < 4 | l/h < 8 | l/h > 8 |
| l/h < 4 | 1 | 4 | 7 |
| l/h < 8 | 4 | 7 | 8 |
| l/h > 8 | 7 | 8 | 9 |

### 4 Manoeuvring or cornering - roadway side area

Drivers (both short and tall) need to be able to see to manoeuvre past objects which are located in the roadway. They should be able to see side areas of a typical roadway (both to the off side and near side) between the front of the vehicle to a distance 2 metres beyond the vehicle up to a height of 0.5 metres above the highest part of the vehicle.

| Off side | Near side | | |
|---|---|---|---|
| | fully met | >50% met | less than 50% |
| fully met | 1 | 4 | 7 |
| >50% met | 2 | 5 | 8 |
| less than 50% | 3 | 6 | 9 |

### 5 Manoeuvring or cornering - periphery of vehicle

The short driver needs to see the full periphery of the vehicle. The drivers' view must not, therefore, be obstructed by items located on top of the vehicle. Primary and secondary zones are used (see criteria 1).

| Secondary Zones | Primary Zones | | |
|---|---|---|---|
| | fully met | >50% met | less than 50% |
| fully met | 1 | 4 | 7 |
| >50% met | 2 | 5 | 8 |
| less than 50% | 3 | 6 | 9 |

Where the nature of the vehicle inevitably results in large areas where it would be impractical to see the periphery of the vehicle a line can be projected across the gap and the assessment made to this notional line.

### 6 Manoeuvring or cornering - obstacles/pedestrians directly ahead

The short driver needs to see the floor at least 3 metres in front of the vehicle in either direction to a width 1 metre either side of the vehicle.

| | Front zone (load end) | | |
|---|---|---|---|
| Rear zone | fully met | >50% met | less than 50% |
| fully met | 1 | 4 | 7 |
| >50% met | 4 | 7 | 8 |
| less than 50% | 7 | 8 | 9 |

**For Supplies or LHD vehicles only: (Complete 7, 8 and 9)**
**For Manriding vehicles only: (Complete 10)**

### 7 Manoeuvring or cornering - fully laden - roof area

Where the roof clearances above loads can be less/equal to 1 metre the tall driver should be able to see:

(i) the full area of the roof between the leading edge of the load up to a distance 2 metres in front of the load

(ii) the full width of the roof above the load

| | fully met | >50% met | less than 50% |
|---|---|---|---|
| zone (i) | 1 | 2 | 4 |
| zone (ii) | 1 | 2 | 4 |

### 8 Manoeuvring or cornering - fully laden - roadway side area

Both tall and short drivers should be able to see the space between the sides of the load and up to a distance of 2 metres in front of the load to a distance 1 metre behind the load. This space should be visible up to 0.5 metres from the sides of the load and up to a height of at least 0.1 metres above the load.

| | Near side | | |
|---|---|---|---|
| Off side | fully met | >50% met | less than 50% |
| fully met | 1 | 4 | 7 |
| >50% met | 2 | 5 | 8 |
| less than 50% | 3 | 6 | 9 |

### 9 Safe loading and unloading of supplies/materials

The short driver needs to see both sides of a flat bed platform or bucket from the leading corners back a distance of 0.5 metres towards the driver.

| | Near side | | |
|---|---|---|---|
| Off side | fully met | >50% met | less than 50% |
| fully met | 1 | 4 | 7 |
| >50% met | 2 | 5 | 8 |
| less than 50% | 3 | 6 | 9 |

**For Manriding vehicles:**

### 10 Safe boarding and alighting of passengers

Short drivers need to see all access/egress openings and all opening where passengers could lean out and become injured.

| | Checking passengers are aboard | |
|---|---|---|
| Monitoring passengers are fully inside cabins when travelling | All access openings easily visible (or doors fitted) | Unable to easily see all access openings |
| Able to monitor all openings (or non available) | 1 | 7 |
| Unable to monitor all openings | 7 | 9 |

## For SHUTTLE CARS

Sightlines are assessed separately from both seating positions. Forwards is defined in this methodology as driving in the direction with the cab at the front. Reverse is driving with the cab at the rear. Shuttle cars therefore drive forward fully loaded to the discharging points and reverse to the loading point/continuous miner.

### 1 Starting and moving off safely

The small driver must be able to see a height of at least 1 metre for the primary zones and 1.3 metres in the secondary zones measured only to a point ahead of the drivers eye position. These zones are taken at a distance of 0.5 metres from the profile of the vehicle.

**FORWARDS - Assessed with vehicle fully loaded**

| | FORWARD PRIMARY ZONE | | |
|---|---|---|---|
| SECONDARY ZONE | fully met | >50% | <50% |
| fully met | 1 | 4 | 7 |
| > 50% | 2 | 5 | 8 |
| < 50% | 3 | 6 | 9 |

**REVERSE - Assessed with vehicle empty**

| | REVERSE PRIMARY ZONE | | |
|---|---|---|---|
| SECONDARY ZONE | fully met | >50% | <50% |
| fully met | 1 | 4 | 7 |
| > 50% | 2 | 5 | 8 |
| < 50% | 3 | 6 | 9 |

### 2 Normal driving along straight roadways

The short driver should be able to see obstacles on the floor and sides up to a height 0.5 metres above the highest point of the vehicle (not the load) between 20 and 30 metres from the driving position(s) in both directions. Where the roof may be less than 1 metre above the maximum height of the vehicle, the tall driver should be able to see the roof at least 20 metres from the driving position across the full width of the roadway in either direction.

**FORWARDS - Assessed with vehicle fully loaded**

| | fully met | >50% | <50% |
|---|---|---|---|
| roof | 1 | 2 | 3 |
| sides | 1 | 2 | 3 |
| floor | 1 | 2 | 3 |

**REVERSE - Assessed with vehicle empty**

| | fully met | >50% | <50% |
|---|---|---|---|
| roof | 1 | 2 | 3 |
| sides | 1 | 2 | 3 |
| floor | 1 | 2 | 3 |

### 3 Manoeuvring or cornering - roof area

A tall driver must be able to see sufficient roof when driving in both the forwards and reverse directions. This is assessed by measuring/estimating the distance above the canopy (h) and the distance between the leading edge of the canopy and the closest point on the roof at which the roof can be seen across the full width of the roadway (l).

The value of l/h is calculated.

**FORWARDS - Assessed with vehicle fully loaded**

| | |
|---|---|
| l/h < 4 | 1 |
| l/h < 8 | 5 |
| l/h > 8 | 9 |

**REVERSE - Assessed with vehicle empty**

| | |
|---|---|
| l/h < 4 | 1 |
| l/h < 8 | 5 |
| l/h > 8 | 9 |

### 4 Manoeuvring or cornering - roadway side area

Drivers (both tall and short) should be able to see the sides of the typical roadway (both to the off side and near side) between the front of the vehicle to a distance 2 metres beyond the vehicle up to a height of 0.5 metres above the highest part of the vehicle.

**FORWARDS - Assessed with vehicle fully loaded**

| | NEAR SIDE | | |
|---|---|---|---|
| OFF SIDE | fully met | >50% | <50% |
| fully met | 1 | 4 | 7 |
| > 50% | 2 | 5 | 8 |
| < 50% | 3 | 6 | 9 |

**REVERSE - Assessed with vehicle empty**

| | NEAR SIDE | | |
|---|---|---|---|
| OFF SIDE | fully met | >50% | <50% |
| fully met | 1 | 4 | 7 |
| > 50% | 2 | 5 | 8 |
| < 50% | 3 | 6 | 9 |

**5 Manoeuvring or cornering - periphery of the vehicle**

Short drivers must be able to see the full periphery of the vehicle ahead of the eye position in each driving position. Primary and secondary zones are used (see criteria 1). A line is drawn above the conveyor at each end of the vehicle at a height of the top edges of the sides of the vehicle. It is only necessary to see this line and not the conveyor ends.

**FORWARDS - Assessed with vehicle fully loaded**

| | FORWARD PRIMARY ZONE | | |
|---|---|---|---|
| SECONDARY ZONE | fully met | >50% | <50% |
| fully met | 1 | 4 | 7 |
| > 50% | 2 | 5 | 8 |
| < 50% | 3 | 6 | 9 |

**REVERSE - Assessed with vehicle empty**

| | REVERSE PRIMARY ZONE | | |
|---|---|---|---|
| SECONDARY ZONE | fully met | >50% | <50% |
| fully met | 1 | 4 | 7 |
| > 50% | 2 | 5 | 8 |
| < 50% | 3 | 6 | 9 |

**6 Manoeuvring or cornering - obstacles/pedestrians directly ahead**

The short driver needs to see the floor at least 3 metres in front of the vehicle when travelling in either direction to a width of 1 metre either side of the vehicle.

**FORWARDS - Assessed with vehicle fully loaded**

| | |
|---|---|
| fully met | 1 |
| > 50% | 5 |
| < 50% | 9 |

**REVERSE - Assessed with vehicle empty**

| | |
|---|---|
| fully met | 1 |
| > 50% | 5 |
| < 50% | 9 |

## Part Two: DETAILS OF VEHICLE FEATURES

This section uses a collection of checklists and worksheets and enables a revised operability index to be developed and completed by HSEC. It does not automatically rely on previous criteria but where necessary attempts to obtain further subjective assessment of the drivers and assessors which may influence the final criteria recommended.

### Ergonomic Checklist for Trackless Vehicles

| | | |
|---|---|---|
| f3 | DRIVER PROTECTION | |
| 1 | can a driver lean and place his head outside the profile of the vehicle? | YES ?? NO |
| 2 | are there sharp objects in the cab which could injure a driver jolted against them? | if YES note/sketch sharp object(s) |
| 3 | is driver at risk of being thrown from the cab if the vehicle suddenly stops? | YES ?? NO |
| 4 | does the canopy protect all parts of the driver's body? | YES ?? NO |
| 5 | could the canopy uprights trap the driver's head against objects in the roadway? | YES ?? NO |
| 6 | is seat to canopy less than 1050mm, or is it possible to lower the canopy below 1050 mm above seat squab? | YES ?? NO |
| 7 | can the driver reach and operate a fire extinguisher from the cab? | YES ?? NO |
| 8 | can the driver operate the vehicle from a position other than sat in the cab? | YES ?? NO |
| 9 | if applicable - is a mechanical device provided to prevent vehicle articulation during maintenance etc? | YES ?? NO |
| f4 | ACCESS & EGRESS FACILITIES | |
| 1a | is there sufficient legroom during access/egress to the cab? | YES ?? NO |
| 1b | is there sufficient body room for large operators to climb in and out of the vehicle? | YES ?? NO |
| 2 | what is the cab floor to under canopy height? | below canopy ht: ________mm |
| 3 | what is the height from roadway floor to the first step? | first step ht :__________mm |
| 4 | if applicable - what is the height to the bottom of the lowest hand hold? | lower hold: __________mm |

| | | |
|---|---|---|
| 5 | if applicable - what is the height to the top of the highest hand hold? | highest hold: ________mm |
| 6 | can a full closed grasp be made on all hand holds? | YES ?? NO |
| 7 | can full ball of the foot be placed on any foot holds? | YES ?? NO |
| | if 4 to 7 not applicable - sketch/make note of any improvised hand holds | |
| 8 | does the driver need to hold onto the canopy while swinging himself in? | YES ?? NO |
| 9 | are all doors and latches (if fitted) easy to reach and operate to open and shut? | YES ?? NO |
| 10 | do drivers have to stand on the seat to gain access? | YES ?? NO |
| 11 | could a driver accidentally catch and operate a control during access or egress? | if YES which controls and what could happen |
| 12 | are there any projections which could snag on clothing or cap lamp cable during access/egress? | If YES describe |
| 13 | is a second means of egress available should the normal access route become blocked? | YES ?? NO |
| f10 | MACHINE LIGHTING | |
| 1 | do lights illuminate the outer corners of the FSV? | YES ?? NO |
| 2 | where applicable - do lights illuminate the articulation area? | YES ?? NO |
| 3 | how many spot lights are there in each direction?<br>how many flood lights are there in each direction? | number of spots: _______<br>number of floods: _______ |
| 4 | do lights illuminate the floor and sides down to at least 5 metres in front of the vehicle in either direction? | YES ?? NO |
| 5 | do the light covers unduly restrict light output or restrict the cleaning of the glass? | YES ?? NO |
| 6 | are the alignment of the lights easy to adjust? | YES ?? NO |
| 7 | where applicable - is lighting provided to aid loading and unloading operations? | YES ?? NO |
| 8 | where applicable - will large loads obscure significant parts of the lighting? | YES ?? NO |

| | | |
|---|---|---|
| 9 | are any significant areas of driver vision in shadows cast by vehicle lights | YES ?? NO |
| 10 | estimate the distance at which a miner not wearing reflective clothing could be reliably seen using only the machine lights | seeing distance: ________ m |
| f11 | ENVIRONMENT | |
| 1 | do the noise levels from the vehicle require the driver to use hearing protection? | YES ?? NO |
| 2 | are drivers located close to any loud noise source on the vehicle? | if YES give source |
| 3 | where applicable - do the noise levels impede spoken communications with the driver - including using radio? | YES ?? NO |
| 4 | are any surfaces which the driver is in contact with uncomfortably hot to touch? | YES ?? NO |
| 5 | do cooling fans etc. force hot air towards the drivers? | YES ?? NO |
| f12 | WARNING SYSTEMS | |
| 1 | are horns or other auditory warnings likely to be effective in background noise and for people wearing hearing protection? | YES ?? NO |
| 2 | could the vehicle horn be confused by pedestrians for other warnings? | YES ?? NO |
| 3 | could reverse warnings startle people close to the vehicle or tempt people to mute the warning? | YES ?? NO |
| 4 | do reverse warnings solely rely on changes of colour of the lights? | YES ?? NO |
| f9 | SEATING - see also workspace chart | |
| 1 | does seating design provide good back support for drivers wearing of cap lamp battery and self rescuer? | YES ?? NO |
| 2 | for sideways seated driving positions, does the workspace and/or seating design restrict rotation of the trunk? | YES ?? NO |
| f5 | CONTROL/DISPLAY LOCATION - see 2nd pack | |
| 1 | are the clearances around all controls sufficient for unimpeded selection and operation? | YES ?? NO |
| 2 | are emergency stop facilities located at each corner of the vehicle? | YES ?? NO |
| 3 | are appropriate controls functionally grouped? | YES ?? NO |

| | | | | |
|---|---|---|---|---|
| 4 | are appropriate controls sequentially grouped? | YES | ?? | NO |
| | OTHERS | | | |
| 1 | where applicable - does the driver receive sufficient prior warning before a diesel engine shuts down through overheating, or a battery vehicle runs too low on power? | YES | ?? | NO |
| 2 | are all labels designed and located so as not to become covered by dirt or easily damaged? | YES | ?? | NO |
| 3 | are all emergency devices labelled in red? | YES | ?? | NO |

## FOOT PEDALS

* IF LARGE SHOE/BOOT LIKELY TO HAVE PROBLEMS OPERATING PEDALS
** measured between adjacent pedals or to objects to side/front/back of pedal
*** T - top, B - bottom, R - rear

| | Operation by: | | | * Min Clearanc e | Hinge d T/B/R | Non slip |
|---|---|---|---|---|---|---|
| PEDAL | LF | RF | either | ** mm | *** | Y/N |
| Accelerator | | | | | | |
| Brake | | | | | | |
| In Position Pedal | | | | | | |
| Other Pedal | | | | | | |

Are pedals easy to operate if ankle flexion is restricted due to high boots? Y/N

Are there problems moving quickly from accelerator to brake? Y/N
if YES give details

Is the footwell generally clear of objects? Y/N

Will the footwell remain well drained and clear of mud/dirt? Y/N

## PEDAL LOCATION: Complete dimensions

| | a | b | c | * l/r |
|---|---|---|---|---|
| Accelerator | | | | |
| Brake | | | | |
| In Position Pedal | | | | |
| Other Pedal | | | | |

• l - left, r - right

All dimensions from SRP (in as found position) to centre of pedals.

If seat is adjustable estimate the movement range up/down and fore/aft from the 'as found' position.

## DRIVER SEATING & POSTURE

Sketch showing shapes of squab and backrest - in particular curve of backrest and shape of top edge of backrest.

| **SEATING** | | |
|---|---|---|
| Squab | SRP above cab floor<br>width at front<br>width at rear<br>depth (SRP to front) | |
| Backrest | SRP to top of backrest<br>SRP to bottom of backrest<br>width at top<br>width at bottom | |
| Angles | squab tilt - estimate<br>backrest tilt - estimate | |
| Padding | thickness in squab<br>thickness in backrest | |
| Seat Condition | good condition<br>slight damage<br>moderate damage<br>severe damage | |
| Seat Adjustment from as found SRP | SRP to max forward<br>SRP to max rear<br>SRP to max raise<br>SRP to max lower | |
| **POSTURE** | | |
| Trunk Twist to side(s) | none<br>medium<br>severe | |
| Trunk Support | none<br>lumbar region<br>mid back | |
| Head Rotation | mainly ahead<br>moderate turning to side(s)<br>extreme turning to side(s)<br>moderate held<br>extreme held | |

## WORKSPACE - WORKPLACE LAYOUT

Sketch (not to scale) plan and side elevation showing approximate location of the seat and all controls and gauges. Also show location of any canopy supports in relation to the seat.

Sketch Plan

Sketch Side

Key:

| | | | |
|---|---|---|---|
| Controls | C1 | Gauges | G1 |
| | C2 | | G2 |
| | C3 | | G3 |
| | C4 | | G4 |
| | C5 | | G5 |
| | C6 | | G6 |
| | C7 | | G7 |
| | C8 | Pedals | P1 |
| | C9 | | P2 |
| | C10 | | P3 |

## SECTION 4 DRIVER QUESTIONNAIRES

### Details of the drivers problems and discomfort

Driver questionnaire:

### Part One: Determine typical sites and severity of postural discomfort for 2 - 3 drivers

Show each driver Diagram 1 - explain the different body parts. Say you want to know if he has any aches and pains after driving this vehicle for a shift.

Ask: "At the end of a shift have you any aches or pains?" If YES

"Please indicate on this diagram the part (or parts) of your body which gives you the most discomfort" - record body zone(s) in 'first region(s)'

Difficulties with languages may affect this section. Two options are available. Either ask the driver to estimate how much discomfort he feels on the scale at the foot of the Diagram. You will read out the options. Record his response in the 'first region(s)'. Alternatively, ask him to describe the discomfort and you decide which scale best fits his description.

Ask him again, "apart from the ...first body region(s)..are there any other parts of your body where you have any aches or pains at the end of a shift?" If YES repeat and enter body region(s) and estimate of discomfort in 'second region(s)'.

(This rating should be less than the first - check: if not ask if they are about the same)

Repeat process a maximum of one final time.

**Part Two: Driver Questionnaire**

**Aim:** to determine driver views on a number of health and safety factors:
*- stress you are not recording his name, this is not a test, we want you views to help us make better machines in the future*

Vehicle Type: ____________________

*Ask:*

Is your view from the driving position sometimes restricted? Yes No

*if yes:*

What do you have most difficulty in seeing?

______________________________ ______________________________

______________________________ ______________________________

Do you think there is enough light to see to drive safely? Yes No

Do you find the driving position comfortable? Yes No

Do you drive this type of vehicle most of the time? Yes No

*if no: end survey*

How long have you been driving at the mine? ________

Did you receive training on this type of vehicle? Yes No

*if yes:*

How many weeks did you spend training? ________

When did you last receive training? ________

Did your training cover:

inspection of vehicle at the start of the shift? Yes No

safety of people walking or working in the roadway? Yes No

Is your vehicle fitted with a brake pressure gauge? Yes No

*if yes:*

What is the minimum pressure before you should set off? ________

What is the maximum speed you should travel at? ________

For diesel vehicles only:

How often do you get the flame trap changed? ________

How often do you get the conditioner box refilled? ________

Do you do these jobs yourself? Yes No

For LHDs only:

How often do you carry passengers on this vehicle? ________

DIAGRAM 1

*A manakin drawing is shown with different body parts numbered. Drivers indicate the body parts giving discomfort*

**Estimate of Discomfort** ( to be classified by assessor after interview)
0 No discomfort - *definitely no discomfort*
1 Little discomfort - *usually only minor inconvenience - not long lasting*
2 Moderate discomfort - *usually not long lasting and only after long periods driving*
3 Great discomfort - *very uncomfortable - often for most of shift & long lasting*
4 Severe discomfort - *very painful - often builds up quickly & is felt between shifts*

**Machine:**

| | Body Region(s) | Discomfort Level(s) |
|---|---|---|
| First Region(s) | | |
| Second Region(s) | | |
| Final Region(s) | | |

## SECTION 5 ROADWAY/JUNCTION ASSESSMENTS

### Details of the roadway features where the vehicle travels

Walk roadway used (where possible/practical) and determine roadways and junctions with particular risk. Select a Maximum of 5 locations - For each:

Sketch in side/plan details sufficient from reproduction using VR application. The sketch should include the following (where applicable):

- dimensions (size and shape)
- gradients - estimate if necessary
- corners/radius - estimate if necessary
- fixed illumination (type, locations) - show bright/dark spots if apparent
- objects hung from walls
- objects hung from roof
- objects on floor
- sign posts (size, colours, wording, position etc)
- refuge hole locations

Also obtain an indication of:

- pedestrian movement (route, numbers at peak times, etc)
- pedestrian clothing worn (esp details of reflective strips - locations)

Complete the following checklists for each location

Roadway/Junction:

| GENERAL HAZARDS | Added Risk - select high/medium or low |
|---|---|
| Typical clearances to the sides and top | High - less than 0.5 m<br>Medium - between 0.5 and 1.0 m<br>Low - more than 1.0 m |
| Clearances: worst case on route to sides and top | High - less than 0.3 m<br>Medium - between 0.7 m and 0.3 m<br>Low - greater than 0.7 m |
| Proximity of floor debris & general house keeping standards | High - general untidiness in some parts<br>Medium - objects always neatly stacked at side<br>Low - no objects at all allowed in roadway |
| Amount of vehicle running time per shift | High - more than 5 hours on a typical shift<br>Medium - between 1 hour and 5 hours a shift<br>Low - less than 1 hour a typical shift |
| Familiarity of drivers to the roadway | High - drivers regularly travel unfamiliar routes<br>Medium - drivers occasionally travel unfamiliar routes<br>Low - drivers almost never travel unfamiliar routes |
| Number of bends/corners in the typical journey | High - more than 10 junctions/bends<br>Medium - up to 10 junctions per journey<br>Low - no sharp junctions/bends |
| General level of fixed roadway lighting | Medium - no roadway lighting<br>Low - good standard of lighting in roadways |
| Illumination of junctions, transfer points, etc | High - no lighting in some/all junctions<br>Medium - all lit but to variable standards<br>Low - good standard of lighting at all junctions<br>Low - not applicable |
| Effectiveness of machine lighting | High - poor standard/maintenance or non fitted<br>Medium - use of single spot or flood types only<br>Low - maintained spot and flood combinations<br>Low - general mine lighting throughout journey |
| Effectiveness of cap lamp lighting within acceptable postures | High - VAAs not lit by cap lamp<br>Medium - VAAs only lit by extreme head postures<br>Low - VAAs close to machine easily illuminated<br>Low - general mine lighting throughout journey |
| Restrictions on the movement of pedestrians in vehicle areas | High - free and regular access to FSV routes<br>Medium - most areas controlled<br>Low - total controlled absence of people<br><br>if Low disregard Hazard G2 - see later |
| Use of high visibility clothing | Medium - none used or rarely used<br>Low - compulsory wearing of reflective clothing |
| Visibility of obstacles in roadway - use of reflective paints/notices etc | Medium - non used or rarely used<br>Low - routine use and maintenance of job aids |
| Warning notices of local hazards in roadways | Medium - none used or rarely used<br>Low - routine use and maintenance of job aids |

The final rating should be used to determine risk of sightline hazards G1 to G7

Roadway/Junction:

| **MANRIDING HAZARDS** | Added Risk |
|---|---|
| Restrictions in cabins to keep passengers within profile of the manriding pod | High - very open sides & cramped conditions<br>Medium - very open sides OR cramped conditions<br>Low - barriers or doors fitted and always used<br><br>**IF LOW then ignore the following factors** |
| Typical clearances to sides and top | High - less than 0.5 m<br>Medium - between 0.5 and 2.0 m |
| Clearances worst case to sides and top | High - less than 0.3 m<br>Medium - greater than 0.3 m |
| Proximity of floor debris & general house keeping | High - general untidiness in some parts<br>Medium - objects always neatly stacked at sides |
| Familiarity of drivers to the roadways | High - drivers regularly travel unfamiliar routes<br>Medium - drivers occasionally travel unfamiliar routes |
| General level of fixed roadway lighting | Medium - no roadway lighting |
| Illumination at junctions, boarding stations | High - no lighting at all/some areas<br>Medium - variable standards but all lit |
| Effectiveness of machine mounted lights | High - poor standard or maintenance or non fitted<br>Medium - single type of spot/flood lamps only |
| Effectiveness of cap lamp lighting within acceptable postures | High - VAAs not lit by cap lamp<br>Medium - VAAs only lit by extreme head postures |
| Visibility of obstacles in roadway - use of reflective paints/notices etc | Medium - none used/rarely used |
| Warning notices of local hazards in roadways | Medium - none used/rarely used |

Roadway/Junction:

| SUPPLIES HAZARDS: | Added Risk |
|---|---|
| Congestion at loading/unloading points | High - close proximity or objects<br>Medium - variable standards<br>Low - free from objects/clutter |
| Condition of floor | High - no controls & chance of debris piles on floor<br>Medium - occasional floor clutter, piles, holes<br>Low - floor always clear and level |
| Load carried at the rear | High - for most/all of journey<br>Medium - for small part of journey only<br>Low - always carried at the front |
| Familiarity with load carried | High - large variability in load types and sizes<br>Medium - some variability in load types and sizes<br>Low - standardised loads always carried |
| Containment of loads | High -loads protrude in front of vehicle > 1 metre<br>Medium - loads protrude in front of vehicle < 1 metre<br>Low - loads always contained within profile |
| Size of loads (worst cases) | High - wider than vehicle & higher than eye height<br>Medium - wider than vehicle or higher than eye height<br>Low - no wide or high loads carried |

Roadway/Junction

| SHUTTLE CAR & LHD HAZARDS | Added Risk |
|---|---|
| Pedestrian access around vehicle | High - necessary & frequent access around vehicle<br>Medium - access limited and controlled<br>Low - access never required operationally |
| Familiarisation of vehicle operating cycle | High - people unfamiliar sometimes present<br>Medium - people with limited familiarity present<br>Low - only experienced team members present |
| Proximity of other manual operations | High - operations regularly near vehicle route<br>Medium - other operations occasionally near machine<br>Low - no other operations near vehicle |

# Appendix Seven

## Virtual reality in design appraisal

## 7.1 Introduction

This work was aimed at using virtual reality (VR) to assess the driver sightline implications of various driver positions during underground shuttlecar operations.

### 7.1.1 Methodology

A computerised VR representation of a junction in a room and pillar operation was built and used as a testbed for a variety of analyses. The configuration was built on the information provided by HSEC Ltd. A medium height JOY shuttle car was used for this evaluation.

The simulation allowed a number of scenarios to be tested. These included 4 main situations all of which were based on a vehicle travelling towards and round a junction turning to the left;

| | |
|---|---|
| View 1 | Cab on front right - vehicle turning left |
| View 2 | Cab on back right - vehicle turning left |
| View 3 | Cab on back left - vehicle turning left |
| View 4 | Cab on front left - vehicle turning left |

Due to the effects of symmetry, these four configurations effectively allow any turning situation to be simulated. For example, the sightline restrictions for situation View 1 for a right turn would effectively be that for situation View 4 for a left turn.

The simulation broke the travel path of the shuttlecar into a number of frames. Each frame represented a distance of travel of approximately 0.25m. Thus in the simulation, frames 0-20 represent the vehicle travelling towards the junction in a straight line, frames 21-70 represent the turning manoeuvre whilst frames 71-100 represent the vehicle travelling away from the junction in a straight line.

#### 7.1.1.1 The visibility analysis

Each frame in the simulation was assessed for a visibility rating based on a matrix approach. A matrix of points was set up around the shuttlecar in plan at a spacing of 0.5m. For each point on the matrix a visibility value was calculated using a line-of-sight test. The basis of this test involved the following stages:

1. The viewpoint of the driver is defined in 3 dimensional space.

2. A test point is defined at ground level for a matrix point.

3. A line of sight test is carried out to see if the driver can see the test point. Obstruction due to the vehicle structure or mine wall will result in failure of the test.

4. If the line of sight test fails then the test point is raised by 0.1m and step 3 is repeated. If the test is successful (i.e. the test point can be seen) then the value of the test point height is stored for that matrix position.

At the end of the test a matrix of minimum visible heights is produced for that frame.

Once a simulation has been carried out and the matrix visibility produced, there is a post processing option which is used to obtain an index of visibility for that frame. This involves calculating the percentage of matrix heights around the vehicle that are above a reference height. Thus a value of 15% for a reference height of 1.0m means that 15% of a horizontal plane 1.0m above the floor can be seen from the drivers' eye position.

Graphs can then be plotted for a given configuration of scenario and driver position. From these graphs it is possible to obtain a quantitative estimate of the relative improvement/reduction in visibility for changes in driver viewpoint.

#### 7.1.1.2 The VR interface

The VR interface allows the user to visualise the results of various analyses freely and intuitively. In particular the following options are available:

- The user can view a scenario from the viewpoint of the driver.
- The user can view a scenario from the viewpoint of a pedestrian miner
- The user can view a scenario from a floating viewpoint.
- Matrix results can be visualised as vertical colour coded 3 dimensional bars. The bars are colour coded based on the minimum visible height. Green equates to high visibility, yellow equates to medium visibility and red to low visibility.

### 7.1.2 Results

From each view, graphs were produced of the percentage of near space around the vehicle which could be seen by a small driver of the floor level (taken as 0.1.m above ground), 0.3 metres above floor level, 1 metre above floor level (chest and head of small miner in a stooped position), and 1.3 metres above floor level (head of a small miner in a stooped position). Studies have shown that reliable visibility of mineworkers around trackless vehicles is achieved if the chest and head are visible but that fairly good detection is achievable if only the head/helmet are visible (see main report).

Each graph shows the percentage visible as the shuttle car manoeuvres a bend with results from 5 different driver eye positions being shown. The lowest eye position represents the current vehicle being examined. This eye height represented that of the small driver sat on the seat. This was 1.0 metres above the floor of the cab. This eye height was then raised to 1.2 metres and 1.3 metres above the floor to determine the visibility improvements from practical increases in cab or seat height. Two further eye positions were also examined. These were at the 1.2 m and 1.3 m heights but with the eye points 0.5 metres further out. This represents the eye point if the cab was extended outwards by 0.5 metres (feasible without compromising the turning circle) or if the driver leant out by this amount (feasible if the cab design and safety considerations permitted).

Each graph sheet allows a comparison to be made between different eye point positions. In particular it is possible to identify how moving the eye point position can;

- Increase or decrease visibility on the viewing horizon

- Bring forward or push back the point of maximum visibility

The graphs are shown in Figures 7.1 to 7.16.

The results are summarised below for two critical viewing planes; the view at floor level (important for seeing and avoiding obstacles on the floor) and the view at 1.3 metres (the height at which a standing mineworker would be detected in most situations). These results are summarised only for the vehicle manoeuvring in the corner - ie. from frame 21 to frame 70.

***Table 7.3.1***
***Summary of sightlines to ground level***

| **Sightline Condition** | | **View 1** | **View 4** | **View 2** | **View 3** |
|---|---|---|---|---|---|
| % of floor area visible at the manoeuvre frame with the best visibility | standard driver eye height | 20 | 43 | 2 | 1 |
| | eye height raised 20 cm | 22 | 52 | 3 | 6 |
| | as above + moving out 50 cm | 24 | 57 | 4 | 8 |
| | eye height raised 30 cm | 23 | # | 4 | 5 |
| | as above + moving out 50 cm | 24 | 66 | 4 | 8 |
| % of manoeuvre with no floor surface visible | standard driver eye height | 28 | 6 | 52 | 86 |
| | eye height raised 20 cm | 12 | 0 | 34 | 40 |
| | as above + moving out 50 cm | 2 | 0 | 14 | 40 |
| | eye height raised 30 cm | 6 | 0 | 26 | 62 |
| | as above + moving out 50 cm | 2 | 0 | 14 | 38 |
| % of manoeuvre with 50% or more floor area visible | standard driver eye height | 0 | 0 | 0 | 0 |
| | eye height raised 20 cm | 0 | 7 | 0 | 0 |
| | as above + moving out 50 cm | 0 | 17 | 0 | 0 |
| | eye height raised 30 cm | 0 | # | 0 | 0 |
| | as above + moving out 50 cm | 0 | 19 | 0 | 0 |

(# it was not possible to obtain these figures)

*Table 7.3.2*
*Summary of sightlines to 1.3 metres above floor level*

| Sightline Condition | | View 1 | View 4 | View 2 | View 3 |
|---|---|---|---|---|---|
| % of area 1.3 m above floor visible at the manoeuvre frame with best visibility | standard driver eye height | 36 | 45 | 2 | 8 |
| | eye height raised 20 cm | 50 | 65 | 13 | 11 |
| | as above + moving out 50 cm | 50 | 66 | 17 | 15 |
| | eye height raised 30 cm | 57 | | 14 | 11 |
| | as above + moving out 50 cm | 65 | 75 | 16 | 15 |
| % of manoeuvre with no surface 1.3 above floor visible | standard driver eye height | 30 | 26 | 52 | 44 |
| | eye height raised 20 cm | 0 | 0 | 20 | 26 |
| | as above + moving out 50 cm | 0 | 0 | 12 | 38 |
| | eye height raised 30 cm | 0 | 0 | 12 | 26 |
| | as above + moving out 50 cm | 0 | 0 | 10 | 38 |
| % of manoeuvre with 50% or more area visible at a height of 1.3 m | standard driver eye height | 0 | 0 | 0 | 0 |
| | eye height raised 20 cm | 1 | 31 | 0 | 0 |
| | as above + moving out 50 cm | 1 | 33 | 0 | 0 |
| | eye height raised 30 cm | 16 | | 0 | 0 |
| | as above + moving out 50 cm | 28 | 40 | 0 | 0 |

## 7.1.3 Conclusions

The following general conclusions can be drawn from the trends in these graphs.

### 7.1.3.1 Viewing the head of the small standing mineworker ( 1.3 m viewing plane)

The maximum visibility of 75% is obtained when the cab is at the front and on the inside of the turn and when the eye position was raised by 30 cm and when the driver's eye position was also moved outwards by 50 cm. The maximum visibility when the cab is at the back right and with the standard eye height is much reduced at only 2 %.

Increasing the drivers viewing height by 30 cm appears to give a worthwhile increase in maximum visibility, but only when driving from the leading end of the shuttle car. It also brings forward the timing of maximum visibility by up to 10 frames. This equates to approximately 2.5 metres of advance warning in the best case. This figure can be used, in conjunction with the speed of travel, to provide an estimate of increased reaction time available to drivers.

Moving the cab outwards by 50 cm, or allowing the drivers to lean out by this amount, gives less improvement in sightlines.

The most favourable sightline improvement results from a combination of a viewing height increase of 30 cm and the eye point moved out by 0.5 m. This combination increases the maximum vision at the point of the best sightline in a corner by about 30% when driving from the leading cab but only up to 18% when driving from the rear cab.

It is therefore concluded that worthwhile improvements to the drivers' vision are achievable by practical increases in the height of the driver's seat (and, if necessary the canopy), and also in extending the cab outwards from the vehicle. Nevertheless, even the adoption of these retrofit changes will not give sightlines without risk to mineworkers in the vicinity of the vehicles.

#### 7.1.3.2 Viewing floor level

As expected, vision to the floor is not as good as vision to a plane 1.3 m above the floor. Unfortunately, the best combinations of raising the eye point and moving the eye point outwards give negligible increases in vision (typically 4%) when the cab is on the outside of a bend. The improvement increases slightly to 8% when the driving position is at the rear on the inside of a bend. A sizeable improvement of 23% is only achieved when the leading cab is located on the inside of a bend where drivers' vision is noticeable better than in the other 3 conditions anyway.

These modifications are unlikely to produce significant benefits for the driver for viewing the roadway floor.

#### 7.1.3.3 Overall conclusions

The gains in sightlines from these two practical measures (raising the eye height and extending the cab outwards) are disappointing. While it is recommended that they be adopted where feasible they will not, by themselves, satisfactorily remove the risks to mineworkers in the vicinity of trackless vehicles.

Further research should address the benefits of fitting close circuit televison to improve vision when shuttle cars are being reversed.

Further research should also address the practicality of using radio sensors carried by mineworkers to automatically stop shuttle cars if they come into close proximity to the vehicles.

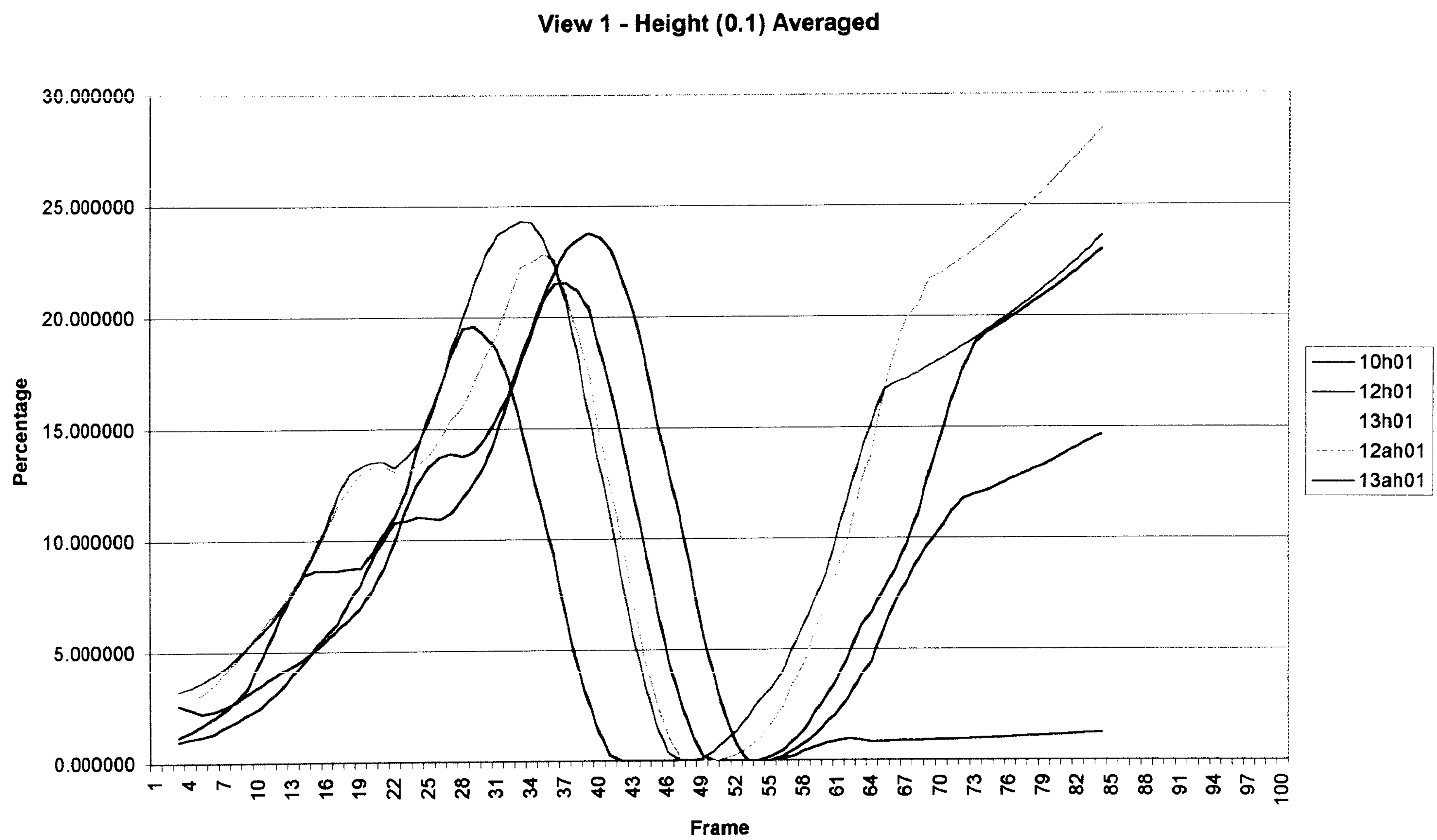


*Figure 7.1 Cab on front right - vehicle turning left - view at floor level*

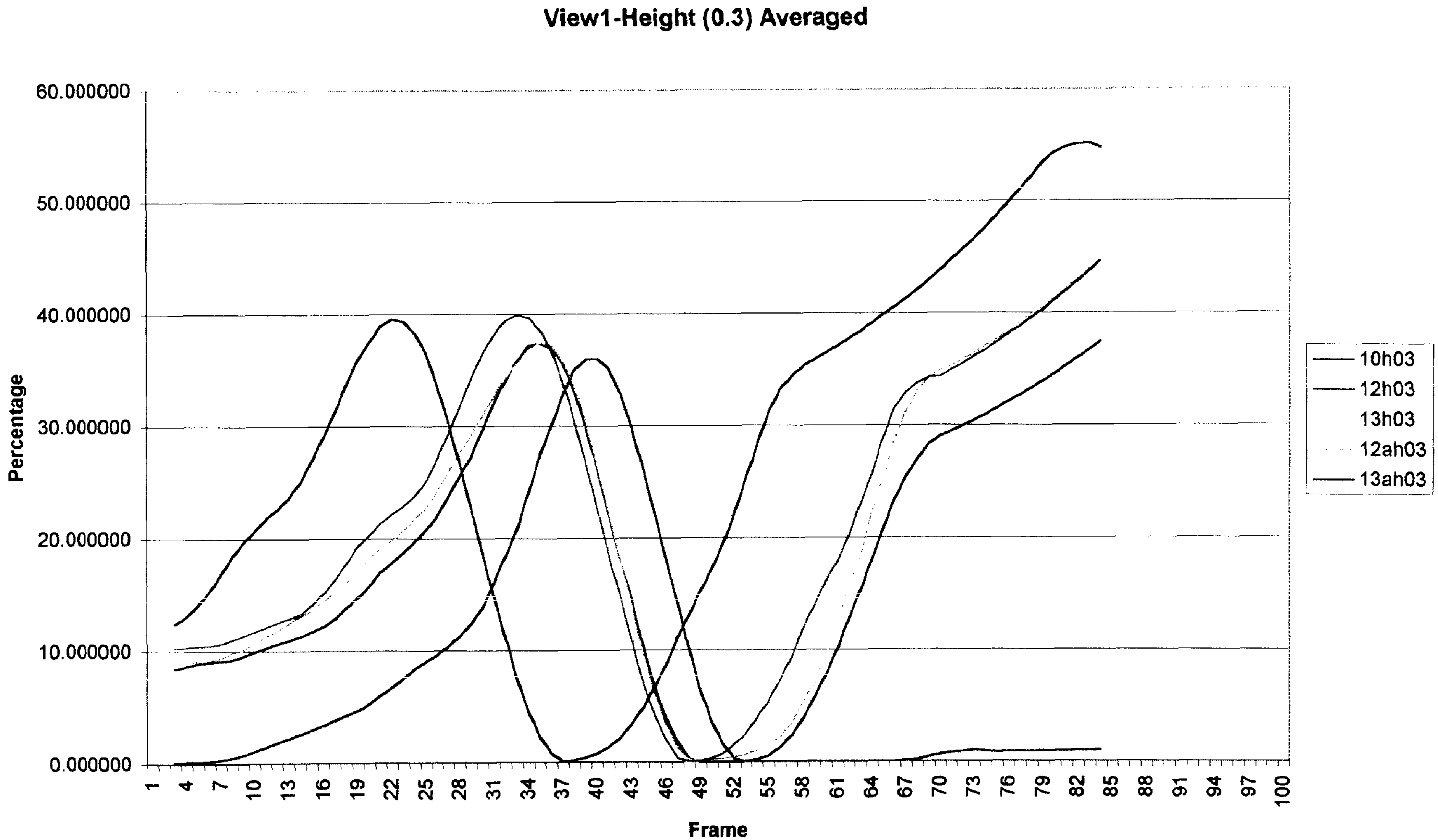


*Figure 7.2 Cab on front right - vehicle turning left - view at 0.3 m above floor*

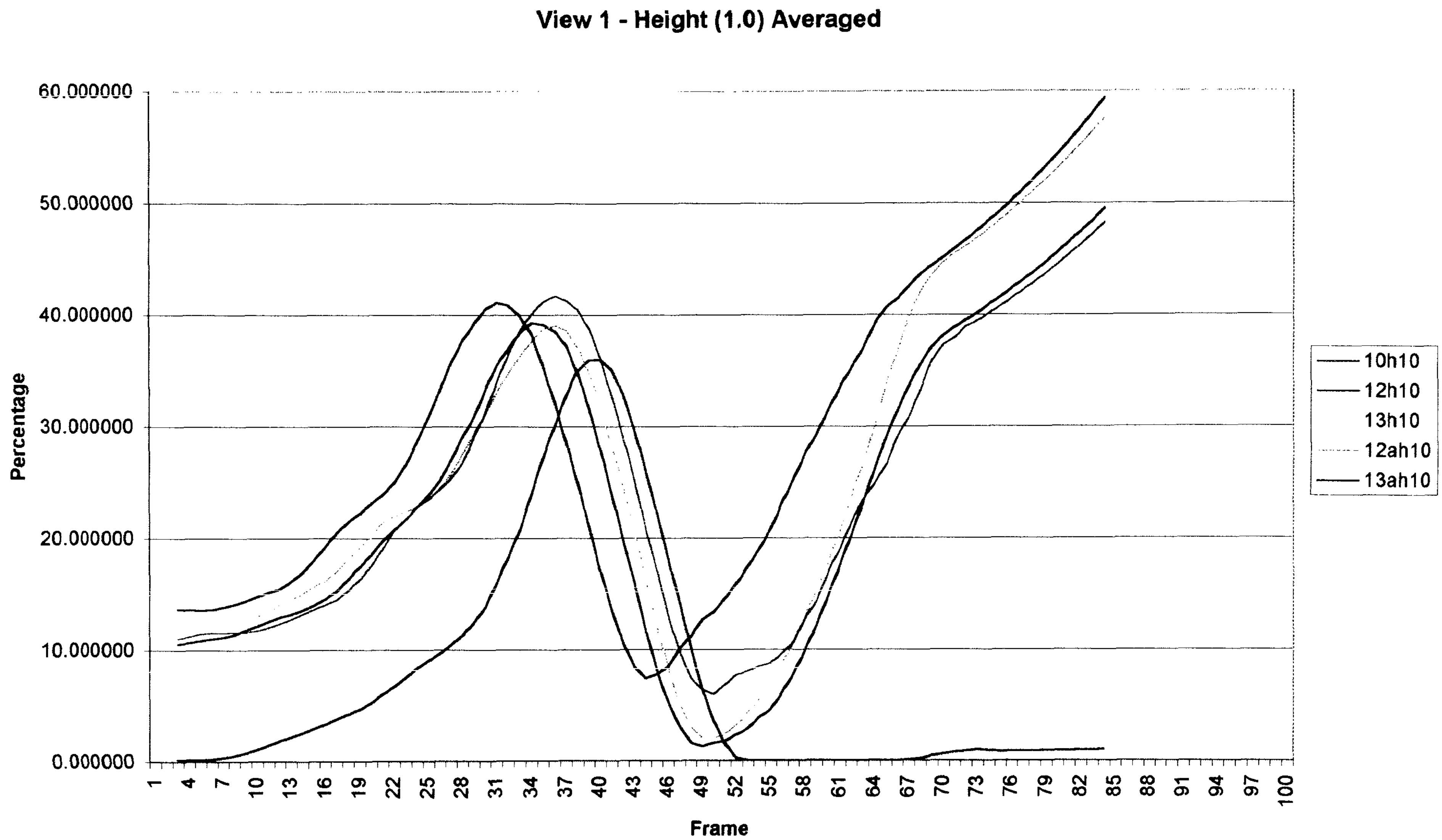


*Figure 7.3 Cab on front right - vehicle turning left - view at 1 m above floor*

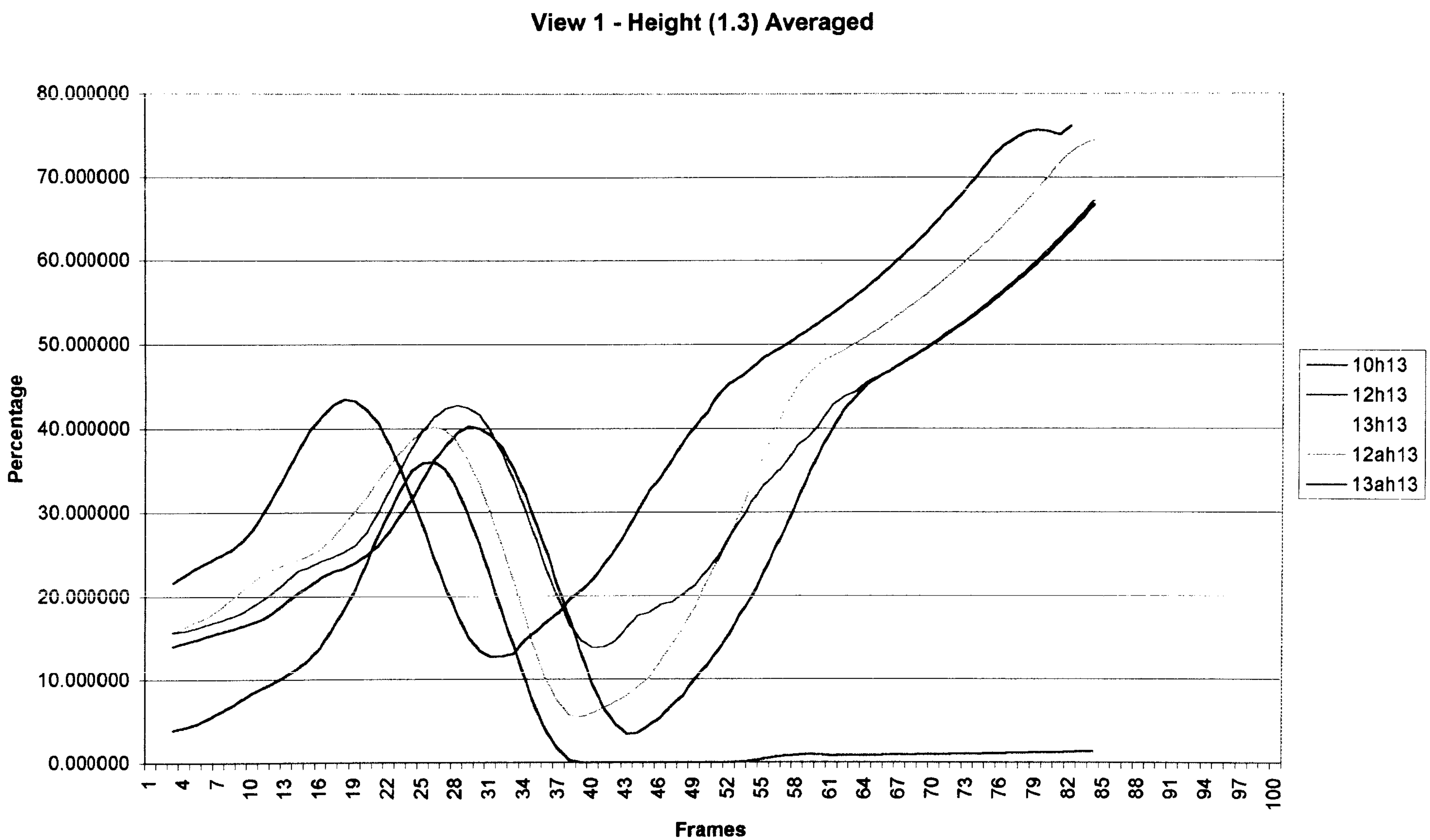


*Figure 7.4 Cab on front right - vehicle turning left - view at 1.3 m above floor*

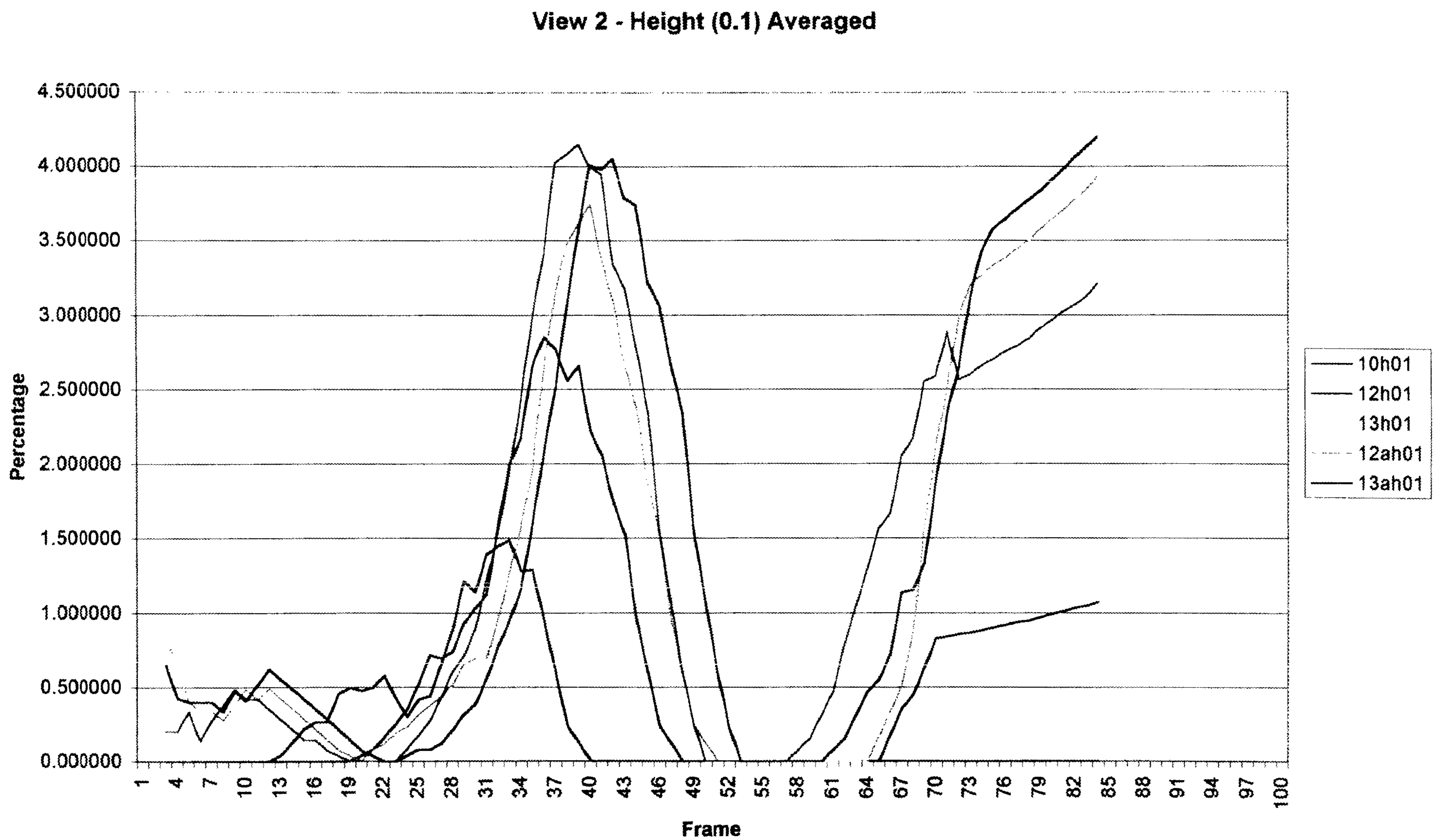


*Figure 7.5 Cab on back right - vehicle turning left - view at floor level*

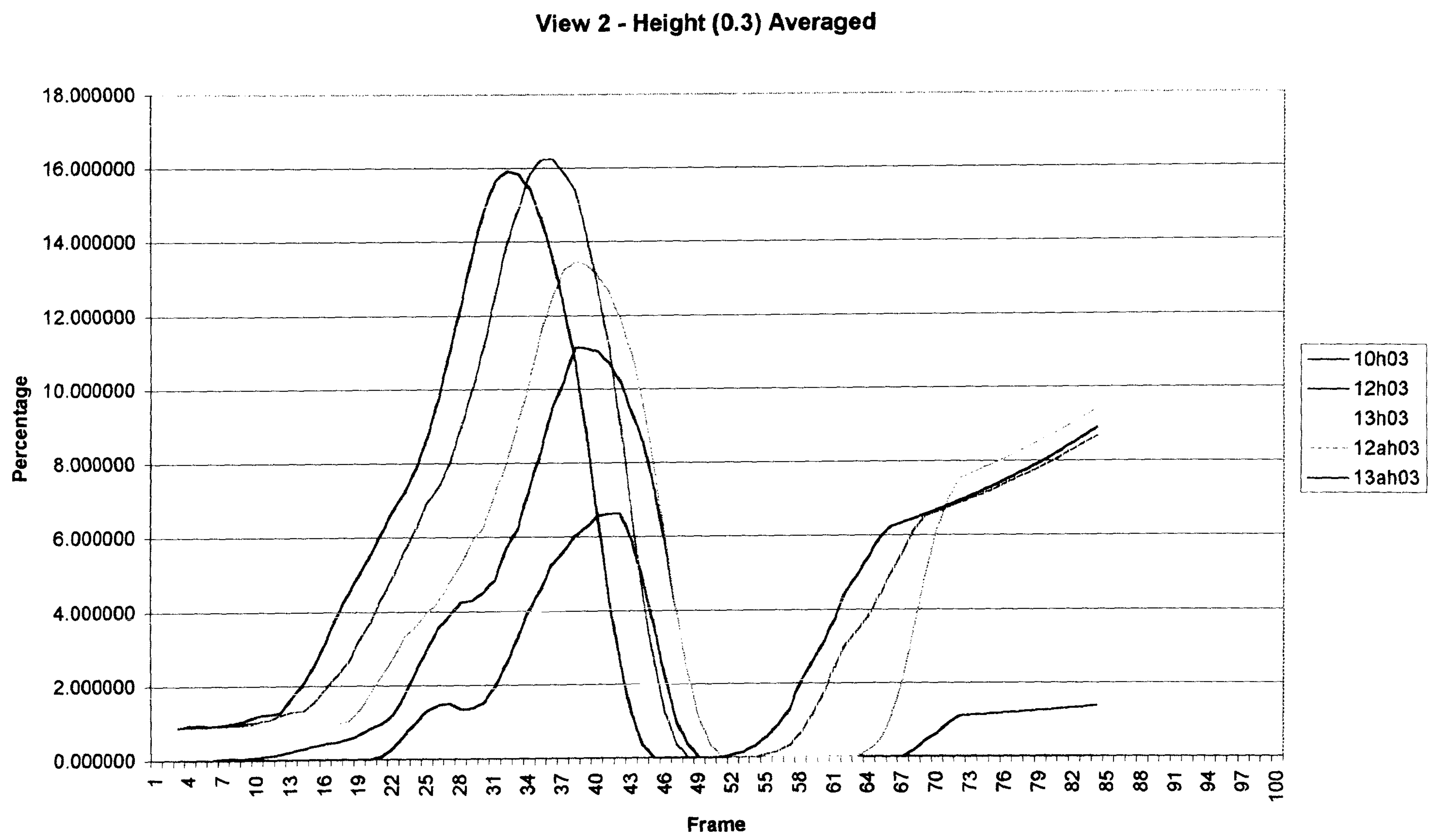


*Figure 7.6 Cab on back right - vehicle turning left - view at 0.3 m above floor*

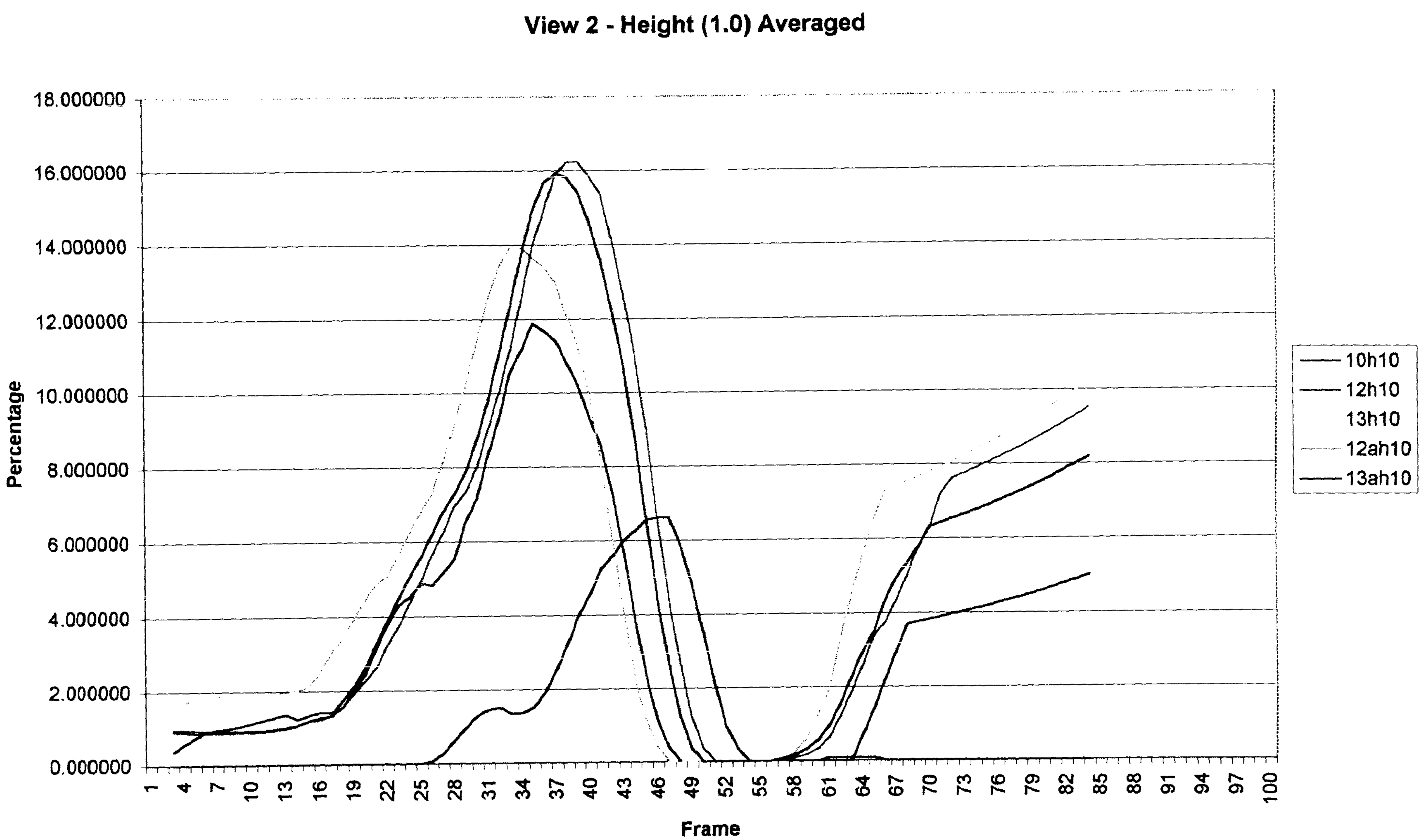


*Figure 7.7 Cab on back right - vehicle turning left - view at 1 m above floor*

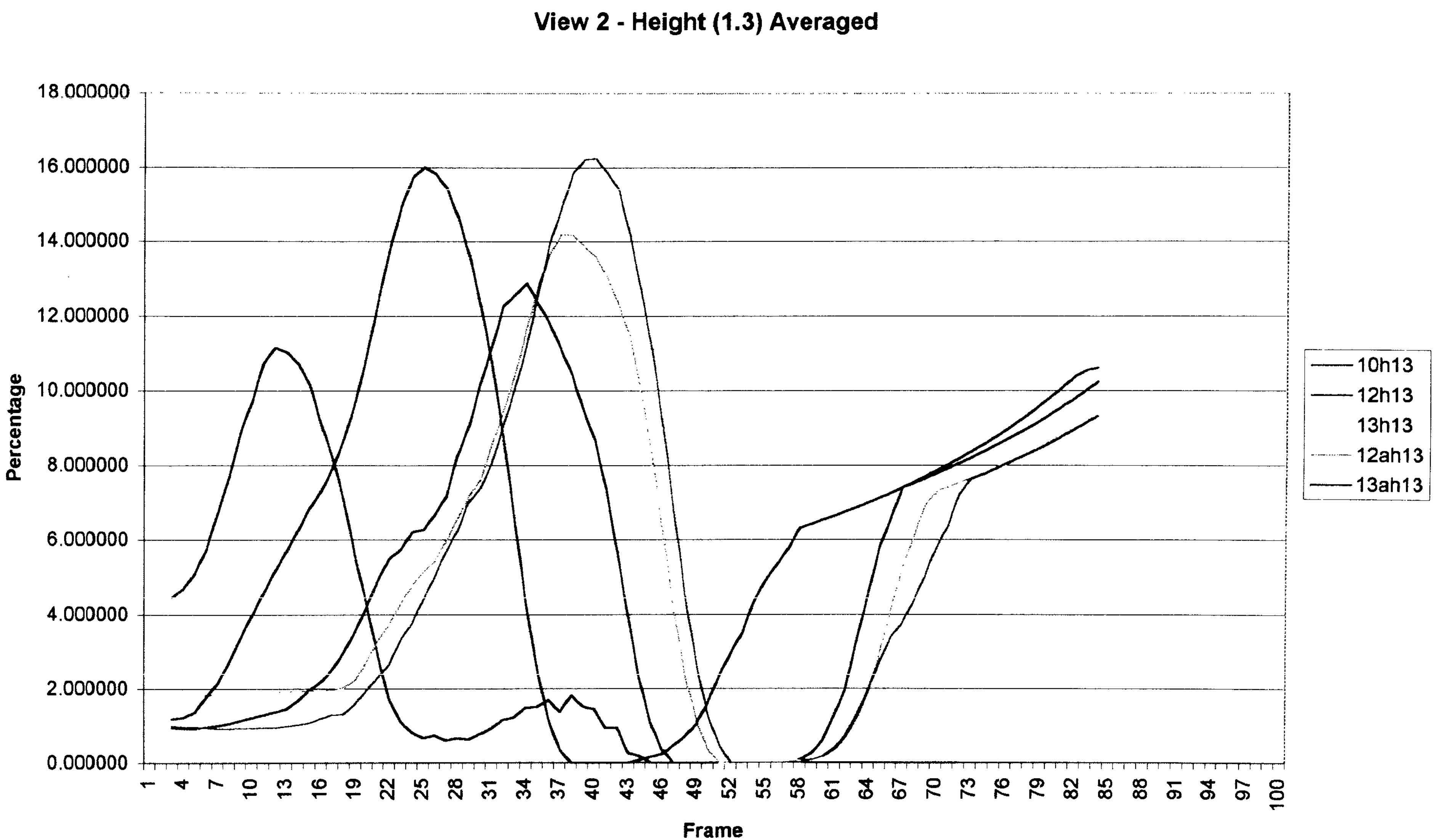


*Figure 7.8 Cab on back right - vehicle turning left - view at 1.3 m above floor*

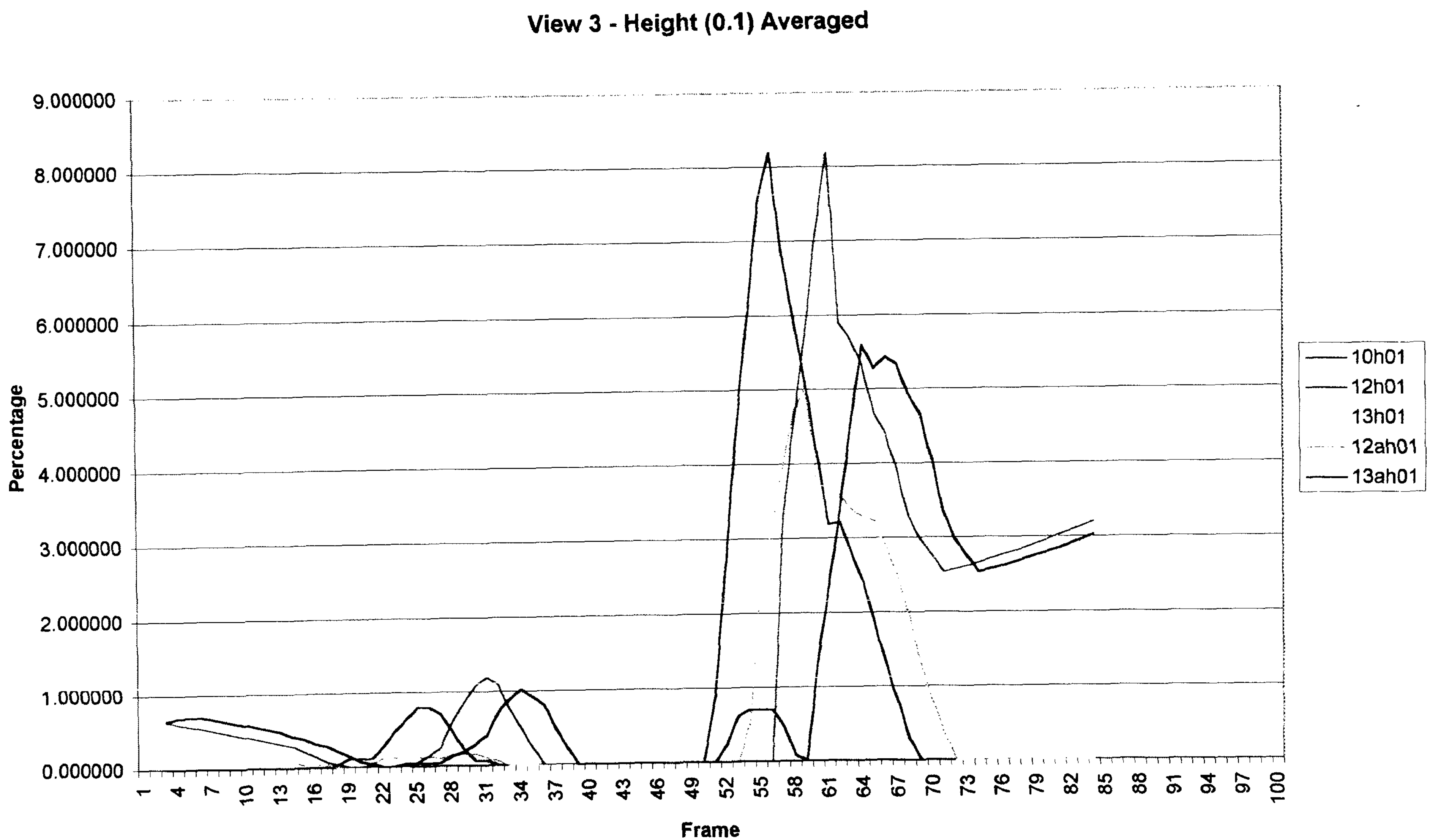


*Figure 7.9 Cab on back left - vehicle turning left - view at floor level*

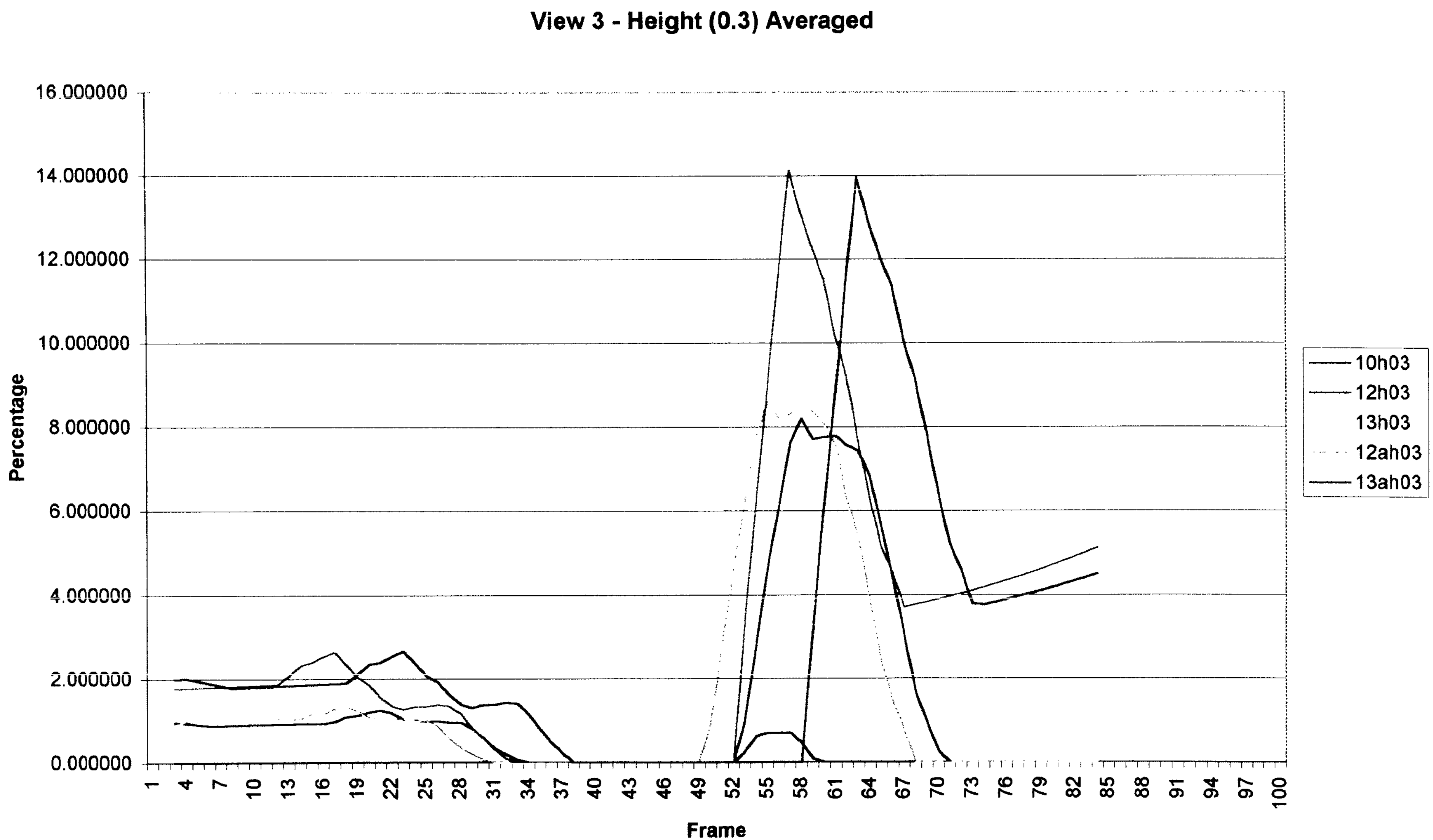


*Figure 7.10 Cab on back left - vehicle turning left - view at 0.3 m above floor*

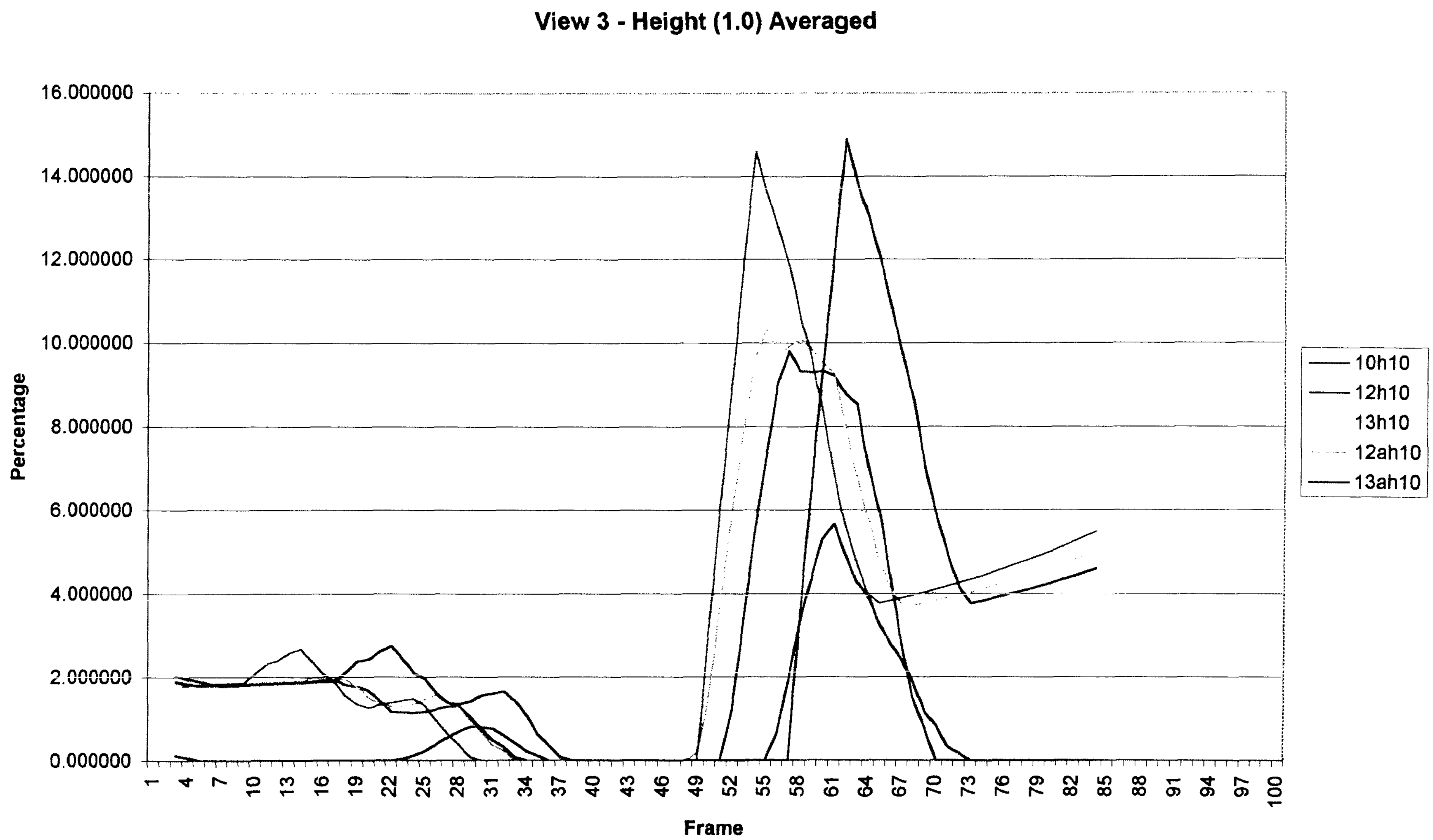


*Figure 7.11 Cab on back left - vehicle turning left - view at 1 m above floor*

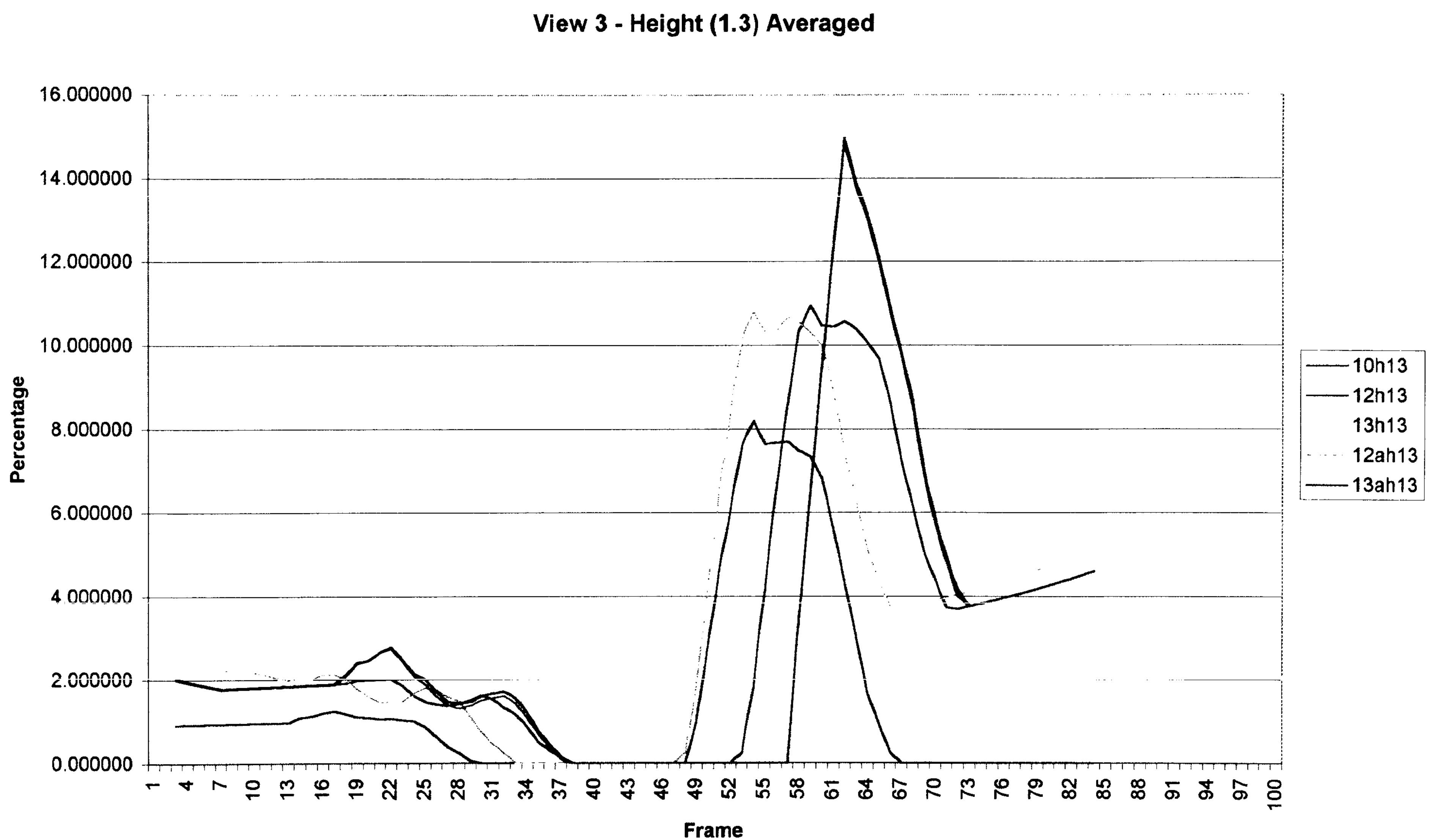


*Figure 7.12 Cab on back left - vehicle turning left - view at 1.3 m above floor*

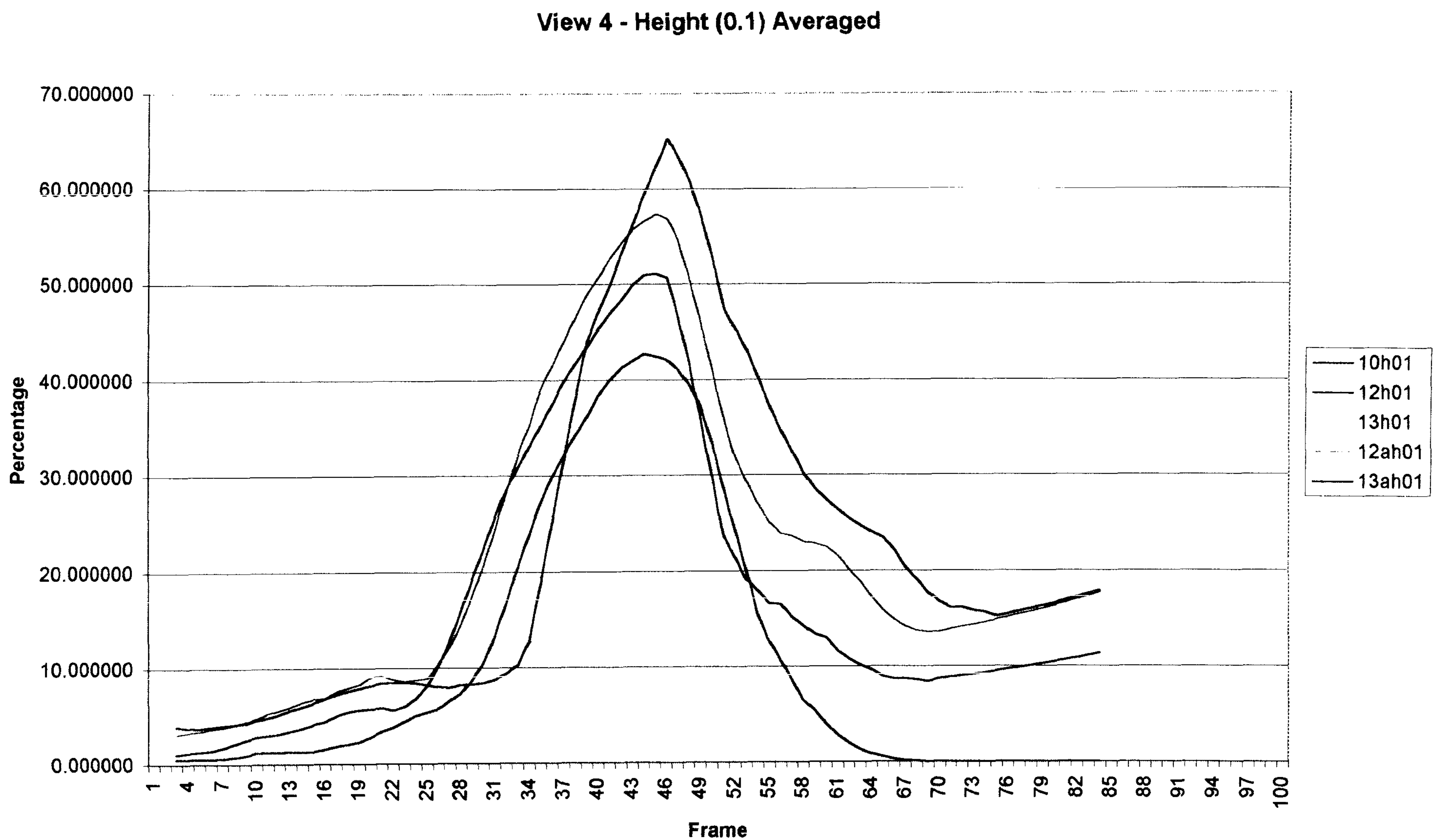


*Figure 7.13 Cab on front left - vehicle turning left - view at floor level*

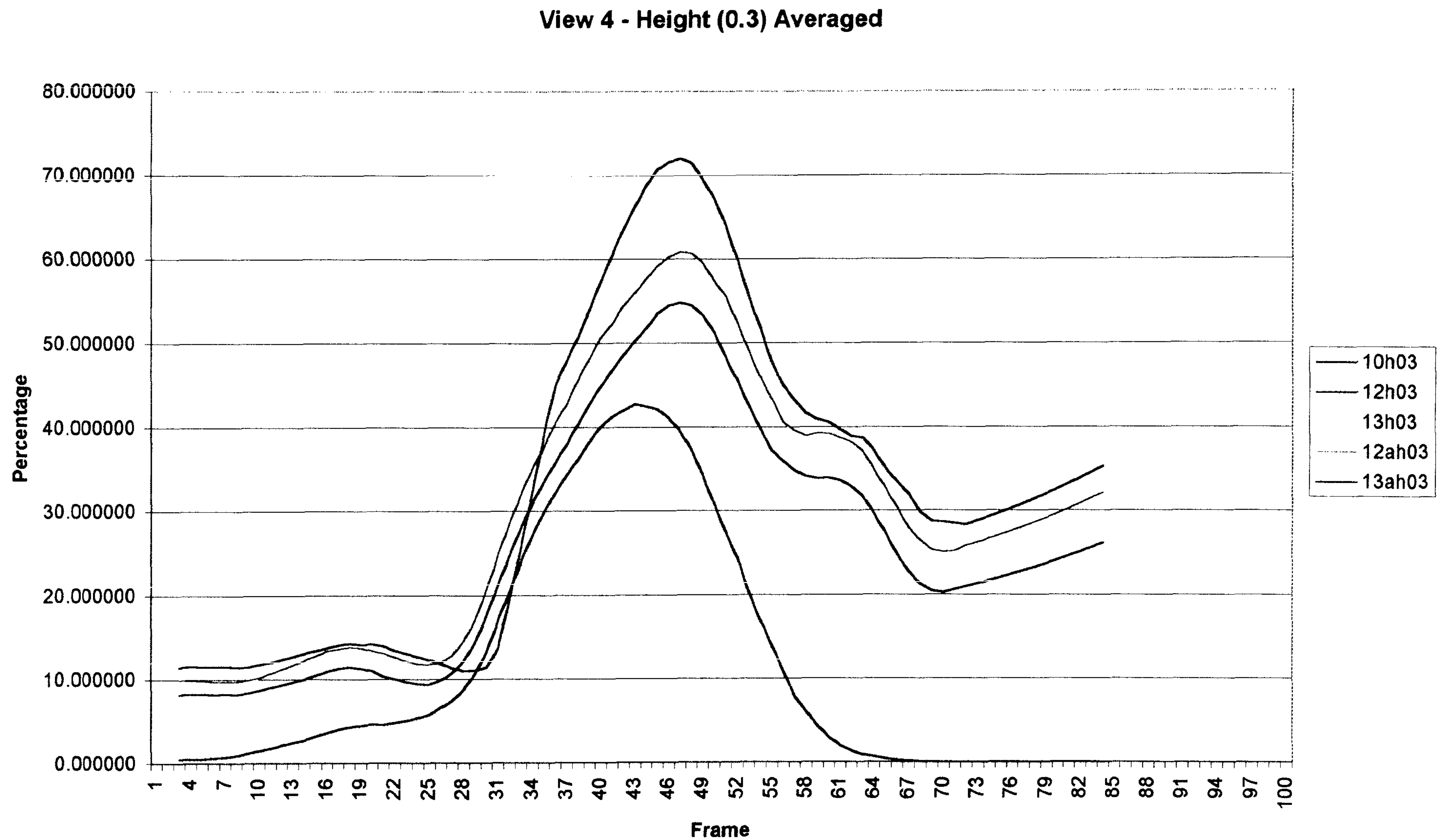


*Figure 7.14 Cab on front left - vehicle turning left - view at 0.3 m above floor*

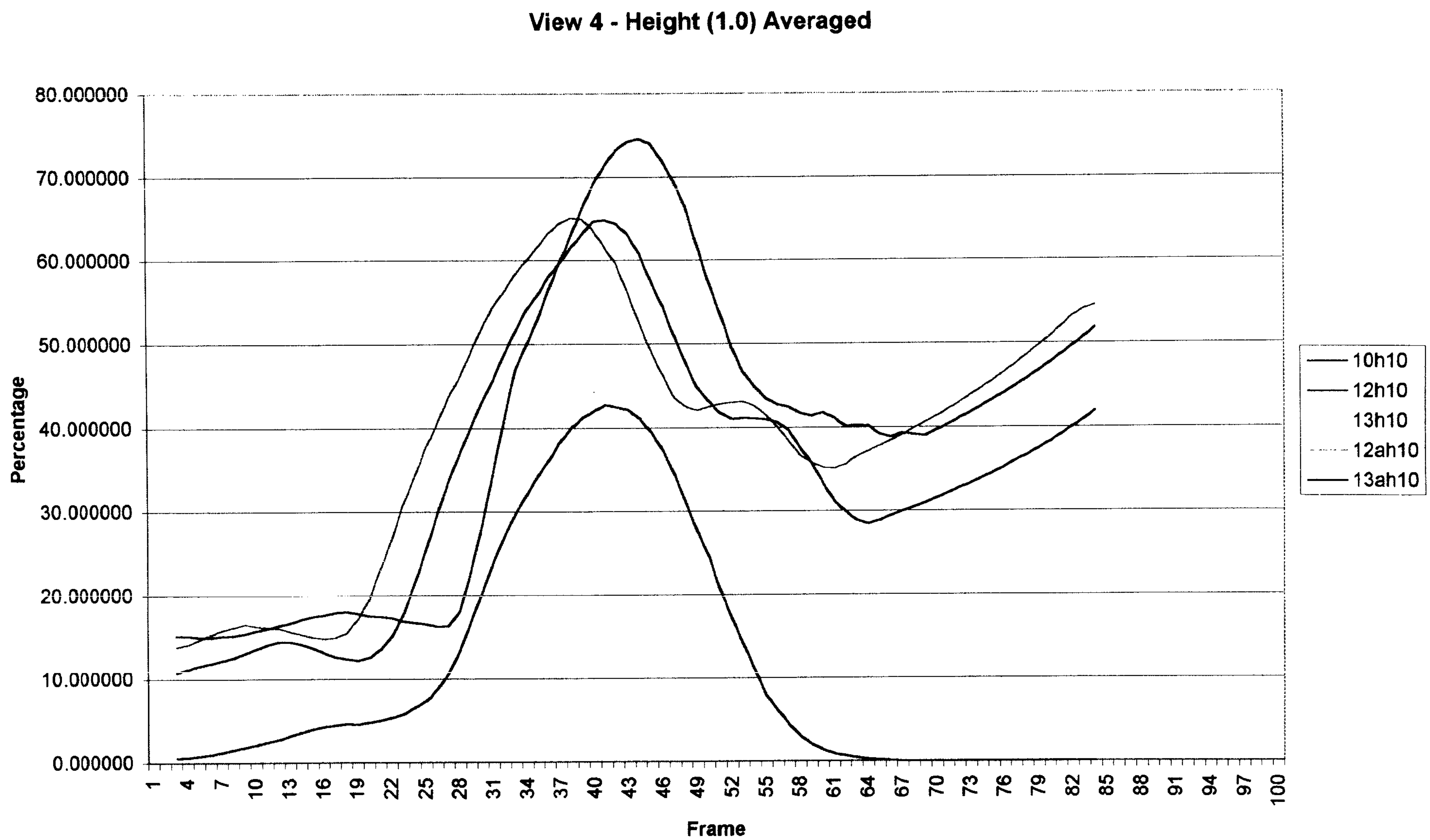


*Figure 7.15 Cab on front left - vehicle turning left - view at 1 m above floor*

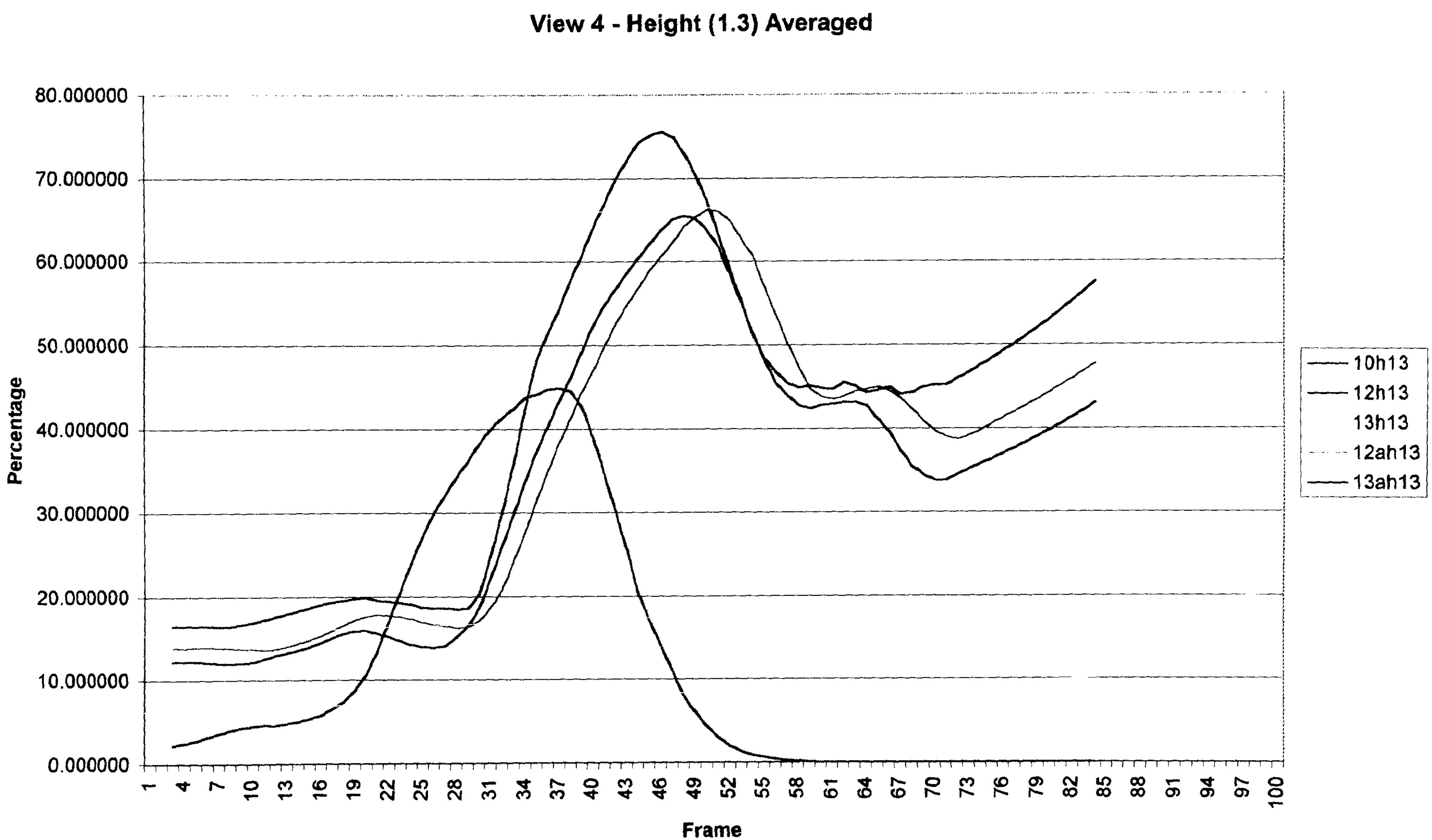


*Figure 7.16 Cab on front left - vehicle turning left - view at 1.3 m above floor*