Safety in Mines Research Advisory Committee

Second Revised Draft

The Ergonomics of Locomotive Design in South African Gold and Platinum Mines

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Executive summary

This research report discusses the ergonomics of locomotive designs in South African gold and platinum mines. The purpose of the study was to identify safety aspects of the existing fleet of mine locomotives and rolling stock that could be improved through ergonomics interventions.

In order to obtain this objective it was, firstly, necessary to determine the types of locomotives used at gold and platinum mines. This was followed by the objective and subjective evaluation of the existing fleet to determine the ergonomic aspects affecting human performance and human-machine interaction. The key ergonomics characteristics related to safety and work performance were identified for the mine locomotive, and based on this information, an ideal design was formulated. The practical implication of implementing the ideal design was defined, and the required changes and modifications to improve the safety aspects of the existing fleet were determined. Finally, a practical strategy was devised for the improvement of the current fleet.

Aspects covered during the study included:

- analysis of the locomotive operator tasks.
- identification of the ergonomics aspects and mechanical engineering characteristics of the locomotives, which could affect the safety and task performance for the locomotive operators.
- evaluation of the perceptual assessments of the locomotive operator.
- three-dimensional CAD assessments of the current locomotive designs to determine reach, posture, field of view and control locations for the operator.
- determining the design modifications, which would improve the overall operation of the mine locomotives in South African gold and platinum mines
- formulation of an ergonomics intervention strategy that would address the deficiencies in the current design (based on the anthropometric data for the South African user population, and local mining conditions).

The ergonomics assessment of the existing fleet of mine locomotives at gold and platinum mines highlighted various deficiencies in the design of the working system (most typically at the operator-machine interface). Poorly designed workstations make the operator's tasks more difficult and thus render him more error-prone. A number of safety related design deficiencies were also identified that can be improved through ergonomics intervention.

The ergonomics interventions required to improve the safety aspects of the existing fleet should address the following aspects:

- access to the cab of the locomotives
- forward visual access
- seating and posture
- communication and warning systems
- labeling of controls and displays
- equipment storage
- pre-operational safety and mechanical checks, and
- modification of the park brake.

The ergonomics interventions required to improve the safety aspects of the existing rolling stock should address access, seating and space provisions of man carriages.

In terms of ergonomics, the ideal design for a locomotive is considered to be one that follows the stereotype of motor vehicles. This incorporates the use of hand and foot controls, a body orientation facing in the direction of travel and adequate body support in the form of a well-

designed seat. The ideal design also makes provision for two locomotives per train, one at each end.

Practical considerations frequently influence the “ideal” design concepts to ensure safe as well as cost-effective workable solutions. This can be done while still incorporating sound ergonomics. A practical design for a locomotive include an enclosed cab, the use of current railbound stereotypes (i.e. hand control of direction and speed), and as far as the train is concerned, a single locomotive with a guard car at the other end. The guard car replicates the controls and the control system of the locomotive, but is not self-propelled.

In order to reduce the safety risks involved with locomotive operations as a result of poor ergonomics, the following strategy is proposed. Firstly, priority should be given to the implementation of the proposed ergonomic interventions for the existing fleet. The second phase should focus on the development of locomotive cabs, incorporating the proposed ergonomics of the practical design, which can be retrofitted to the existing fleet. Finally, attention should be given to the development of new locomotives according to the ideal design proposals.

It is further recommended that all interested and affected parties (manufacturers and suppliers) be involved in the practical implementation, manufacture and installation of the proposed ergonomics interventions and conceptual designs. This is essential in terms of Section 21 (1) (c) of the Mine Health and Safety Act (Act 29 of 1996).

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Glossary of terms

Anthropometry: The branch of ergonomics that deals with the measurement and application of human body dimensions and human physical characteristics to the design of products or systems that people use.

Control: Device that allows the operator to change the status of the system. Examples are handwheels, cranks, levers, push buttons, joysticks and lever switches.

Display: A feedback device that allows the operator to monitor the status of the system such as gauges and indication lights.

Front driver train: A train where the operator is on the leading end of the train and in control of the train.

Guard car: A railbound car coupled to a train for the purpose of accommodating a guard.

Locomotive: A railbound machine that is self-propelled, requires an operator and is used for the purpose of horizontal transport in or on a mine.

Percentile: Statistical term referred to in this report as a body dimension measurement percentage in relation to a population. Percentiles are specific to the population it describes. A 20^{th} percentile body measurement value would indicate that 20 % of the population would have equal or smaller measurements for that body dimension.

Rolling stock: Any railbound car that is not self-propelled. Typical rolling stock include hoppers, man carriages and material cars.

Task analysis: The study of what a user is required to do, in terms of actions and cognitive processes, to achieve task objectives. Task analysis is used to test the human-machine system interface to ensure compatibilities with operator abilities.

Train: A locomotive with rolling stock attached to and pulled or pushed by it.

1. Introduction

According to the South African Mines Reportable Accidents Statistics System (SAMRASS) trains contributed to approximately 16 percent of all reportable accidents in the gold and platinum mines in South Africa over the period 1 January 1998 to 31 October 2000. The main causal factors for these accidents are given in Table 1.1.

Table 1.1: Main contributing factors for the accidents involving trains

Contributing factor	NUMBER OF ACCIDENTS			TOTAL
	1998	1999	2000	
1. Bad driving practices	234	208	154	596
2. Lack of caution (signalling)	61	79	114	254
3. Failure to use safety provisions	53	28	16	97
4. Obstruction (visibility)	42	37	-	79
5. Mental or physical limitation	29	28	11	68
6. Inadequate preventative maintenance	28	20	8	56
7. Inadequate examination or inspection	7	12	6	25

The information contained in Table 1.1 suggest that human factors and the current design of the locomotives used in mines could, at least in part, have played a significant roles in the causation of these accidents.

Ergonomics can be defined as the study of human abilities and characteristics which affect the design of equipment, systems and jobs and its aims are to improve efficiency, safety, and well being (Clark and Corlett, 1984). It is therefore, essential to consider man's limitations and abilities when looking at the interface between people and machines in systems. Ergotech Ergonomics Consultants was commissioned by the Safety in Mines Research Advisory Committee (SIMRAC) to conduct research on the ergonomics of locomotive design in the gold and platinum mines in South Africa. The purpose of the study was to identify safety aspects of the existing fleet of mine locomotives and the rolling stock that could be improved through ergonomics intervention.

In order to achieve the above objective it was, firstly, necessary to determine the types of locomotives used at gold and platinum mines. This was followed by the objective and subjective evaluation of the existing fleet to determine the ergonomic aspects affecting human performance and the human-machine interaction. The key ergonomics characteristics related to safety and work performance were identified for the mine locomotive, and based on this information, an ideal design was formulated. The practical implication of the ideal design was defined, and the changes and modifications to improve the safety aspects of the existing fleet were determined. Finally, a practical strategy was devised for the improvement of the existing fleet.

This report deals with the findings of the above phases of the project and is detailed in the respective sections of the report.

2. Overview of track bound transportation

The number of mine locomotives currently used in the underground gold and platinum mines in South Africa is approximately 6 750. A detailed list of the distribution of these locomotives is presented in Appendix 1. Fifty-nine percent of these locomotives are battery powered, 34 percent are diesel powered and seven percent are electricity powered. The distribution of the mine locomotives according to the manufacturer and propulsion type is presented in Figure 2.1.

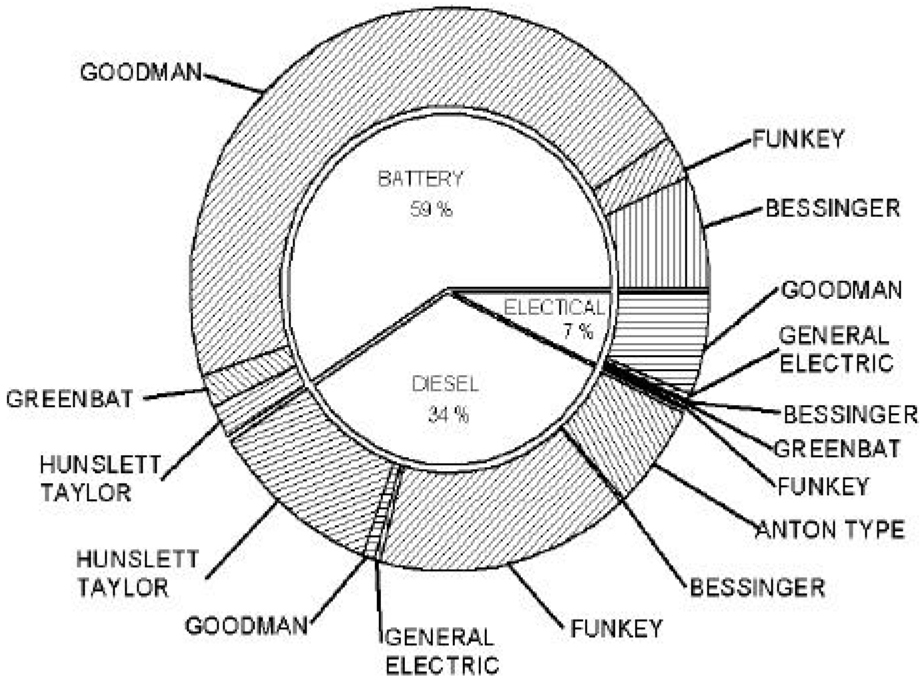


Figure 2.1: Distribution of mine locomotives

As shown in Figure 2.1 above, Goodman locomotives are the commonly used battery and electrical locomotives. Funkey locomotives are the most commonly used diesel locomotives. Based on these statistics, this study aimed at addressing the safety aspects of the commonly used locomotives.

2.1 Powering systems

Locomotives are classified according to their size, since ultimately it is the weight of the locomotive that will constrain its maximum traction and braking effort. Two basic power systems are available, namely diesel and electric. Electric power is derived from either an overhead trolley line or a battery unit.

A wide range of locomotive sizes is available, from small five ton units to 18 ton locomotives, larger or smaller units can also be produced. The ultimate constraint on size is the maximum permissible axle load, which is set according to the standard of the track. Speeds vary from 8 km/h to the maximum of 16 km/h allowed by law for underground use.

The common types of locomotives currently in use are listed below.

- Diesel powered locomotives
  - Diesel hydrostatic
  - Diesel hydrokinetic

- ♦ Diesel Mechanical

- Electrical powered locomotives
  - ♦ Battery powered
  - ♦ Overhead trolley
  - ♦ Combined battery and overhead trolley

The different powering system influence the human-machine interface, primarily with regard to the type of controls employed for operation of the locomotives. These interfaces are discussed in more detail in the following sections.

3. Dimensional and physical characteristics of the existing fleet of mine locomotives

The ergonomics of mine locomotive driving depends largely on the design features of the workstation of the operator. The design features typically include aspects such as access to the cabin, protection, controls and displays, and the support provided for the human body to maintain a posture from which sensory input can be received and control actions be performed. Furthermore the required body posture, sensory input and control actions must be within the operator's physical and psychological capabilities.

In order to objectively determine the ergonomics factors affecting the safety of locomotives and rolling stock, a dimensional evaluation was carried out on a range of locomotives and rolling stock.

The dimensional evaluation of the commonly used locomotives and rolling stock was carried out at a number of gold and platinum mines and at the manufacturer's plant. Appendix 2 presents the mines that participated and also provides the manufacturer detail. The main focus of the evaluation was the functional areas inside the operators cabin. This included the position, size and layout of the protection structures, controls, displays, seating, storage space, access to and from the operator position and viewing characteristics afforded to the operator. Modifications made to the cab or the general layout of the controls were also noted.

3.1 Results of the dimensional evaluation

The general positioning and layout of the functional areas in the mine locomotives are illustrated in Figure 3.1.1. From the illustration it is apparent that for a locomotive with the cab at the leading end, seating is located towards the left, directional and speed controls towards the right and the brake control centrally to the rear. Variations to this layout were observed for some diesel locomotives and monorails.

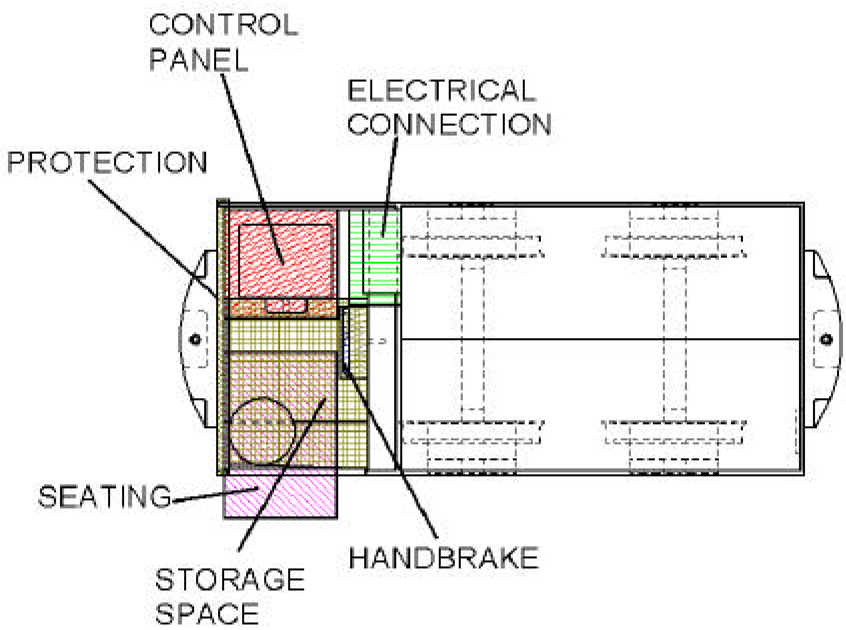


Figure 3.1.1: General layout of functional areas in a locomotive

Table 3.1.1 presents the primary dimensions of the areas within a locomotive that was used in the evaluation of the suitability of the size and layout configuration for operation of the locomotive. The dimensions are also referred to in Figure 3.1.2.

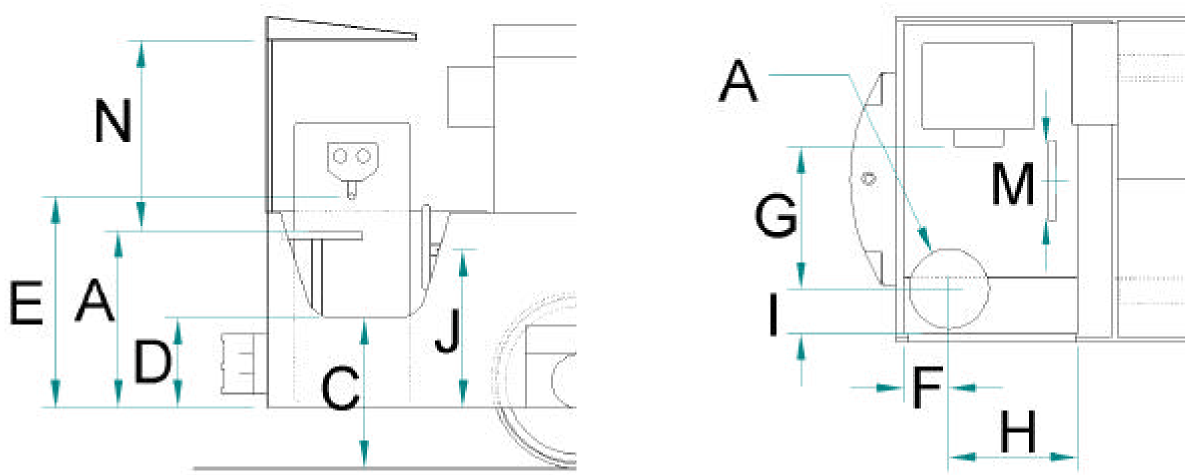


Figure 3.1.2: Primary dimensions on locomotives

Table 3.1.1: Primary dimensions and characteristics used for dimensional evaluation

A	Seat height from floor
B	Seat dimensions (WxD) or (∅)
	Seat material
C	Surface to entrance height
D	Entrance to floor height
E	Controller handle height
F	Seat to front wall distance
G	Seat to controller distance
H	Seat to rear wall distance
I	Seat to side wall distance
J	Park brake height from floor
K	Foot brake height from floor
L	Hand brake height from floor
M	Park brake dimensions
	Canopy (Yes/No)
N	Canopy to seat height
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height

In addition to the primary dimensions, forward viewing angles from a static point and the dynamic side viewing angles were determined for the seated position and is presented for each locomotive. A discussion on the results for each locomotive and addressing access, controls and displays, posture and seating and viewing angles are also included. The results of the dimensional evaluation of all the locomotives are presented in Appendix 3. The three dimensional computer aided design modelling of the cab areas of the locomotives was used to address the ergonomics requirements for workspace, posture, reach and layout of controls and displays. Workspace, reach and posture requirements were based on the anthropometric dimensions of the South African population as referenced in RSA-MIL-STD-127, Ergonomic Design: Anthropometry and Environment, 1995. The representations of the computer models are also presented in Appendix 3. A total number of 25 locomotives and 3 types of rolling stock were evaluated.

3.2 Discussion on the dimensional evaluation

Analysis of the dimensional evaluation indicates that dimensional differences exist among the size, types and makes of locomotives. It was also found that dimensional differences exist between locomotives of the same type, size and make. This indicates that the dimensional layouts of the locomotive cabs are not standard and could therefore influence operability.

3.2.1 Access

Entry level access to most of the locomotives was found to be more than the recommended value of 380 mm from the floor surface. Entrance cut outs on the side panels to facilitate entry was not consistently applied to the cab design. This frequently resulted in the operation to step over the high ledge onto the cab floor, which was often cluttered with loose equipment. Only one modified locomotive had an entrance height below the recommended value. Handholds or handrails could facilitate entry into and exiting from the cab, but were not frequently observed. Cabs with canopies were restricted at roof level, which would induce a crouched posture on entry.

Access to and from the cab was therefore identified as a safety design aspect, which could benefit from ergonomics intervention.

Man carriages differed in size and access provisions. Entry level access was found to vary significantly. Entry to some of the carriages was severely restricted by narrow doors, only 355 mm wide and unacceptably high entry level. This is unsuitable for the South African adult population.

3.2.2 Seats and posture

Seating in the locomotives ranged from small flat rectangular and circular metal and wooden horizontal support surfaces (refer to Figure 3.2.2.1) to integral skin polyurethane seating systems with T-shaped backrests, making provision for cap lamp battery and self rescuer, and with horizontal adjustment (refer to Figure 3.2.2.2). Some of the seats were in an ill state of repair (see Figure 3.2.2.3).

Figure 3.2.2.1: Wooden seat with sharp edges

Figure 3.2.2.2: T-shape backrest with horizontal adjustability

Figure 2.3.3.3: Worn seat base

For accurate and fine control of hand and arm actions it is necessary to support the body effectively. This is even more important when the platform on which the control and human body is located, is moving. Except for the monorail and modified locomotives, seat backrest support was generally absent. Backrest support is important to reduce fatigue and provide stability to the trunk to allow the upper extremities to effectively operate the controls. Armrests were occasionally included in the seating design. Several of the cabs had cables and connectors impeding on the natural seating posture of the operator.

The seat heights for the stool type seats ranged from 430 mm to 750 mm with most of them approximately 600 mm high. As these heights are beyond the popliteal heights (lower leg length) of the 5th and even the 95th percentile user, the seats can only be used in a semi-standing body posture with some weight supported by the feet. Sitting on the seat with unsupported feet is not suitable for mobile machinery. Most of the seats were not adjustable and would therefore not accommodate the operator population effectively.

The layout of the controls in relations to the seat position and available workspace causes or requires the operator to use a sideways body orientation to the direction of travel. This orientation induces a sustained rotated neck posture towards the direction of movement. The concern is neck muscle fatigue and musculo-skeletal discomfort. Except for the monorail and some of the modified locomotives, the body posture of the operators would not be reconcilable with the task requirements.

The seating provisions in man carriages were bunk type seats of various configurations. The posture of users was upright and awkward due to restrictive seat depths and even roof heights. The number of personnel required to fit into some of the man carriages was more than would be advised based on the body sizes of the South African population. The restrictive sitting posture was also negatively influenced by the cap lamp battery and self rescuer worn at waist level which resulted in side sitting rotated trunk postures.

3.2.3 Controls and displays

The two primary controls were the master controller (usually directional and speed control) and the hand operated park brake. As frequent interaction with these controls is required, the location of the controls within the reach envelope (reach distances) of the operator is important. The hand reach envelope is dependent on the position of the seat and body posture of the operator. The sideways body orientation that is required for some locomotives induces awkward operation of the master controller, because of excessive reach and force exertion with an extended arm across the centre of the body. Operation of the park brake should typically be a two handed operation while facing the brake. Once again, the brake position in relation to the seat forces one-handed operation and in some instances with an extended arm.

Labelling of controls and displays was frequently absent or illegible but was typically within visual access. Obscured positioning restricted physical access to the siren and the headlight controls.

3.2.4 Visual distances and angles

Visibility of the track, switches and warning signs provide important sensory input to the operator. Most of the locomotives had open cabs with mostly unrestricted view to the front and sides of the locomotive. The sideways driving posture influenced the forward view although head and eye movement (dynamic viewing) overcomes this. For locomotives with canopy covered cabs the forward viewing to the track was limited, and in cases, severely limited. Blind spots at the corners of the enclosed cabs also restricted the visual angles. For one locomotive, the 5th percentile operator in the driving posture is incapable of seeing the track. It is proposed that the obscured distance in front of the locomotive for the 5th percentile eye height not exceed 1,5 m and that dynamic side viewing angle be at least 90 degrees to each side of the movement axis.

The forward view of the seated operator is severely restricted when the locomotive is pushing the train or with the locomotive cab at the rear. However, the natural adaptation for the operator to improve his visual field by standing upright is against mining regulations.

3.3 Dimensional evaluation and physical characteristics summary

The purpose of the dimensional evaluation was to assess objectively the physical characteristics of the locomotive to identify safety aspects that can be addressed through ergonomics intervention. Although some locomotives had or made adequate provisions the general dimensional assessment indicated that the following aspects were inadequately addressed:

- Access provisions
- Seating
- Body posture
- Control location and layout
- Control movement in relation to posture
- Forward viewing
- Rearward viewing

Access height and width and seat depth were identified as aspects which should be addressed on man carriages.

4. Task analysis of locomotive operation

The purpose of task analysis is to assess human–machine interfaces to ensure compatibilities with operator abilities. This is achieved thorough systematic analysis of the user's activities and task behaviour. The approach involves the analysis of the activities in existing systems. The results of the analysis are then applied in the design or recommendations of a new system (Wilson and Corlett, 1992).

The process of task analysis can be broken down into three main phases. The first phase of the analysis is the data collection and involves the collection and documentation of various sources of information about the tasks of the operators. The second phase is the description of the tasks. A task description contains task requirements and a process that analyses the behavioural implications of the identified tasks. The final analysis phase generates simple cognitive or physical activities, also called operations.

The task analysis in this study focused on the locomotive operator tasks. It facilitated the safety assessment process by identifying the implications of the tasks for design or modification purposes. This approach was particularly useful when considering the results of the dimensional evaluation discussed in section 3. The two techniques are complimentary in identifying safety deficiencies.

The information on the tasks of the operators was obtained from the mines that were visited during the study. The collaborating mines are listed in Appendix 2. The major tasks of the operators were identified through verbal interviews with training managers and operators, from operator training manuals and related documentation and direct observation of the operators performing the tasks during training sessions as well as during the actual production processes underground. From the task data collected, the overall task requirements of the operators were classified into three main procedures: pre-operational, operational and post-operational procedures.

The main procedural task requirements were broken down into subsidiary tasks. Each of these lower level tasks were then subdivided to give a further level of subtasks. All these tasks at each level fit into the general concept of operator's tasks. This process was continued up to a level consisting of simple cognitive or physical actions. The gross analysis of tasks is presented in the following paragraphs. More detailed analysis is presented in Appendix 3.

4.1 Description of the operator tasks

A locomotive operator normally carries out a variety of activities to effectively and safely run a locomotive under the various operational conditions. The operator's tasks include some of the tasks which do not involve direct interaction with the locomotive, such as when removing the stop blocks, opening the ventilation doors and other tramming tasks. Although these tasks are important safety aspects in the actual operation of the locomotive, the tasks per se have minimal influence on the design of the locomotive. In this study, these tasks were not analysed to great depth.

The emphasis of this study was on the tasks that are directly influenced by the design of the locomotive, specifically human-machine interfaces. Figure 4.1.1 shows the general breakdown of the major tasks of the operator. It should be noted that the lower level tasks may vary according to the operating procedures of the mine, make of the locomotive used, and the type of propulsion mechanism the locomotive uses. However, the gross tasks are universally applicable.

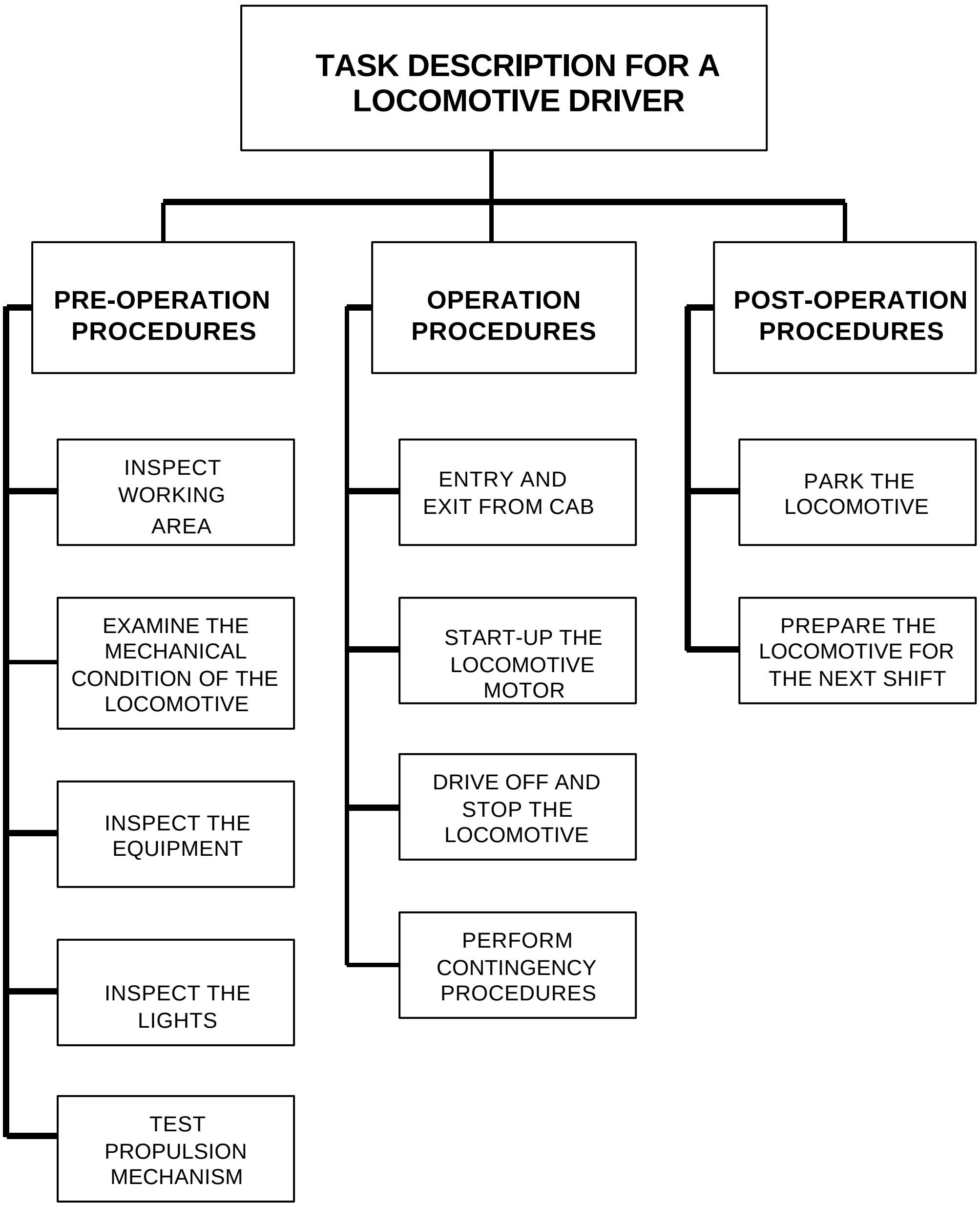


Figure 4.1.1: General breakdown of operator's tasks

4.1.1 Pre-operational procedures

Pre-operational procedures are tasks that are performed at the start of the shift. These tasks include the physical inspection of the working area, inspection of the safety provisions in the locomotive as well as in the work room, examination of the propulsion mechanism of the locomotive, and the examination of the mechanical condition of the locomotive such as the physical condition of the controls and displays, the condition of equipment, and locomotive lights. Figure 4.1.1.1 provides a summary of the pre-operational procedures. The detailed task analysis is presented in Appendix 3.

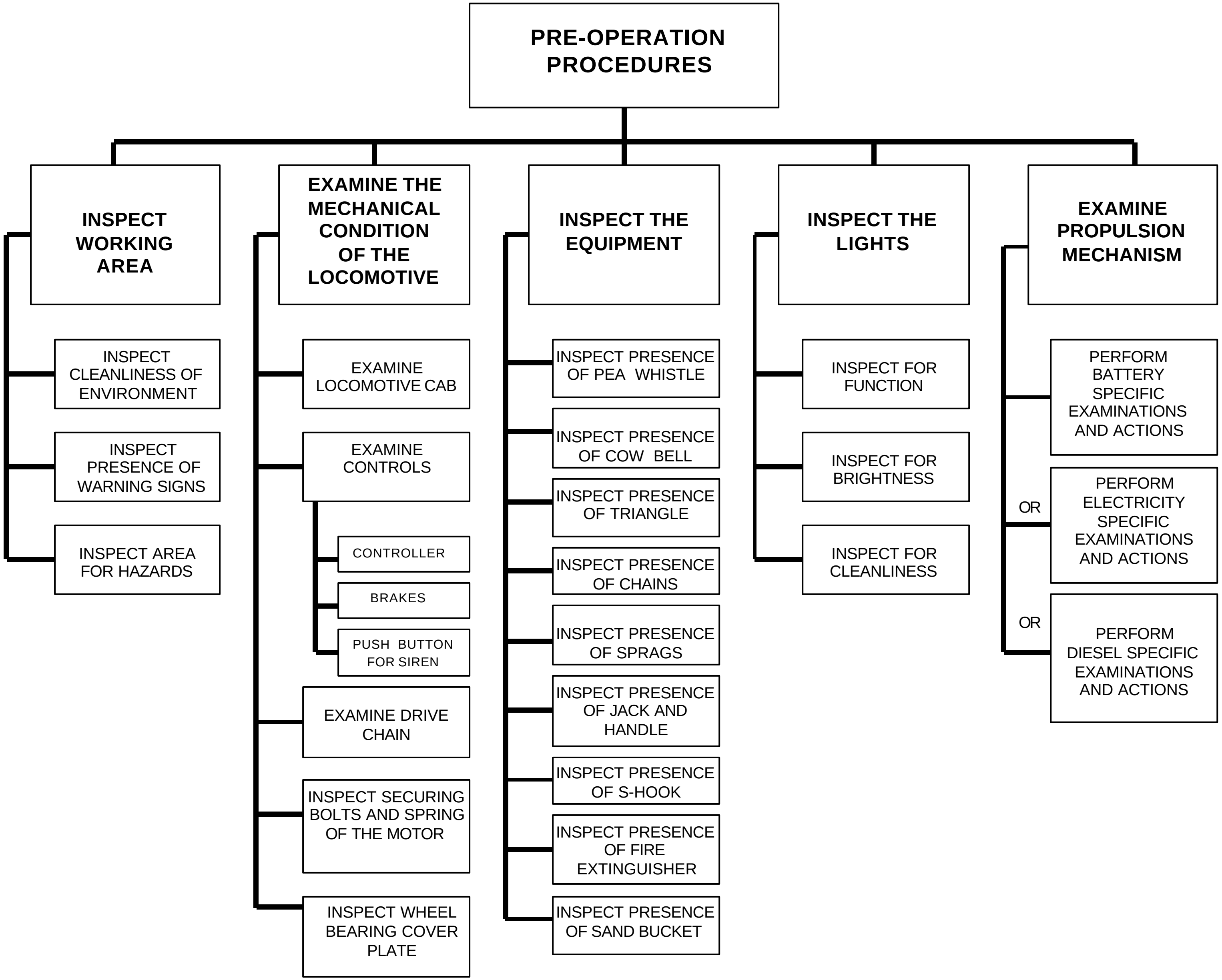


Figure 4.2.2.2: Pre-operational procedures

4.1.2 Operational procedures

The operational procedures are those tasks performed by the operator during the operational processes. These tasks include accessing and exiting from the cab, controlling the locomotive and the contingency procedures aimed at keeping the locomotive in operation, such as "quick-fix" repairs and re-railing. Contingency procedures also include the stopping of the locomotive for other operational tasks such as observing the safety rules. Figure 4.1.2.1 shows the general breakdown of the major tasks. The detailed task analysis is presented in Appendix 3.

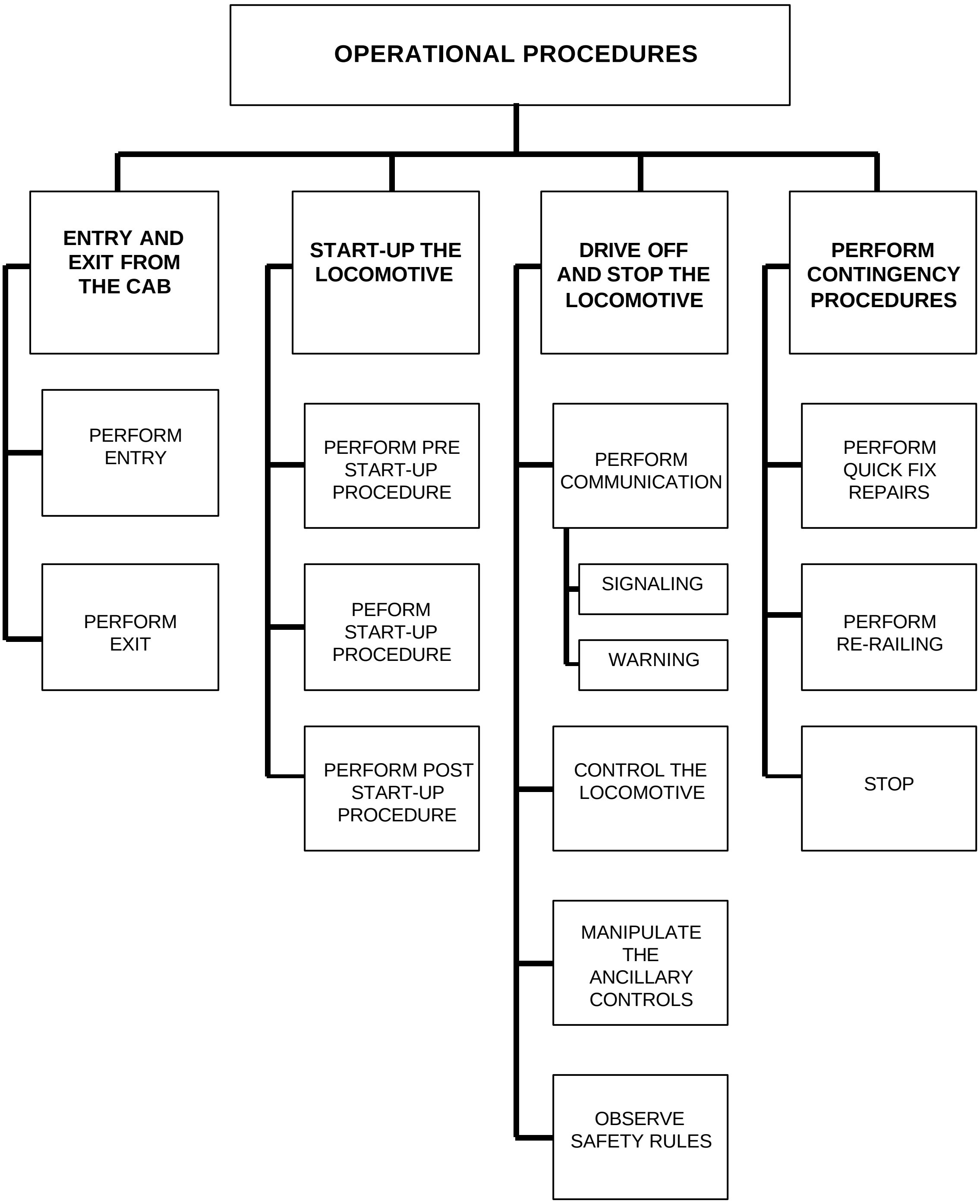


Figure 4.1.2.1: Operational procedures

4.1.3 Post operational procedures

Post-operational procedures are the tasks performed at the end of the shift. These tasks include the parking of the locomotive at the area where it is prepared or "made-ready" for the next shift, such as parking the locomotive at the battery charge bay or re-fuelling station. It also includes the stopping or switching off of the locomotive motor or engine. Figure 4.1.3.1 shows the general breakdown of the major tasks. The detailed task analysis is presented in Appendix 3.

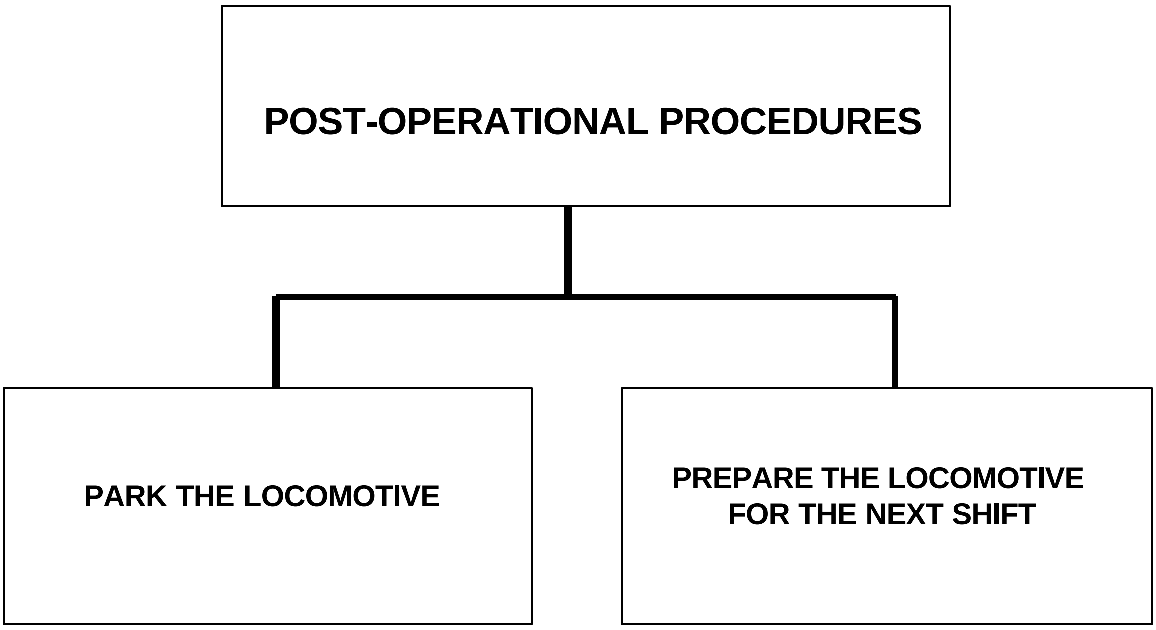


Figure 4.1.3.1: Post-operational procedures

4.2 Evaluation of the operator tasks

The operator tasks were evaluated in terms of the human's ability to perform the tasks. These abilities include physical and psychological factors and include, physical size and reach, physical and visual access, biomechanical considerations, sensory capabilities, physiological characteristics, cognitive ability, language and culture influences, educational level, decision making abilities, skills, experience and motivation. The derivatives of these factors are the ergonomics concepts of likelihood of errors, ambiguity, effective feedback, reliability of system performance and required precision, time and sensitivity of displays and controls. Analysis of these concepts for the locomotive operator tasks provided the basis for proposing possible design alternatives or improvements, enhancing safety while at the same time enhance or maintain operator performance. This was done for each of the high level tasks listed below:

- Inspect safety provisions in the work area.
- Examine the mechanical condition of the locomotive.
- Inspect the required equipment and tools.
- Inspect the locomotive lights.
- Examine the propulsion mechanism.
- Entry to and exit from the cab.
- Start-up the locomotive motor or engine.
- Drive off and stop the locomotive.

- Perform contingency procedures.
- Park the locomotive and prepare the locomotive for the next shift.

To assist operators, most mines make use of checklists to guide operators through routine examination and inspection tasks. Some checklists would concentrate on equipment only while others would be more comprehensive and include locomotive component and system checks.

4.2.1 Inspect safety in the work area

The inspection of safety in the work area is conducted at the start of the shift. This task was found to be easy to perform for of all the operators. Potential emergencies could however arise because of the poor housekeeping and can be aggravated by limited workspace in the workrooms underground.

From the interviews with the operators it was found that there are diverse interpretations of the presented information among operators. In order to improve the effectiveness of the safety provisions only nationally or internationally recognised standard symbols or safety signs should be used, the visibility of the safety signs should be maintained by regular cleaning, safety signs should be displayed in the unobstructed visual field, other safety equipment should be maintained regularly and special attention should be given to language compatibility of the operators.

4.2.2 Examine the mechanical condition of the locomotive

Generally, it was found that the task of examining the mechanical condition of the locomotive was difficult, especially those tasks requiring interpretation of the status of mechanical components. Restrictive visual and physical access to some of the mechanical parts of the locomotive are the main reasons for this.

Examination of the drive chain forms part of the subtask. As only a part of the chain is visually accessible when performing the inspection, the judgement on wear and tear and chain tension can only be based on the visually accessible part. Assistive devices or tools may however be employed to assist the operator in judging the mechanical condition. An example is a hook type tool used to hook and lift the chain to judge chain tension according to physical deviation when visual access is inappropriate or not possible. Another method of facilitating inspection tasks is to mark (even with paint) all the required inspection points. However, to inspect a chain for damaged or broken links requires more actions.

Figure 4.2.2.1 shows typical restrictions of visual access to mechanical components.

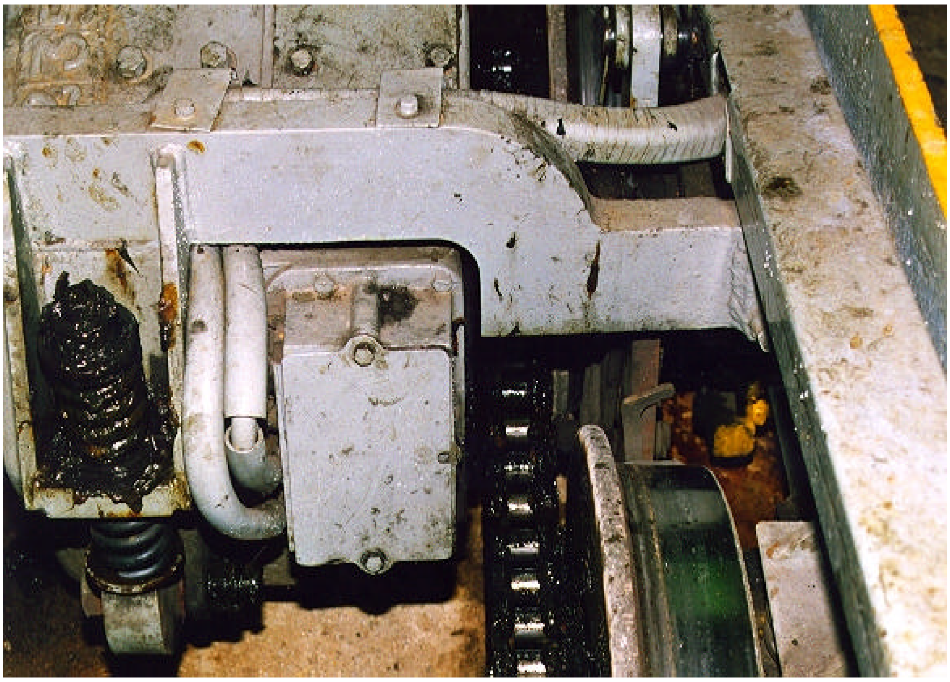


Figure 4.2.2.1: Visual accessibility to chain drive components

The decision making criteria for this task is also presented in a format that is unsuitable for most of the operators because of the relative low mechanical educational, skill or training levels. For example, there are no definitive prescriptions to determine the acceptable degree of wear for the drive chain or brake shoes. Without prescriptive objective methods, this task is executed based on subjective assessment alone.

4.2.2.1 Examine brake shoe wear and tear

Potential incidences could arise from running the locomotive with defective brakes. Therefore, accurate brake shoe wear identification is critical. Currently the task of brake shoe examination is difficult do to the restrictive visual access. Inaccurate reading of the level of shoe wear can more easily occur when based on subjective assessment. Marking or painting the break shoes on a scale up to the wear limit is recommended to provide an objective method for the operator to evaluate brake shoe wear. They can then objectively determine break shoe wear and identify when replacement is required.

4.2.2.2 Examine drive chain wear and tear, and slackness

These tasks were found to be mostly beyond the knowledge of most of the operators. To examine the wear of the drive chain, the operator would require mechanical knowledge and training. Due to the inability of most of the operators to perform these tasks effectively, it is recommended that a mechanic do these tasks during routine weekly maintenance schedules.

4.2.3 Inspect the required equipment and tools

The information required by the operators to carry out this task was usually available on checklists in pictogram format as well as text in “Fanakalo” and English. It was found that pictogram presentation of the information was more effective than structured text. This could be due to a lack of common names for the tools used in the text where identical tools were identified by different names. For example, the “T-sprag” is also called “aeroplane sprag”.

On most of the locomotives there was a lack of dedicated storage space for the equipment and tools required to be carried. As a result of the lack of the storage space, it was found that the equipment and tools were placed anywhere inside the cab. Figure 4.2.3.1 shows a typical situation where tools and equipment are placed on the cab floor. The safety implications as a result of this hazard typically include stumbling and tripping and can therefore influence the safe control of the locomotive. The practice of carrying equipment on the floor would also affect the efficiency and productivity of the operator negatively.

Figure 4.2.3.1: Jack, chain and other equipment encrouching on foot support and space

As shown in Figure 4.2.3.2, the front part of the cab has been modified to carry the locomotive jack. Figure 4.2.3.3 shows storage bins at the front of the locomotive. These are typical examples where the deficiencies of storage space are being addressed through retrofit at minimal cost. Dedicated storage space improves the utilization of workspace inside the cab and can reduce the risks of an accident.

Figure 4.2.3.2: Dedicated jack storage space

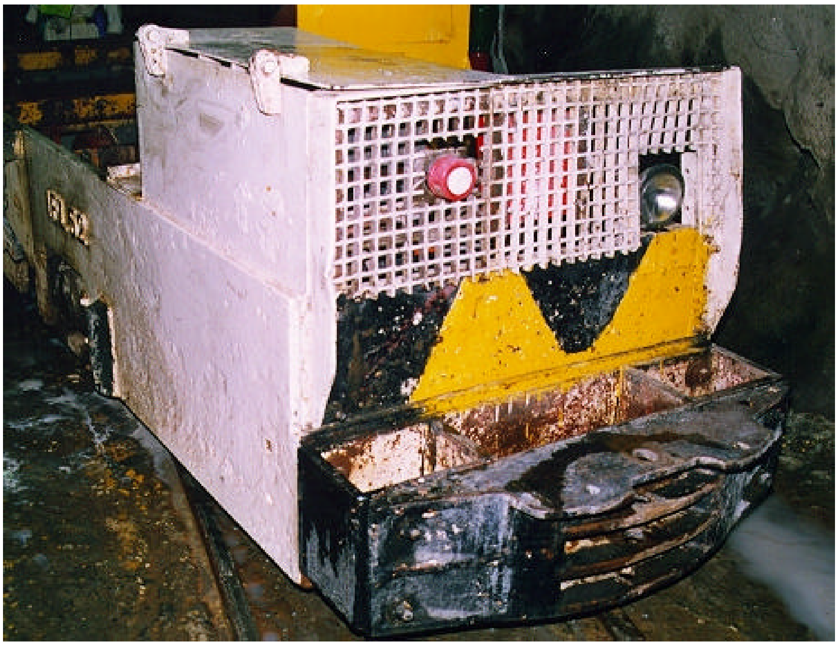


Figure 4.2.3.3: Equipment storage bins

4.2.4 Inspect the locomotive lights

The task requirements for the operators in the examination of the locomotive lights include inspections for functioning, brightness and cleanliness. The task of cleaning the locomotive lamps was found to be simple and easy for all the operators. The task of examining the functioning of the lamps was found to be more intricate on some of the locomotives because of the inaccessibility of the switch positions. The lack of labelling and inconsistent layout of the switches were also found to be problematic.

The task of examining the brightness of locomotive lights was found to be ineffective as operators had to rely on subjective assessment of the brightness of the lights. The practice of brightness inspection was however not implemented at all the mines. Brightness of lights can only be inspected effectively by measurement with suitable test equipment. It is recommended that the locomotive operators not be expected to inspect the brightness of the locomotive lights but only for operation and cleanliness. Brightness measurement should be performed by personnel with approved test equipment.

Consistency among locomotives in the location and layout of the switches would also contribute to simplify the tasks.

4.2.5 Examination of the propulsion mechanism

There are three types of propulsion mechanisms for the locomotives used in South African gold and platinum mines. These are battery, electrical and diesel propulsion mechanisms. The task requirements for the operator in the examination of the propulsion mechanism varies according to the type of the locomotive. More difficulties for the operator in performing this task were observed for the battery-powered locomotives. It was found that the task of examining the battery and loading it onto the locomotive chassis could potentially expose the operator to hazardous conditions.

The task of lifting the battery using a manually operated chain block was found to be less controlled than when electrically operated hoists were employed. Battery attachments for lifting purposes differed among locomotives. One system used a jig with four hooks to attach to the corners of the battery pack. Another system consisted of a single permanent hooking point at the centre of the battery pack, so that no jig was required. It was noted that the jig system required more co-ordination among operators to effectively hook up the battery. A hazardous condition can occur if all the hooks are not positively attached to the battery pack. Figure 4.2.5.1 shows a jig system with hooks at the corners of the battery pack.

Figure 4.2.5.1: Battery pack lifting operation

Figure 4.2.5.2 shows the battery lowering process onto the locomotive. The task of placing the battery on the locomotive chassis was observed to be potentially dangerous as the operator could sustain finger injuries when manually aligning the battery pack with the brackets on the receiving locomotive. Various retaining mechanisms were used to restrict battery pack movement in collisions. Most of the mechanisms restricted horizontal movement of the battery pack and relied on the mass of the pack to keep it in position vertically. It has been reported that battery packs have been dislodged from its retaining mechanisms during severe collisions. A recommendation here is the use of a corner casting and twist lock mechanism as used on freight containers to retain battery packs. This could also reduce the risk of hand injuries on the lowering of the packs onto the locomotive as alignment is facilitated by the peg type protrusion of the mechanism.

Figure 4.2.5.2: Battery pack lowering operation

Figure 4.2.5.3: Isolating switch location

The operation, access, colour coding and location of the battery isolating switch was found to be inconsistent. Figure 4.2.5.3 and 4.2.5.4 show the location of the battery isolating switch on the battery pack. The switch in Figure 4.2.5.4 is not easily accessible due to the cable positions. Isolation switches were also found to be positioned in any orientation (i.e. horizontally and vertically) and did not follow a stereotype consistently. Examples were found where switch activation up is on, up is off, left is on and left is off.

The South African stereotype is down or left or towards the operator as on and up or right or away from the operator is off.

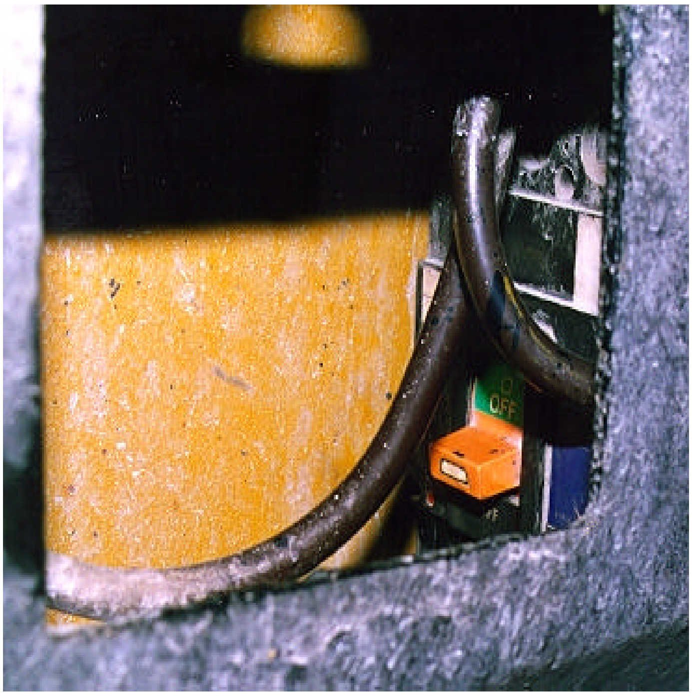


Figure 4.2.5.4: Battery isolation switch accessibility

Figure 4.2.5.5 illustrates a rope attached to the pantograph of an electrical overhead powered locomotive. The rope was used for lowering and swinging the pantograph away from the conductor. The makeshift modification indicates task procedure and equipment deficiencies and increases the risk of electrocution.

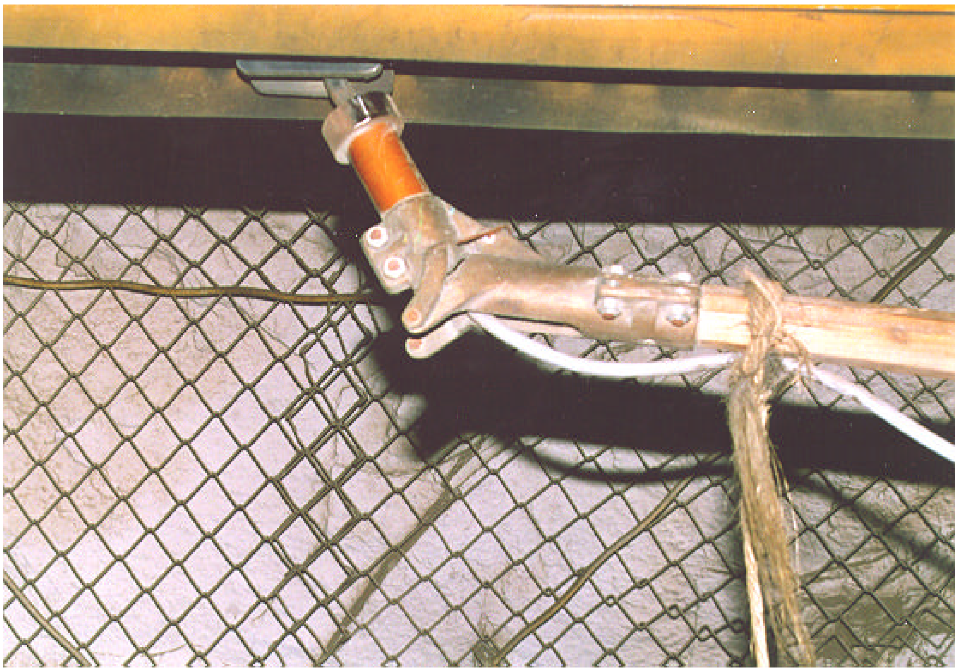


Figure 4.2.5.5: Rope attachment on pantograph

It was found that the information for operators to examine the propulsion mechanism was mainly available in structured text. This was found to be inappropriate for illiterate operators. Furthermore, basic theoretical knowledge is required to perform the task requirements effectively.

4.2.6 Entry to and exit from the cab

The task of entering and exiting the locomotive cab was found to be simple and easy. However, it was observed that there were potential risks in accessing the cab. These risks include the operator stumbling, tripping or slipping either on the track or on the cab surfaces of the locomotive.

Figure 4.2.6.1 a modified version of a mine locomotive. Although the fully enclosed canopy provides protection for the operator, entering and exiting the cab was found to be difficult, especially for taller operators due to the low roof height.

Figure 4.2.6.2 shows a typical fully enclosed canopy of an electrical locomotive. The absence of handholds, and high entrance level increases the hazards of entry and exiting. It was observed that even for open cab locomotives the risk of slipping and tripping was high during the entry and exiting actions. This was due to the high entrance level and the absence of handholds.

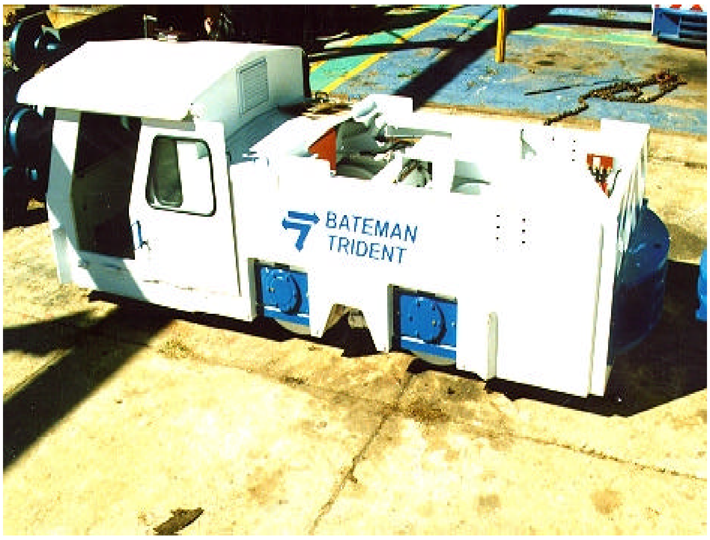


Figure 4.2.6.1: Modified locomotive with enclosed cab

Figure 4.2.6.2: Electrical locomotive with enclosed cab

4.2.7 Start-up the locomotive motor or engine

The task requirements in starting the locomotive vary according to the type of the locomotive. The task of starting the battery and electricity powered locomotives was found to be fairly easy because these locomotives were started by a magnetic switch key, which enables the master controller.

The task of starting the diesel engine locomotives with crank handles was observed to be difficult. The operator had to manually crank the handle and then remove the cranking handle as the engine started. There are however few of these locomotives still running on the South African mines. Newer diesel engine locomotives were found to be easy to start as electric or pneumatic starters were used.

4.2.8 Drive off and stop the locomotive

The primary task here is to control the locomotive effectively. Various types of controls are implemented on the different types of locomotives. Battery operated locomotives made use of a L-shaped spring loaded directional controller (master controller) and handwheel operated park brake (refer to Figure 4.2.8.1 and Figure 4.2.8.2). Electrical locomotives used deadman controls (two actions required to activate) and rotary two position brake levers and monorails and diesel powered locomotives employed levers of various configurations.

Figure 4.2.8.1: Directional controller opposite and brake handwheel to the right (note the cable limiting free access to the wheel)

Figure 4.2.8.2: Control layout with master controller opposite seat

Activation of the directional movement controls did follow the accepted movement stereotype. The locomotive movement would mimic the direction of control activation (e.g. forward movement of the control caused forward movement of the locomotive). In addition to this control action the control deviation also relates to the speed of the locomotive. Control movement away from the neutral (vehicle stationary) position increases the speed of the locomotive incrementally.

Although the directional controls did not in themselves have major ergonomics deficiencies, it was observed that the location of the controller did have serious implications for effective operation of the locomotive control task. The operator would typically sit directly across the controller and facing it. Control activation is then a medial and lateral hand and arm action. This control activation posture was observed to be strenuous for operators, especially for configurations requiring extended arm reach.

Some of the locomotives also had additional controls for direction selection. An example of this is shown in Figure 4.2.8.3. In this example an additional control panel with two push-buttons was located on top of the master controller. To operate this configuration the locomotive operator has to first select the appropriate direction push-button before the controller lever is activated. It is though that the intention of the modification was to provide an additional safety device to reduce the possibility of unintentional selection of direction. However, as can be seen in Figure 4.2.8.3, the push-buttons are mounted the wrong way round. The forward movement button (marked with "F") is mounted to the rear of the reverse push-button. This is contrary to any accepted stereotype and totally defeats the intention of the modification. Operator disorientation in control selection would be expected and control effectiveness would be negatively influenced.

Figure 4.2.8.3: Additional direction selection controls

The controls for ancillary functions such as the lights and sirens were observed to be placed randomly within the cab. The location of these controls caused operators to use awkward hand, arm and even body postures to activate and added to the ineffective control of the locomotive.

The use of a handwheel as park brake was found to reduce the effectiveness of the control task. The handwheel was also used as service brake and was observed to be operated with a single hand while sitting in the operator position. Handwheels are intended to be operated with both hands. The best position to perform this action would be when facing the handwheel. This is difficult to achieve in the locomotive. Forces to activate the brake of up to 350N were measured. A maximum force of 100N would be more appropriate. Access to the wheel was also observed to be restricted on some locomotives. Figure 4.2.8.1 shows the handwheel surrounded to the right and top by control boxes and in front by a power cable. Park brake status feedback to the operator is also required. No handwheel operated park brake during this study was observed to provide feedback to the operator regarding the status of brake activation. Because the handwheel brake control action is progressive, it was frequently observed that operators were operating the locomotives with partially activated brakes. This is ascribed to the fact that no indication of brake activation status is available to the operator. Furthermore, handwheels are not suitable for functions where speed of control operation is critical, i.e. braking during emergencies. The use of a handwheel as service brake for mine locomotives is judged to be ergonomically inappropriate. This is also thought to contribute towards the operator not feeling in control of the locomotive (refer also to paragraph 5.2.5) and to rather opt for jumping free on the imminent risk of a collision.

The inconsistency in the layout of locomotive controls, the lack of appropriate labelling and the physical access to controls are negatively influencing the control task of the operator. The inconsistencies were found not to be limited to different manufacturers or locomotive types but among mines and even within a mine. Locomotives used for training could therefore be substantially different from the locomotive used for production. This could also negatively influence the safety and effectiveness of the control task execution.

Communication with pea whistles between the locomotive operator and guard was observed to be effective in quiet surroundings and where production pressure was low, typically the training environment. It was also observed that under production pressure, in high ambient noise environments the whistle communication was less effective. This was aggravated by any non-standard type of shunting task where it was found that verbal commands would increase effectiveness. Unassisted verbal communication underground is not feasible, generally due to the high ambient noise levels. A communication system with two way communication capacity would however contribute to the effectiveness and safety of all communication related tasks.

It was noted that locomotive operators carefully observed the statuary and operational safety regulations such as stopping at prescribed points and sounding the siren before driving off. The operation of the lights and the use of a red taillight was however not carefully observed and locomotive head lights were, for example, switched on independently of the direction of travel.

4.2.9 Re-railing the locomotive

Re-railing a locomotive or rolling stock was observed to require strenuous physical activity. Furthermore, because of the potentially unstable support, either due to the derailment or as a result of the jacking actions, the operator and guard are frequently exposed to the risk of injury by a shifting, falling, or sliding locomotive or rolling stock. Figure 4.2.9.1 shows a locomotive jack, which is usually carried as standard equipment on the locomotive. Figure 4.2.9.2 shows a re-railing mechanism, which attaches securely to the buffer for jacking up the locomotive and a transverse mounted lever-operated jack to move the locomotive sideways onto the track. These mechanical assistive devices were observed to lower the risk of injury as it reduces or eliminates the physical manoeuvring of the locomotive and rolling stock when under unstable support. With the standard jack it was observed that there is a risk of the jack slipping from underneath locomotive on rolling stock chassis. A number of special jacking points on the chassis of the locomotive and rolling stock could reduce this risk.

Figure 4.2.9.1: Standard locomotive jack

Figure 4.2.9.2: A mechanically assistive re-railing device

4.2.10 Parking the locomotive and preparing the locomotive for the next shift

The parking task is essentially similar to the control of the locomotive tasks described in paragraph 4.2.8. The additional actions include the removal of the magnetic switch key, closing fuel valves or connecting plugs and securing the locomotive with skid sprags.

Next shift preparations depend on the type of locomotive. Where applicable, pantographs are checked and diesel refuelled. For battery powered locomotive, specific inspections of the battery condition and charging procedures are prescribed. The tasks are all within the capabilities of the operators.

4.3 Task analysis summary

The purpose of the task analysis was to determine compatibility of operator actions with the inherent abilities of operator in performing the operator tasks and in using the human-machine interfaces of the locomotive and associated equipment. Some tasks were found to be simple in nature and easy to perform. Task executions and design features influencing the tasks that can benefit from ergonomics intervention were identified as:

- inspection of mechanical components
    - ♦ brake shoes
    - ♦ chain wear
- storage provisions for tools and equipment
- battery pack lifting, retention and battery isolation switch coding and stereotype
- entry to and exit from the cab
- the control of the locomotive
    - ♦ master controller location and operation
    - ♦ inappropriate service brake control type
    - ♦ ancillary control layout
- communication

5. Perceptual assessment of the locomotive operators

The purpose of administering the perceptual assessment was to obtain the subjective opinions from the operators, who are the ultimate end-users of the mine locomotives. This information often provides practical insights by the end user and may assist with identifying potential ergonomic problems. The process of perceptual assessment is complimentary to the dimensional evaluation and task analysis in identifying the safety aspects that can be improved through ergonomics intervention.

Interviews were conducted with sixty male operators from six mines (refer to Appendix 2). This choice of the mines was primarily based upon the diversity of the type of locomotives currently used in operation. The operators were interviewed in the language of their choice and asked to give a rating and/or comment on issues that included access, aspects of operation, communication methods, safety and the general working environment. The perceptual questionnaire is presented in Appendix 4.

The demographic profile of the interviewed operators showed the average age to be 39 years old with an average of 11 years working experience. The majority of the operators had achieved an educational level of a standard six.

The only physical measurement taken of the operators was their stature while in mine protective clothing. The average height was 1745 mm (24^{th} percentile of the South African male) and the range was between 1620mm to 1930mm (2^{nd} to 93^{rd} percentiles).

5.1 Perceptual assessment and results

A summary of the questionnaire results is presented below in Table 5.1.1.

Table 5.1.1: Summary of the result of perceptual assessment with the locomotive operators

Factor		Operators response
	WORKSPACE	
1.	Entry and exit	Difficult
2.	Seat Comfort	Uncomfortable
3.	Seat Height	Just right
4.	Leg Space	Restrictive
5.	Operator protection and safety	Poor
	CONTROLS AND DISPLAYS	
6.	Control manipulation	Extremely difficult
7.	Control labels and instructions	Poor
8.	Understanding the meaning of controls colours	Understood
9.	Preference for the driving position	Face direction of travel
	VISUAL FIELD	
10.	Visibility with the hoppers in front	Very poor
11.	Visibility with the hoppers at the back	Good
	COMMUNICATION	
12.	Ability to hear warning signals	Good
13.	Interpretation of the pea whistle signal	Difficult
14.	Preference to radio communication	High

	Factor	Operators response
	ENVIRONMENT	
15.	Noise levels in: Electricity powered Battery powered Diesel powered	 Low Low High
16.	Vibration levels	High

With regard to questions rated by the operators regarding the workspace, the access and leg space were poorly rated due to restrictive available space. The seats were almost without exception rated as uncomfortable to extremely uncomfortable due to the materials used, poor repair and the lack of backrest supports. Interesting to note, the operators rated the height of the seats to be 'just right', which does not coincide with the ergonomic dimensional evaluation. All indications are that this rating was based upon visual access from the seated position, as visual access was perceived to be imperative for operability and to ensure safety. It was more important to the operators to be able to see the track and guards than to be seated in a stable and supported posture. The cabs without canopies are perceived as leaving the operator vulnerable to dangers.

There was a strong preference to be forward facing in the direction of motion and to be pulling the hoppers and other rolling stock. This orientation was requested by the operators primarily for visual access for safety reasons, but would indeed be recommendable for an improved body posture.

The controls were rated as difficult to manipulate, particularly the handwheel brake and the crank handle starter. Understanding or reading of the labels of the controls was 'poor' as they were often illegible or absent. The communication system of the pea whistle was rated 'good' for hearing, although in additional comments it was noted that there were instances of limitations to this fact. The interpretation of the auditory signals however, was poor due to ambient noise. The operators rated a high preference to verbal communication suggested to be through a form of radio communication.

The environmental factors that received high ratings were exposure to vibration level (which was not specifically related to only one type of locomotive or mine) and noise levels on the diesel powered locomotives.

The majority of the questions requiring rating were rated poorly (low scores) and the issues of seating, orientation and visual access were indicated as extremely important to the operators.

5.2 Summary of the comments from the locomotive operators

The following information is derived from comments made by the operators additional to the rating responses to the standard questions discussed above.

5.2.1 Access

Operators perceived the available leg space in the cab to be inadequate to sit comfortably or be able to change their leg position. The space was further reduced by the use of the leg space for the storage of tools and emergency equipment.

5.2.2 Seats and Posture

The majority of the operators rated the seats of the locomotive as being uncomfortable. Many complained of the condition and poor repair of the seats and indeed reported that certain locomotives had had the seat completely removed. Seats that were constructed of metal or wood were rated as extremely uncomfortable. There were wooden seats that were observed to have sharp, geometric edges to the seatbase (refer to Figure 3.2.2.1). The operators described an adjustable, well-cushioned seat that had a back rest, as being suitable for their job.

5.2.3 Controls and Displays

The operators complained of being unable to easily access the brake or to apply the necessary forces quickly under emergency conditions. They did not report having problems understanding the controls or the displays. The cranking method of starting the locomotive was described as strenuous. The method of choice was a key start. They also made note that they prefer a foot brake to the handwheel system as they perceive the latter to be too slow to effectively apply in times of emergency.

5.2.4 Viewing angles

The operators reported a strong preference for facing the direction of locomotive movement while in transit. They would always want to pull rather than push the hoppers. There was perceived danger in having the guard use a hopper as a guard car, as the operator could not clearly see the guard to react to an emergency situation. There was also a perception that the guard was at risk of falling out of the hopper and sustaining critical if not fatal injuries.

There were complaints of the operators' restricted field of view of the guard when the guard stands in front of the hoppers. The size and position of the battery in relation to the operator in the cab was identified as the primary cause.

5.2.5 Safety hazards

The operators were concerned about the potential hazard of the loose lying equipment at their feet, flying and striking them in the event of an accident. The request for a dedicated storage, out of the cab for the tools was often noted. Likewise, they reported being concerned about the potential hazard of falling rocks and water while operating locomotives that did not have canopies. The operators requested a cab with a canopy for protection.

Operators were dissatisfied with maintenance and service of the locomotives and at times perceived the operation of said locomotives to be unsafe. The operators identified the poor maintenance of the rails and the locomotive as being the major cause of derailment accidents. They considered re-railing a locomotive or hopper as time consuming, strenuous and interfering with production.

The operators rated the task of changing the battery using the chain block method as very strenuous, time consuming and dangerous. They requested the availability of improved systems and/or equipment to safely change batteries. They voiced a preference for the remote control method (electric hoist) of changing the battery.

The battery was perceived as being a danger to themselves during a collision or derailing. They reported the battery as not being securely clamped to the chassis, which under emergency conditions may result in a shearing action towards the operator. This perception may contribute towards the reaction of the operators to jump clear of the cab in emergency conditions.

5.2.6 Environmental exposure

Operators of the diesel powered locomotive complained of exposure to smoke from the diesel engine. The same operators complained of the exposure to the high level of noise from the engine as being disturbing, as well as the noise from the ventilation fans interfering with communication.

They also reported visibility in the haulage as poor due to excessive smoke from the diesel-powered engine.

Vibration was reported by some of the operators as causing body discomfort, particularly around the kidney area. They perceived the cause of the vibration to be as a result of poor maintenance of the rails.

5.2.7 Method of Communication

The operators reported the pea whistle communication method as becoming increasingly ineffectual when locomotives are pushing a long line of hoppers.

The operators reported the misinterpretation of the pea whistle signal in areas of high ambient noise such as near the fans or when in travelling through bends. The operators preferred the concept of radio communication to pea whistle communication particularly in instances of high noise levels and long distances between the guard and the operator.

5.3 Additional Remarks

The operators identified other factors that were affecting his operational tasks and safety, but which were not directly related to the interface with the locomotives as the following:

- The spaces at the ore passes are too small and/or filled with water for an operator to easily escape if there were imminent danger.

- The handheld locomotive tail end battery lamp was reported as being too heavy and bulky to carry during the entire shift. The lamp was also noted to be of a disturbance to other passengers when being transported in the cage. The operators recommended having the lamp charged on the same charging system as the locomotive battery i.e. keeping the lamp with the locomotive rather than returning it to the cap lamp battery charging area on the surface.

- Jacking equipment was heavy and requires extremely high forces to operate.

5.4 Summary of perceptual assessment

The main factors perceived by the operators to be the common contributing causes of accidents were:

- Restricted visual field leading to collision
- Misinterpretation of the pea whistle
- Braking system being difficult to apply
- Heavy load haulage of the locomotive causing ineffectual braking
- Jack slipping from the attachment surface
- Procedure of re-railing the locomotive or hopper
- Procedure for changing the battery.

In general, the operators perceived the locomotive operator’s job to be dangerous and have identified several factors that confirm the ergonomic deficiencies of the locomotives.

6. Summary of the design deficiencies in the existing fleet of mine locomotives

The objective and subjective evaluations on the existing fleet of mine locomotives indicated safety related design deficiencies that can be improved through ergonomics intervention. The dimensional evaluations related the physical dimensional characteristics of the locomotives to the physical characteristics of the design population and ergonomics design standards, guidelines and recommendations. Complimentary to this, the task analysis of locomotive operator tasks indicated operability issues that require intervention. Lastly, the locomotive operator's subjective perceptual rating on ergonomic aspects contributed towards formulating the safety, design and operability deficiencies of mine locomotives. These deficiencies are discussed briefly in the following paragraphs.

6.1 Access provisions

Entry to and exit from the locomotive cabin were identified as a deficiency of the existing fleet. High entrance heights and low roof restrictions in the absence of handholds and handrails were noted.

6.2 Seating

Seating in mine locomotives was found to be generally poor. The stool type seats provided inadequate support due to the seat size, provided no support for the back, were not adjustable and were in a poor state of repair. Deficiencies of other seats included the lack of provision for the cap lamp battery and self-rescue devices.

6.3 Body posture and orientation

It was found that locomotive operators adopted awkward body postures to perform the required tasks safely, effectively and comfortably. This was caused by the control location, seat position and body orientation to the direction of travel. Standing, semi-standing or seated postures with unsupported feet were deficiencies as a result of the absence of a seat or the seat height.

6.4 Workspace

Legroom inside the locomotive cabs was found to be restrictive due to the cab size and layout and equipment being carried on the cab floor.

6.5 Controls and displays

Control and display layout coding and stereotype were found to be inconsistently applied to the design of the locomotives. The application of a handwheel as service brake is a major deficiency. Physical reach to controls and labelling were also identified as deficiencies.

6.6 Visual access

Forward and rearward visual access to the track were identified as deficiencies. This was attributed in part to the body orientation in relation to the travel direction and restrictive cab structures.

6.7 Communication

The current guard and locomotive operator method of communication with pea whistle were found to be deficient.

6.8 Inspection requirements

The inspection and examination requirements for mechanical components were found to be incompatible with operator abilities.

6.9 Storage provisions

Provisions for tool and equipment storage on the locomotive were inadequate.

6.10 Changing and retaining the battery

The battery handling methods and retaining mechanisms were identified as deficiencies.

6.11 Re-railing and jacking

The requirement for manual handling and the risk of the jack slipping during re-railing procedures were found to be deficiencies.

6.12 Operator protection

Frequent remarks concerning the requirement for operator protection from falling rocks, water and accidents were noted. This concern is related to the operator's perception of safety, well being, and ability to be in control under normal and emergency conditions.

6.13 Rolling stock

Access, seating and space provisions of man carriages were identified as deficiencies.

7. Ideal design for a mine locomotive

The ergonomically ideal design of a mine locomotive should address the aspects of efficiency, safety and operator satisfaction for the South African user population and local mining conditions. The objectives of the ideal design are to provide work surroundings which foster effective procedures, work patterns, operator safety and health and minimise aspects which degrade human performance or increase error. The design must ensure that operator workload, accuracy, time constraints, mental processing and communication requirements do not exceed operator capabilities.

7.1 Ergonomics requirements for ideal design

The ideal design of a mine locomotive must reflect the following ergonomics factors:

- Adequate space for operators, equipment and free volume for the activities and movements they require to perform the task under normal and emergency conditions.
- Adequate physical, visual, auditory and other communication links between operator and between the operator and the locomotive and between the operator and the outside under normal and emergency conditions.
- Efficient arrangement of controls, displays and equipment, and compatibility of the design, location and layout of controls, displays and workspaces with the clothing and personal equipment to be worn by operators.
- Safe and adequate provisions for entry and exit under normal and adverse conditions.
- Body orientation to facilitate safe and effective task performance.
- Protection from thermal, electrical, mechanical and electromagnetic hazards.
- Safeguards against uncontrolled vibration, acceleration, noise and toxic fumes.
- Adequate illumination for inspecting, operating and controlling the locomotive.
- Provision of acceptable body support in the form of seating.
- Adequate emergency systems for contingencies, escape, survival and rescue.
- Fail-safe design to protect against damage to equipment, injury to operators or inadvertent operation of critical controls.
- Simplest design consistent with functional requirements and service conditions.
- Applicable system and operator safety factors to minimise human error, particularly under non-routine and emergency conditions.

7.2 International locomotive design status

In order to come to a more workable design solution for a mine locomotive it is required to conciliate these high level design requirements discussed above with the current best practices world-wide and the deficiencies identified for the current fleet. The international survey of mine locomotives included extensive literature and internet searches, product information brochures, catalogues and personal correspondence. Information was obtained from manufacturers of locomotives in the United States of America, United Kingdom, Canada, Germany, Sweden and Russia. The investigation into the design status of the international fleet of mine locomotives involved two approaches : firstly, how and to what degree the international locomotive manufacturers addressed and overcame the major design deficiencies identified for the local fleet and secondly, to what extent the local ergonomics requirements for the ideal design have been met. Paragraph 6 provides a summary of the design deficiencies in the existing fleet while paragraph 7.1 list the ergonomics factors that should be addressed and should be reflected in the ideal design. It should be noted that there is a close relationship between these approaches. The deficiencies were identified and analysed and this led into the requirements for an ideal design. The levels of the approaches are however significantly different with the ideal locomotive requirements being rather at systems safety and efficiency level rather than a detail component level. As the deficiencies of the existing fleet were to a large degree generic in nature across the spectrum of locomotive types (i.e. battery, diesel and trolley/electric) the different types were not addressed individually.

The assessment of the international locomotives is presented in Appendix 6. A discussion on the generic deficiencies among the locomotives and features of the ideal design are also included. The detail results and findings are not repeated here. The results indicate that international designs still include locomotives that are, with regard to ergonomics comparable with the local fleet, including some of the deficiencies. Ergonomics advances include a tendency towards body orientation in the direction of travel, semi-enclosed and fully enclosed cabs and improved driver protection structures.

From the results it is clear that the current international locomotive ergonomics characteristics are not universally superior to that of the local fleet. There is also no one locomotive currently in production that addresses all the deficiencies of the local locomotives or satisfy all the requirements of the ideal locomotive design. It was apparent that for the smaller tonnage locomotives, the same deficiencies as for the local fleet were identified. However, for the larger tonnage locomotives the locomotive ergonomics improved, but still incorporated design features that cannot be reconciled with sound ergonomics.

From this assessment it is also concluded that the monorail type of locomotive manufactured in Europe currently provides the "best practice" regarding the ergonomics of the locomotive cabin designs even though same changes are indicated in order to accommodate the South African user population. The challenge is to convert or modify the design of the monorail cabin to that of conventional rail bound locomotives. It should further be noted that the introduction of foreign designs into South Africa would nevertheless require a thorough ergonomics evaluation to assess the compliance to South African anthropometric and biomechanic characteristics and thereafter the modification to rectify deficiencies. An alternative approach would be to provide the international manufacturer with detailed specifications and guidelines (as contained in this report) according to which the equipment that would be suitable for the South African work force can be manufactured.

7.3 Ergonomics guidelines for mine locomotive and rolling stock design

Table 7.3.1 presents the ergonomics guidelines for the design of locomotives. The guidelines are based on the anthropometry and biomechanics of the South African population and to accommodate the 5th percentile to 95th percentile male and female user. Other guidelines are derived from national, international, commercial and military standards. Table 7.3.2 presents ergonomics guidelines for the design of man carriages.

Table 7.3.1: Ergonomics guidelines for mine locomotive design

Parameter	Range of Values	Preferred
Access		
Surface to entrance level height	380 mm (maximum)	
Entrance level to floor height	0 mm – 200 mm	0 mm
Entrance width	500 mm – 760 mm	760 mm
Entrance level to roof line		1300 mm (minimum)
Handgrips:		
• length	150 mm – 300 mm	200 mm
• diameter	25 mm – 32 mm	32 mm
• hand clearance between the retaining surface to inner surface of handgrip		76 mm

Parameter	Range of Values	Preferred
• hand clearance area surrounding the handgrip		76 mm
• centre of handgrip to ground	1000 mm-1470 mm	1250 mm
Workspace		
• leg clearance (forward horizontal distance from SRP to cab panel)	910 mm – 1000 mm	1000 mm
• head clearance (vertical distance from SRP to roof line)	Erect seated stature of the 95th percentile man +100 mm	1070 mm
• arm clearance (dynamic elbow/abducted arm space, the minimum width of the cab)	910 mm (minimum)	
• foot clearance (the envelop surrounding the feet on the floor line)	64 mm x 64 mm to 100 mm x100 mm	100 mm x 100 mm
Seating		
Type	Cushioned seat with backrest that can accommodate the personal protective equipment, no sharp edges	T-back cut out
Vertical adjustment range from recommended midrange	0 mm – 40 mm up and down	80 mm
Horizontal adjustment to the fore and aft positions	150 mm – 200 mm	150 mm
Seat base:		
• cushion thickness	25 mm – 50 mm	38 mm
• width	485 mm – 510 mm	
• depth	420 mm – 445 mm	
• height (SRP to floor)	300 mm – 550 mm	350 mm
• Slope down towards the SRP	5° - 8°	
Seat back:		
• height (from SRP)	300 mm – 650 mm	600 mm
• width	480 mm – 510 mm 200 mm minimum only in area where provision for personal protective equipment at waist level is required	485 mm
• Angle from vertical plane	6.5° - 30°	
Arm rest:		
• SRP to top surface of the armrest		235 mm
• width	50 mm – 120 mm	75 mm
• length	210 mm – 300 mm	220 mm
• Spacing	480 mm – 510 mm	480 mm
Controls		
Angle between the upper arm and the trunk link (abduction)	0° - 45°	30°
Forward reach distance (from SRP to hand controls in the most forward seat position for the 5th percentile person and in the most rear seat	Forward seat position: 180 mm – 330 mm	

Parameter	Range of Values	Preferred
position for the 95th percentile person	Rear seat position: 350 mm – 500 mm	
Vertical distance from SRP to the hand controls	300 mm – 380 mm	320 mm
Hand controls		
• clearance area around the control	76 mm	76 mm
• clearance – front		75 mm
• minimum length of hand control portion	115 mm – 150 mm	150 mm
• hand control diameter	25 mm – 32 mm	32 mm
• diameter of push button controls	13 mm – 19 mm	19 mm
• force activation of lever hand controls	200 N (maximum)	150 N
• force activation of push buttons	0.26 N – 4.5 N	1 N
Foot controls		
• distance from SRP to bottom of foot pedals	690 mm – 860 mm	
• angle of foot pedals	< 30°	20°
• width of foot pedals and depth	75 mm x 100 mm	
• force of activation of foot pedals	400 N (maximum)	
• clearance between pedals (must allow sufficient space to avoid inadvertent application or sufficient space to pass a boot in between the pedals.)	50 mm or 150 mm	50 mm
Viewing angles		
Eyeview above 0° horizontal	15°	
Eyeview below 0° horizontal	30°	
Eyeview to either side	90° / 90°	
Distance obscured in front of the vehicle	1500 mm (maximum)	
Parameter	**Range of Values**	**Preferred**
Body orientation	in direction of movement	
Method of communication		
	Verbal and auditory	Radio
Storage provision		
• Personal protective equipment		Dedicated area
• Personal items such as food and water	Dedicated storage area	
Environmental influences		
Noise	Hearing protection > 85 dB	Enclosed cab <65 dB
Vibration		Attenuation of vibration should be handled by seat suspension and material to reduce exposure to vibration
Smoke, dust		Half mask with cartridge filter
Safety warning systems		Red flashing cap light Red/white light on

Parameter	Range of Values	Preferred
		locomotive
Controlled environmental factors		
Airflow		
Ventilation for cab space < 4.25 m^3	0.85 m^3 air per minute	
Air-conditioning		
Air-conditioning used for temperatures exceeding (air must not be positioned to directly flow onto operator)	> 29°C	>25°C
Humidity	45% relative humidity at 21°C, value will reduce down to 15% with increasing temps	
Heating Required for dry bulb temperature (air must not be directed onto operator)	< 10 °C	
Illumination		
Interior enclosed cab	Instrumentation lighting	
Displays - backlit	Red or white flood light 0.07 cd/m² – 0.35 cd/m²	
Forward headlight	20 lux (minimum)	80 lux
Displays		
Label placement		Above the controls
Label type		Symbols
Alphanumeric characters and displays		
• Width	70% of the height	
• Height	5 mm (minimum)	
Viewing angle from centre axis	0° - 65°	0° - 45°
Viewing distance from eye reference point	330 mm – 630 mm	
Orientation of display from normal line of vision	>45°and 90°<	
*SRP = is the point of reference where the three axis intersect between the seatbase and seatback.		

Table 7.3.2: Ergonomic guidelines for rolling stock

Parameter	Range of Values	Preferred
Access height to entrance level	380 mm (maximum)	
Access width	610 mm (minimum)	760 mm (minimum)
Seat depth	380 mm to 445 mm	425 mm
Seat width required with self rescuer and battery at waist level	500 mm (minimum)	
Handgrips at doorways	Refer to Access in Table 7.3.1	

7.4 Ideal locomotive design

The ideal locomotive design is intended to include the ergonomics requirements and guidelines presented in the preceding paragraphs into a workable concept while at the same time addressing the deficiencies identified for the current fleet.

The design follows the stereotype of motor vehicles. This incorporates the use of hand and foot controls, body orientation facing in the direction of travel and adequate body support. The layout and major components of the cab are presented in Figure 7.4.1, Figure 7.4.2 and Figure 7.4.3. The features of the design is presented in the paragraphs below.

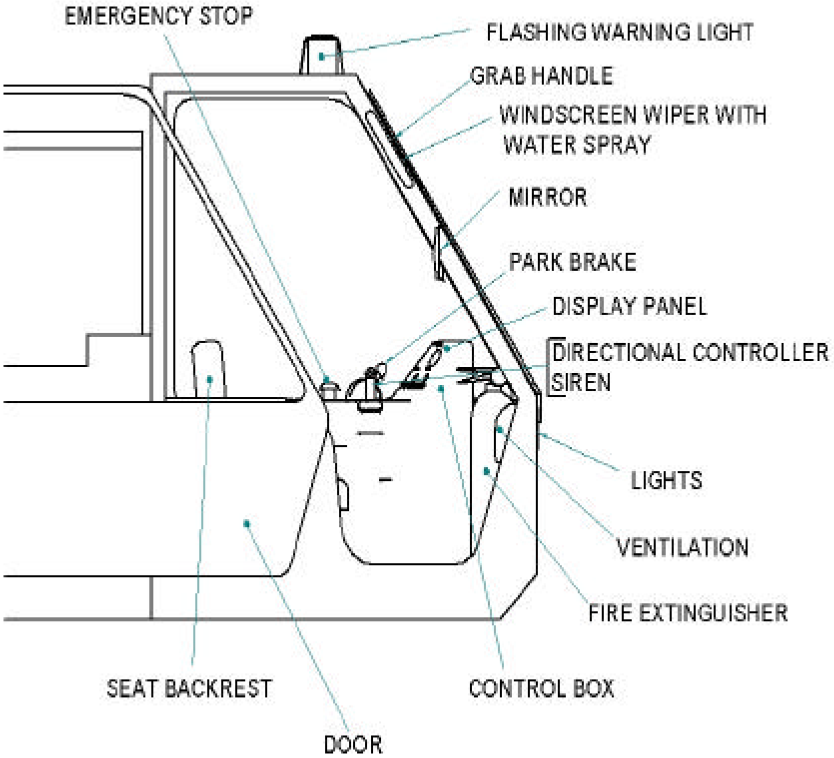


Figure 7.4.1: Ideal design – cab side view

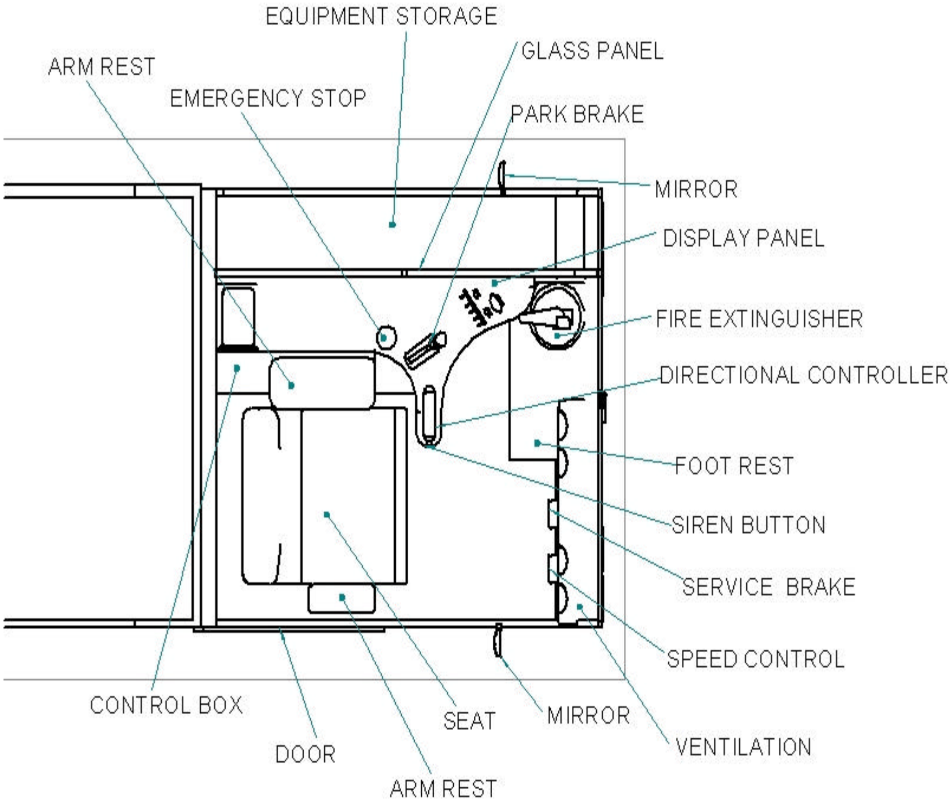


Figure 7.4.2: Ideal design – cab top view

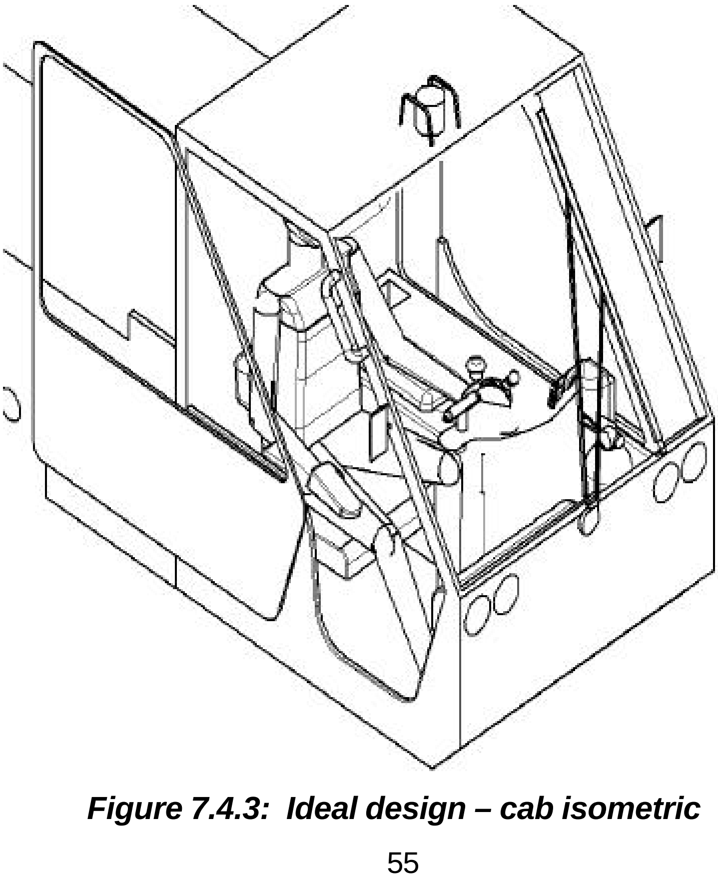


Figure 7.4.3: Ideal design – cab isometric

7.4.1 Access and workspace

Access to the cab and seat is provided from the right hand side of the cab. An emergency exit is available towards the left over the control box and equipment storage bin. The workspace is adequate for the 95th percentile user (refer to Figure 7.4.1.1). Provision is made for equipment storage, personal protective equipment storage and hand portable protection devices (fire extinguisher).

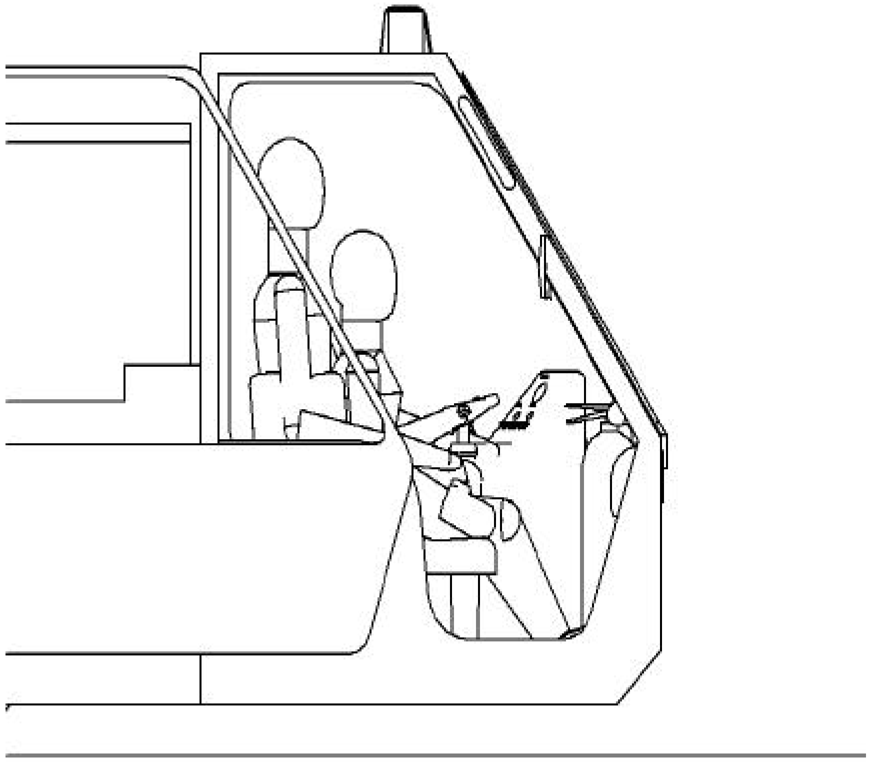


Figure 7.4.1.1: Ideal design – operator accommodations, 95th percentile male and 5th percentile female

7.4.2 Seating

An integral skin flame retardant polyurethane foam type seat with horizontal adjustment and T-shape backrest is provided. Horizontal adjustment provides adequate movement to effectively support the 5th percentile to 95th percentile male and female operator. As forward vision was found adequate, vertical adjustment is not required. The T-shaped backrest provides space for the belt worn cap lamp battery and self-rescuer. As whole body vibration can negatively influence health, a mechanical or pneumatic suspension is included in the seat configuration.

7.4.3 Controls

A magnetic switch key or access card switch system affording the same level of access security is used to activate the controller. A directional controller is provided for left hand operation and with palm activated (switch on top) deadman switch in the location indicated in Figure 7.4.1 and Figure 7.4.2. The controller is spring loaded with neutral centre position. The direction of control movement relates to intended locomotive movement. The warning siren pushbutton is incorporated on the right side of the directional controller for thumb operation, even when operating the controller. The directional controller controls only direction, the acceleration and speed component is provided through a floor mounted, right foot operated pedal (similar to the accelerometer pedal in a motor vehicle). The sequence of operation is fixed so that the directional controller has to be operated (direction selection) before the speed control (accelerator) would have any effect. The combination of control actions where the speed control is depressed and the directional controller moved to the opposite direction would disconnect or switch off propulsion to the wheels. Releasing of the speed control will have the same effect.

A floor mounted, foot operated power assisted service brake in the location indicated in Figure 3.4.2 is provided. A hand operated power assisted park brake is provided to the left of the directional controller. An emergency stop hand operated push button switch is provided to the left of the park brake. The switch will cut the propulsion to the wheels and apply the brakes automatically. Resetting will require an intentional action from the operator.

7.4.4 Displays

All controls and displays are labelled with symbols rather than text. Displays for speed indication, hydraulic or pneumatic pressure, voltage, amperage and charge condition (as appropriate for the propulsion type) are functionally grouped on the display panel. Primary displays are positioned towards the right on the display panel.

7.4.5 Body orientation and visual access

The operator orientation is in the primary direction of travel for a front driven train. The angles of view are presented in Figure 7.4.5.1 and Figure 7.4.5.2. Rear view mirrors are provided only to confirm the guard's position during shunting operations. It is not intended to be used as driving aids.

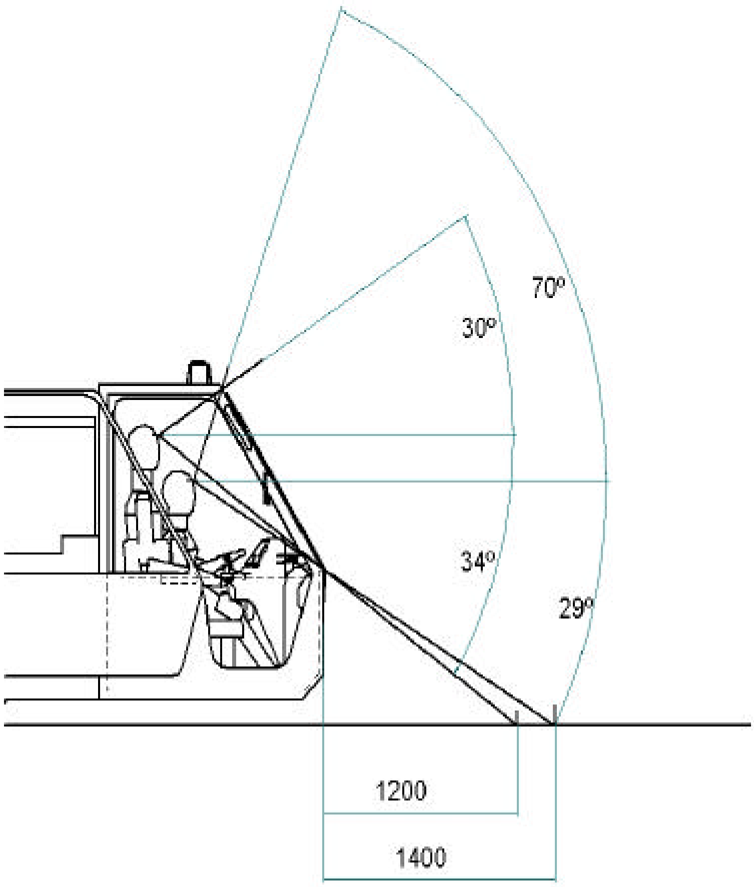


Figure 7.4.5.1: Forward visual angles

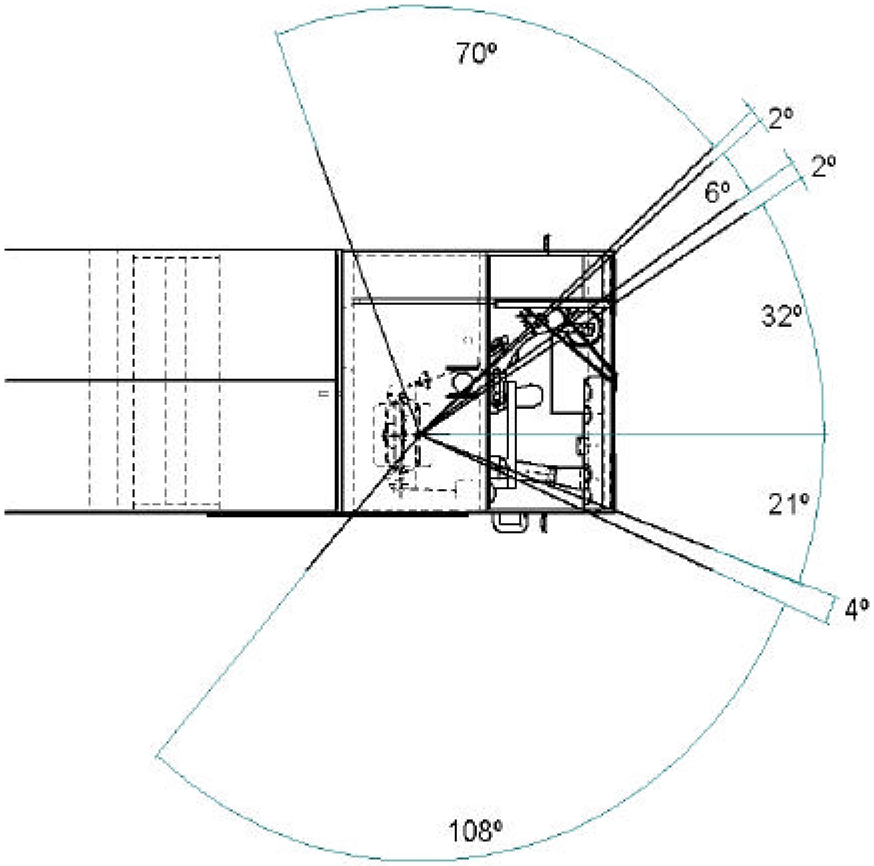


Figure 7.4.5.2: Sideways visual angles

7.4.6 Operational concept

The operational concept for this locomotive is to always employ two locomotives with a train, one at each end and with the cabs at the leading ends (similar to dedicated haulage type trains). Each locomotive would have an operator, but control will only be executed from one cab at any one time. Control over the train is transferred between the operators through a simple procedure; operator A requests control of the train, the request is acknowledged by B, only after A has acknowledged B's acknowledgement will control be transferred to A. This procedure is proposed as an indication light logic control system being displayed on the display panel.

The two locomotive trains will enable longer trains and handle increased tonnage in shorter time periods and thus increase production. The train configuration does not only provide visual access in the direction of travel but would allow the train to be always in a pulling configuration (front driven train). However, a single locomotive will still have to shunt hoppers into development areas where hoppers are required to move into end positions for the loading of ore.

No coupling system or buffer is provided at the front end of the cab. The locomotive is not intended to be operated as pushing a load with the cab leading.

7.4.7 Warning systems

An amber flashing light is mounted on the roof of the locomotive. The light is connected to the logic device monitoring which locomotive of the train has operational control. The amber light will flash on the roof of the locomotive which has no control over the train, irrespective of the direction in which the train is travelling. This additional signal will provide warning to personnel of oncoming or departing trains where special caution is required because the train operator would not be able to keep a proper lookout at the end of the train where the light is flashing.

The locomotives should still be provided with reflective material at least at the front and rear.

7.4.8 Locomotive head and tail lights

The design incorporates an automatic light system, which operates according to the direction of travel. On the insertion of the switch key or card the headlamps at both ends of the train illuminates with white light. Upon operation of the hand operated directional controller and the speed control pedal the headlights will remain illuminated at the leading end of the train and switch off at the trailing end while the red tail light will be illuminated at the end. Head light–tail light activation will occur independently of the operator. A head and tail light test switch is incorporated in the design to facilitate inspection.

7.4.9 Guard personal protective lights

As visibility of the guard remains a safety issue, a small flashing red light (high efficiency light emitting diode) is attached to the back of the hard hat. This red light will provide additional feedback to the operator and other miners as to the position of the guard. The white cap light, in front and the red flashing light at the back will adhere to the stereotype used on the locomotive lighting system.

7.4.10 Battery retaining mechanisms and jacking points

Corner casting with twist lock retaining mechanism is used in the design to ensure that the battery is retained under emergency conditions. Dedicated areas are required to reduce the risk of jack slipping during re-railing procedures.

7.4.11 Operator protection

A solid frame cab with a roof, a single sliding door and safety glass windows are used for temperature, humidity and air flow for optimal operator protection. To the left of the operator, a glass panel divides the cab from the equipment storage. This panel is used as emergency exit. Although glass introduces potential hazards, the use of shatter resistant polymers is not advised due to its low scratch resistance. The enclosed cab will be environmentally controlled for temperature, humidity and air flow.

This cab design protects the operator from exposure to potential hazards such as smoke, noise, falling rocks and water. The closed cab configuration provides a stable seated posture, an extended legs position and the ability to quickly activate the floor service brake, will provide the operator with sufficient psychological confidence in his working environment. A positive perception of the safety and protection of his cab environment will substantially reduce their current reaction to jump clear of the cab in times of crisis.

The design of the cab interior incorporates rounded edges and corners throughout to reduce the risk of injury. The protection structure height and width as indicated in the layout drawings are within the generally acceptable limits for mine locomotives.

7.4.12 Layout drawings

Layout drawings with major dimensions are presented in Appendix 6.

8. Practical design for a mine locomotive

Practical considerations frequently influence ergonomics design concepts in order to generate cost effective workable solutions. The considerations may include legislative and other statuary requirements, mechanical and electrical limitations and requirements, availability of system components (off the shelf vs development of), acquisition cost and cost of maintenance. New guidelines for railbound transport equipment is in development. Two documents of the Department of Minerals and Energy, Mine Health and Safety Inspectorate “Guideline for the Compilation of a Mandatory Code of Practice for Underground Railbound Transport Equipment”, dated 27 September 2000 and “Proposed Regulations for the Operation of Surface and Underground Railbound Transport Equipment”, dated 27 September 2000 provides pertinent guidance on a number or ergonomics factors, both directly and indirectly. Mining groups have also developed guidelines on trackbound operations and locomotives and have included ergonomics factors for consideration. Examples are “Guidelines for Locomotives used for Tramming Operations”, Anglogold Limited (2000) and “Underground Locomotive Practice”, Gold Fields Limited (1998). The following paragraphs address the influence of the practical considerations in the generation of the design while still incorporating sound ergonomics.

8.1 Practical influences

The major practical influences on the ideal design were identified as the following:

- Enclosed cab
- Application of motor vehicle stereotypes to railbound equipment stereotypes
- Two locomotives per train

8.2 Practical locomotive

The practical design follows the concept of the ideal design closely but with the exception of the practical provisions. Figure 8.2.1 to Figure 8.2.3 show the practical design.

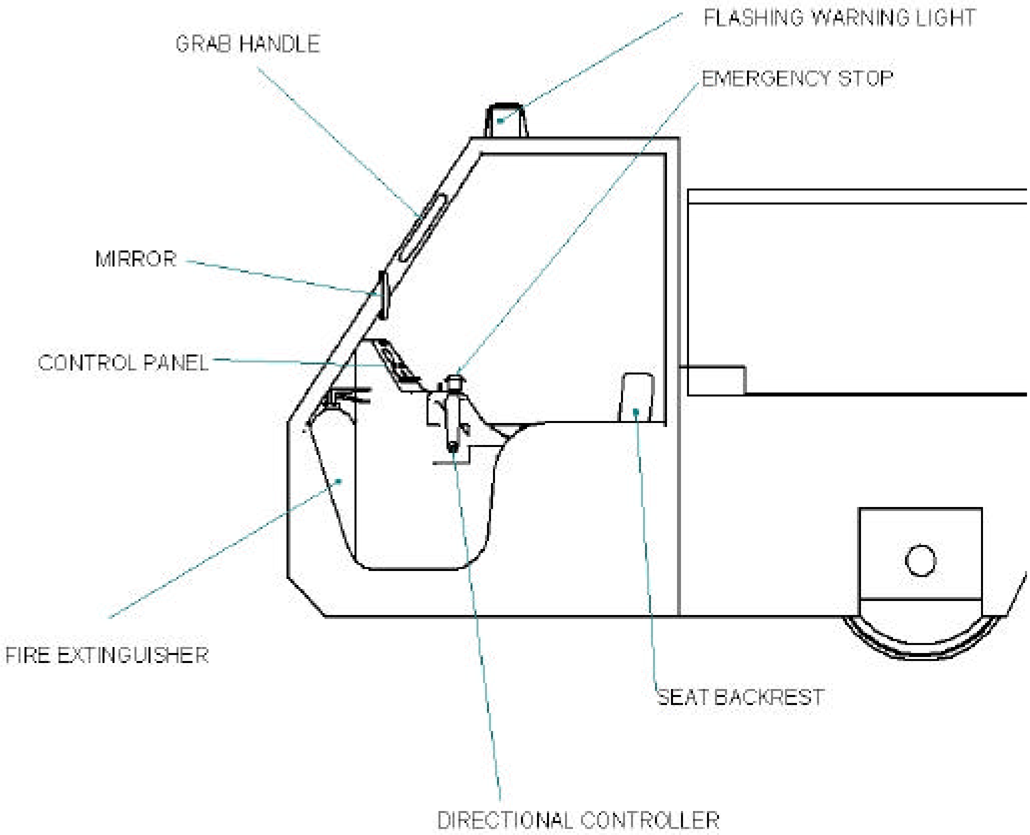


Figure 8.2.1: Practical design – cab side view

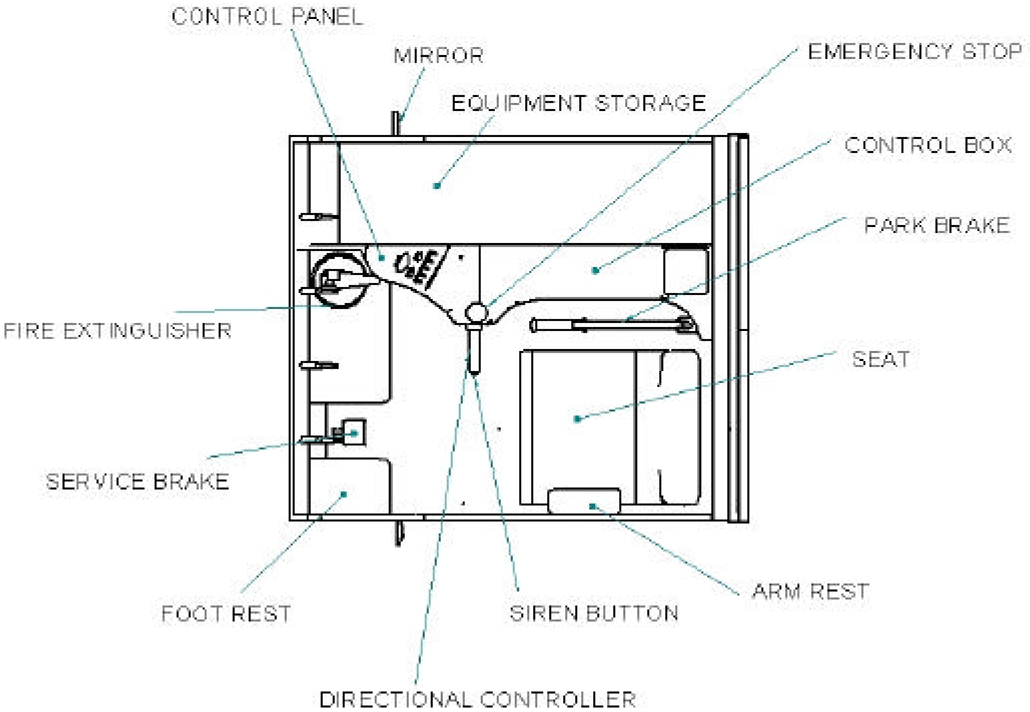


Figure 8.2.2: Practical design – cab top view

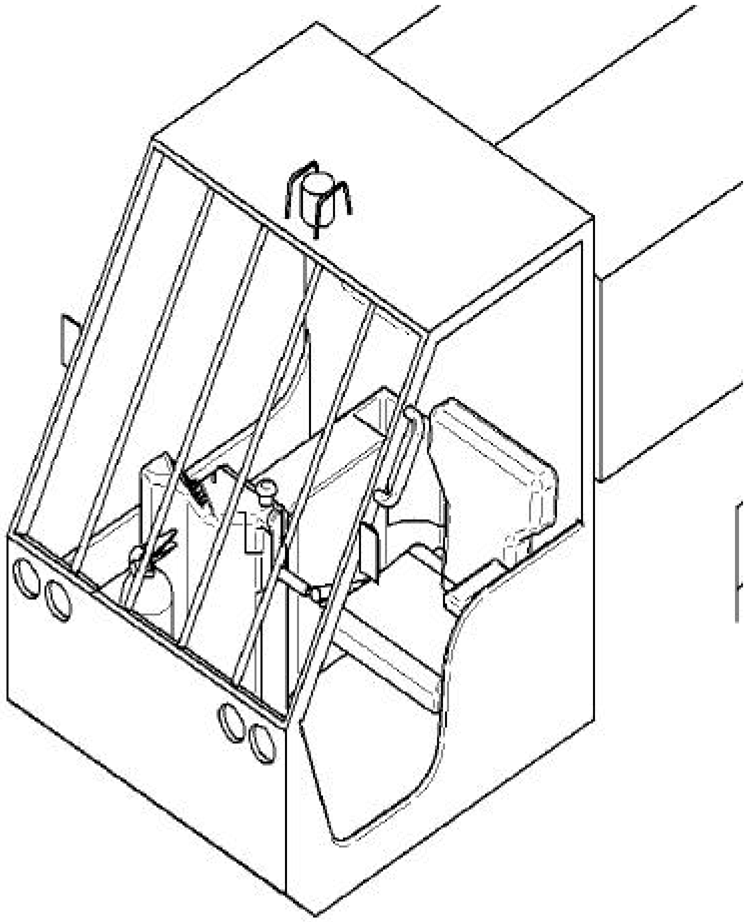


Figure 8.2.3: Practical design – cab isometric

8.2.1 Cab

The major cab changes is related to the enclosed nature of the ideal design cab. Although the normal disadvantages of an enclosed cab have been overcome in the ideal design by providing adequate vision from the cab and easy access, other factors influence the practicality thereof. Due to the low speed of the locomotives, a glass windshield is not an absolute requirement. Cleaning and demisting of the windows, especially with airconditioning provisions, will place additional and tedious tasks on the operator. The use of glass underground remains problematic because it is fragile when applied for large surfaces and, although safety glass, breakage and splinters continue to be a hazard. As cap lamps will, in all probability, still be worn by operators inside the enclosed cab, reflection of the light source from the glass surfaces can reduce operator vision to the outside. Cap lamps will therefore have to be switched off. Another influence is that the operator is partially denied the ability to use olfactory (sense of smell) input as warning of impending danger of smoke, fuel or other vapours.

The design now incorporates a semi-enclosed cab in which the glass windshield has been replaced with protection bars and the sliding side door and glass panel removed altogether. The same protection is still provided against collision. The seat position and operator posture ensures restraint of the operator within the cab.

Entry to the cab is now from the left to enable access to the seat and controls as discussed in the next paragraph.

8.2.2 Controls and control stereotype

In the practical design the major elements of the railbound equipment stereotype are retained, i.e. hand control of direction and speed and hand operated park brake. However, the service brake is allocated to a foot operated pedal due to the high force requirements of the braking mechanism.

The stereotype also calls for right handed operation. As shown in Figure 8.2.1 and Figure 8.2.2 the current master controller type directional and speed control device is used. Activation of the controller is with magnetic isolator or card system as described for the ideal design. An emergency switch is provided in close proximity to the right hand position.

A hand operated long levered park brake is provided. This type of control is appropriate for high force exertion with the hand and arm and power assistance is therefore not necessarily required. A short finger operated release lever is provided at the end of the brake lever. The advantage of the control is also related to the positive visual and tactile feedback that is provided to the operator on the position of the control. In the released position the lever will be down and in horizontal orientation. Driving with the brake partially engaged will be easily recognisable.

A single foot operated service brake is provided.

8.2.3 Single locomotive per train

The ideal design proposed two locomotives per train. This may not be cost effective. The practical design incorporates a single locomotive with a guard car at the other end. The guard car replicates the controls and control systems of the locomotive but is not self-propelled. Figure 8.2.3.1 to Figure 8.2.3.3 show the general layout and configuration of the guard car. The car is electronically connected to the locomotive by cable or radio link and can fully control the locomotive. A redundant braking system is proposed. Due to the relative low mass of the guard car, it cannot effectively brake a fully loaded train and locomotive. Therefore the guard car must have capabilities simultaneously activate the brakes of the locomotive and the guard car. Electronic interlocks are required to preclude the locomotive from driving off with the guard car park brake engaged.

It would still be possible to operate the locomotive alone in the typical configuration used for mine development processes. All other design features of the ideal design, including flashing ambient lights, personal flashing lights and transfer of locomotive control between operators are applicable for the practical design.

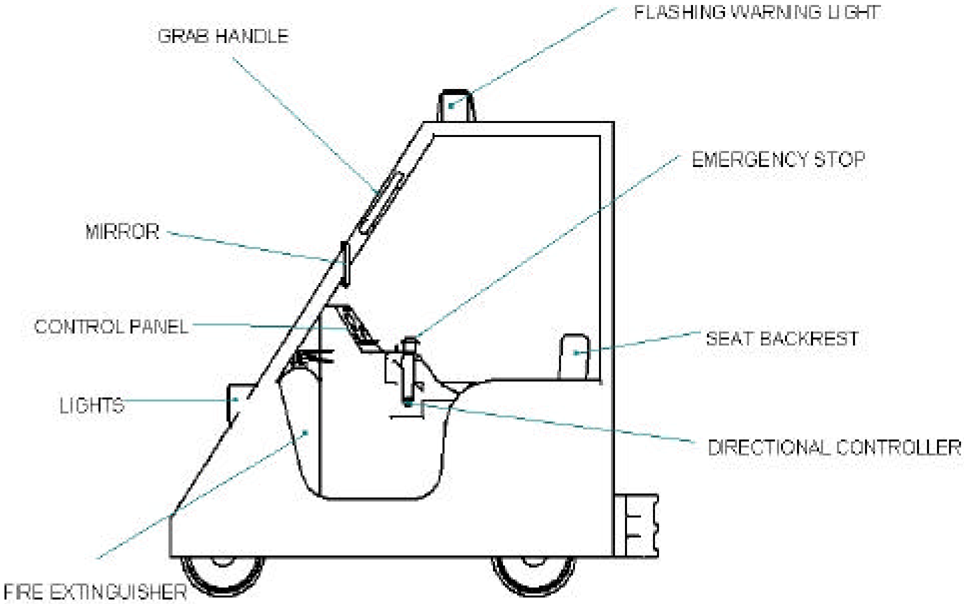


Figure 8.2.3.1: Guard car – cab side view

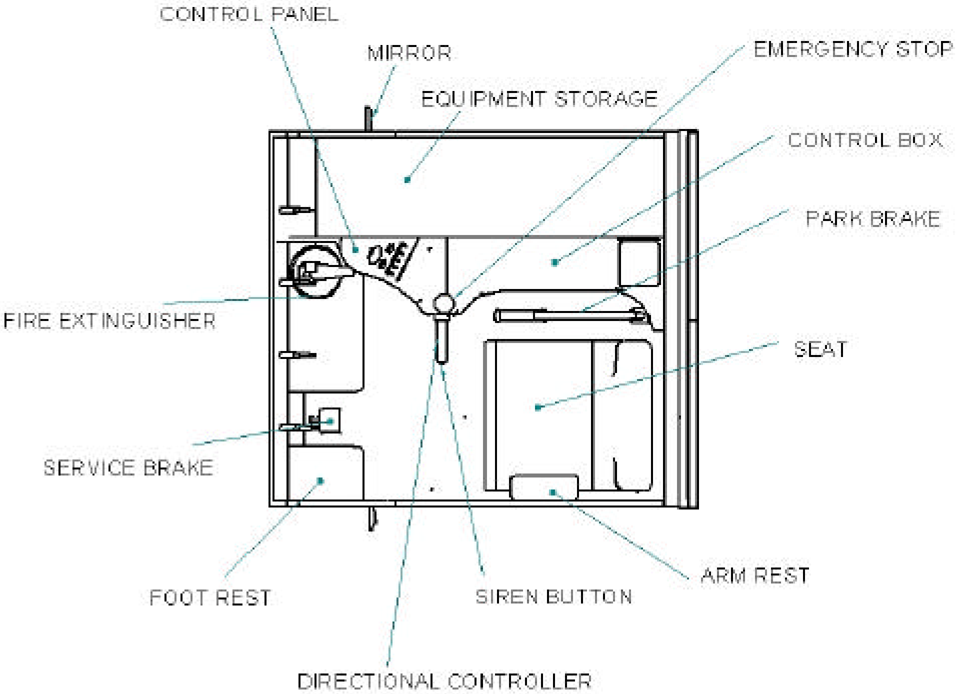


Figure 8.2.3.2: Guard car – cab top view

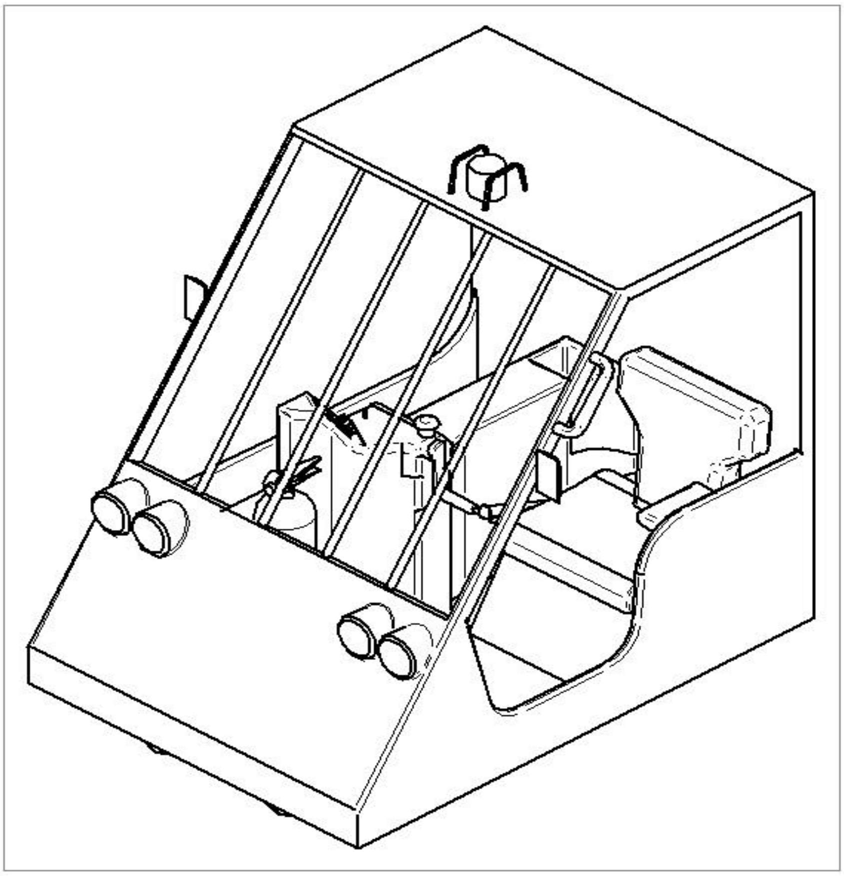


Figure 8.2.3.3: Guard car – isometric view

8.2.4 Layout drawings

Layout drawings with major dimensions are presented in Appendix 7.

9. Proposed interventions on the existing fleet

The ergonomic interventions required to improve the safety aspects of the current fleet are derived from the deficiencies identified from the objective and subjective evaluations and statutory requirements. Section 6 provides the summary of the deficiencies. The interventions have also been deemed as practicable and reasonable adaptations. All of the deficiencies could not be addressed, as many of the current configurations did not allow for further changes without incurring extensive costs. The practical and ideal designs would comprehensively address the entire range of deficiencies.

9.1 Access

Provide a cut-out on the front panel of the leading end of the cab and provide a hinged door. The surface to entrance height should not exceed 380 mm and the width of the access should not be less than 450 mm.

An equipment bin of approximately 450 mm x 1200 mm x 240 mm with a hinged lid can be constructed or attached to the bottom of the entrance level. Tread plates placed on top surface of the lid will reduce slippage. The bin will act a dual capacity as a step to improve access from the side of the locomotive and to store equipment. The present access side panels should be increased in height or replaced with a panel that will be above the level of the seated operator's elbow. Safety provisions would dictate that the operator must access from the side of the locomotive only. The side entry onto the step and then through the access door is safer and easier than stepping over a panel that is too high. Handgrip rails should be attached on the one side of the access opening to assist with safe entry.

The coupling system at the front of the locomotive should be removed so that the train cannot be used for pushing with the cab end leading.

<u>Health and safety implication:</u> The improved access will result in a deduction of slips and falls and awkward postures during entry to and exit from the cab.

9.2 Seating and posture

As the orientation of the operator cannot be changed within the workspace of the existing fleet, an improved seat type and availability of support for the body must be introduced.

It is recommended that a padded seat with a backrest be provided that will allow space for personal protective equipment. The height of the stool from the floor level should be approximately 500 mm. This type of seat will improve comfort and provide support to the trunk. To further improve stability of the operator in an upright seated posture for the 5^{th} to 95^{th} percentile operator, a foot rest should be included in the cab. The rest surface should be approximately 200 mm high by 30 mm wide and be hinged so that it can be folded away and out of the foot space when not needed.

Raising the control box to allow for kick space (space that can accommodate the front part of the feet) underneath the box, in the locomotive configurations that allow for this intervention, will improve the utilisation of the workstation. Kick space would typically be at least 100 mm by 100 mm.

<u>Health and safety implication</u>: The improved seating will provide improved body support while accommodating personal protective equipment for the trunk and lower back it will reduce muscular fatigue. However, the risk remains for musculoskeletal stresses and strains to the neck region due to the lateral rotation of the neck for vision in the direction of travel.

9.3 Controls and displays

There must be a braking mechanism besides the handwheel park brake for service brake purposes. The handwheel brake must be dedicated for parking purposes only. The problem will still exist of the locomotive operating under a partially applied park brake, but reducing the frequency of used of the handwheel brake will reduce the incidence of this problem. The introduction of a T-bar or inverted L-bar hand operated lever as service brake will improve the control afforded to the operator. Where space allows in some configurations, a combined hand-foot operated service brake could be implemented and assist with high force application required for braking.

A siren must be placed within easy reach and visual access in close proximity to the master controller. All labels must be replaced with clearly legible and understood symbols.

Health and safety implication: These interventions will decrease the application of high forces with the upper extremities in awkward postures and result in the reduction of fatigue, trauma to the shoulder, cumulative trauma and other chronic conditions. Proper placement and labelling of controls will reduce operator error and increase speed of activation.

9.4 Visual access

In locomotive configurations where forward visual access is severely restricted, the restricting panel should be reduced to above the elbow level of the 95th percentile operator, which is typically 450 mm from the seat reference point (SRP).

Health and safety implication: Improved visual access will enhance direct visual contact with the surrounding areas and will improve the perceptual capability of the operator and thereby reduce reaction times for unexpected incidents and emergencies.

9.5 Communication

Personal verbal communication systems should be implemented to improve communication between operator and guard. A short distance radio communication device carried on the person is proposed.

Health and safety implication: Verbal communication will improve operator perception of instructions to improve the basis for decision making and reduce the margin for operator error.

9.6 Safety inspections

The mechanical inspection points should be appropriately marked with coloured paint to provide visual guidelines to operators on inspection points.

Health and safety implication: This intervention will improve the perceptual feedback for decision making and lead to a reduction of interpretation errors.

9.7 Equipment storage

A dedicated storage bin for tools should be provided as described in paragraph 9.1. This will eliminate the loose lying equipment on the cab floor as a safety hazard. The fire extinguisher should be removed out of the operator's workspace and securely fastened on the outer wall of the cab.

Health and safety implication: Proper storage of equipment will reduce slips, falls, contusions and the hazards associated with moving objects.

9.8 Other safety aspects

To improve visibility and therefore protection of the guard, a small flashing red light (flashing high efficiency light emitting diode) should be fixed to the back of the guards hard hat.

To comply with statutory regulations a red tail light and white head light system can be implemented on locomotives. Similar to the automatic light system discussed for the ideal design to replace the portable battery operated tail-head light combination. The light system on the hopper end can be cable fed from the locomotive and rolled up onto a winder when not required.

The retaining mechanism for the battery-powered locomotives should be changed to a corner casting with twist lock mechanisms.

Health and safety implication: Improved visibility provides additional feedback for perceptual decision making and reducing the margin for omission or error. Additional safety features on the battery retaining mechanism will reduce the perceived danger experienced by operators. It will therefore reduce the inclination of operators to jump from the cab in emergencies.

9.9 Intervention proposal

Figure 9.9.1 shows the interventions proposed in the preceding paragraphs.

9.10 Rolling stock

Man carriages should be modified according to the guidelines presented in Table 7.3.2 in order to provide adequate access to and from the carriage, adequate seat depth for support during transit and space for personnel wearing personal protective equipment. Specific attention must be given to the relationship between the space availability and the number of personnel transported on the man carriage.

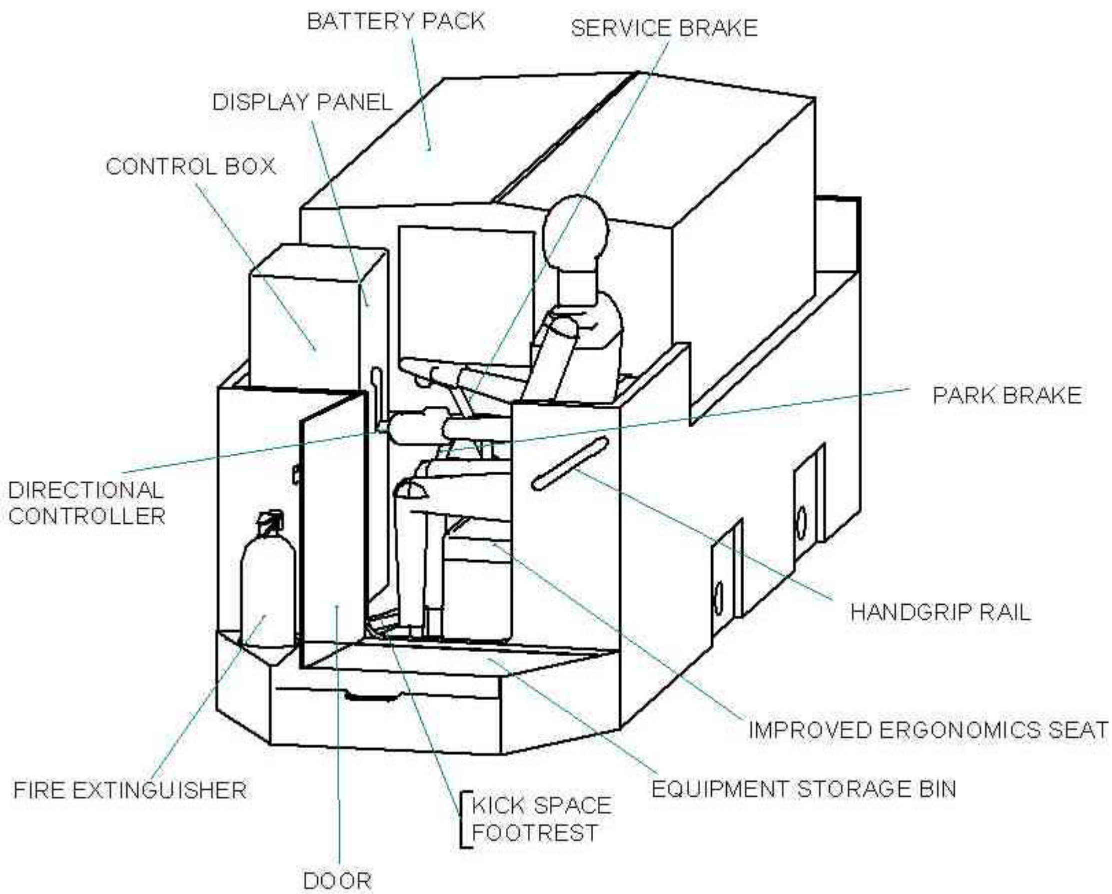


Figure 9.9.1: Interventions proposed for the existing fleet

10. Strategy for implementation of the recommended ergonomics interventions for the existing fleet

The strategy to implement the recommended ergonomics interventions for the existing fleet of mining locomotives will involve the support of manufacturers, rebuilders, mining groups and individual mines but also employees and statutory bodies.

The goals of the strategy are to ultimately implement the ideal and practical locomotive designs in order to substantially reduce the safety risks involved with mine locomotive operations. The development of a new generation of mine locomotives incorporating the proposed ergonomics features, will probably be in the domain of manufacturers and the larger mining groups. Rebuilders and mine workshops can be involved with interim interventions and retrofitting exercises while locomotive operators will have the responsibility to execute the tasks with modified or new equipment and procedures.

The proposal for the strategy involves firstly, the structured implementation of ergonomic interventions to the existing fleet. Secondly, it involves the development of locomotive cabs incorporating the proposed ergonomics features of the practical design that can be retrofitted on the existing fleet. And thirdly, it involves the development of new locomotives according to the ideal design proposal. Intervention actions to the existing fleet were prioritised according to the criticality of the deficiency. It should be clear that some interventions would not be practical to implement, because of limitations that would require major modification and where retrofitting of a practical design cab may be more cost effective. A point in case here is the process of changing the body orientation of the operation from sideways to the direction of travel. The characteristics of existing locomotives are such that the modification to implement it is not practical and not cost effective. Nevertheless, substantial benefit can be obtained by introducing modifications to affected locomotives by following the priority of intervention. The interventions are listed in Table 10.1 in priority order. Section 9 discusses the design modifications for obtaining the intended ergonomics benefit.

Table 10.1: Priority of ergonomics interventions on the existing fleet

1.	Modification of park brake to incorporate hand and foot operated service brake
2.	Increase of forward visual access to track (where applicable)
3.	Seating
4.	Equipment storage provisions and removal of coupling system at the leading end
5.	Access to the cab
6.	Communication and warning systems (amber flashing lights and personal flashing lights for guards and operators)
7.	Battery retaining mechanism and provision of jacking points
8.	Labelling of displays and controls
9.	Inspection provisions

The cost to implement the strategy should be regarded as an investment with short and long term benefits. There will be benefits that are not easily expressed in monetary terms. These would include health, safety, comfort, well-being and operator task effectiveness, which are really the main aims of the ergonomics interventions. Other benefits are directly related to cost. For example, the cost of fatalities, compensation payments and medical costs, mechanical and electrical repairs and loss of production as a result of preventable equipment downtime. The funding required to support a strategy for intervention on this scale may well depend on a number of factors but the success of implementation will ultimately reside on the mining role players' support and acceptance of the priority the strategy should receive.

11. Conclusions and recommendations

The ergonomics assessment of the existing fleet of mine locomotives at gold and platinum mines highlighted various deficiencies in the design of the working system (most typically at the operator-machine interface). Poorly designed workstations make the operator's tasks more difficult and thus render him more error-prone. A number of safety related design deficiencies were also identified that can be improved through ergonomics intervention.

The ergonomics interventions required to improve the safety aspects of the existing fleet of locomotive should address the following aspects:

Ergonomics intervention	Improved health and safety
Access to the cab of the locomotives	Reduce slips, falls, awkward postures
Forward visual access	Improve perceptual capability
Seating and posture	Reduce muscular fatigue, improve body support
Communication and warning systems	Reduce margin for errors
Labelling of controls and displays	Reduce error, improve speed of activation
Equipment storage	Reduce slips, falls and impact injuries
Pre-operational safety and mechanical checks	Reduce interpretation errors
Modification of park brake.	Reduce fatigue, shoulder trauma, increase speed of activation

The ergonomics interventions required to improve the safety aspects of the existing rolling stock should address access, seating and space provisions of man carriages.

In order to reduce the safety risks involved with locomotive operations as result of poor ergonomics, the following strategy is proposed. Firstly, priority should be given to the implementation of the proposed ergonomic interventions (see Section 9) for the existing fleet. The second phase should focus on the development of locomotive cabs, incorporating the proposed ergonomics of the practical design (see Section 8), which can be retrofitted to the existing fleet. Finally, attention should be given to the development of new locomotives according to the ideal design proposals (see Section 7).

It is further recommended that all interested and affected parties (manufacturers and suppliers) be involved in the practical design, manufacture and installation of the proposed ergonomics interventions and conceptual designs. This is essential in terms of Section 21 (1) (c) of the Mine Health and Safety Act (Act 29 of 1996).

References

Anglogold Limited. 2000. Guideline for Locomotives used for Tramming Operations. AGTE 8.2.2.

Clark, T.S. and Corlett, E.N. 1984. The Ergonomics of Workspace and Machines: A Design Manual. Taylor & Francis. London.

Department of Minerals and Energy (Republic of South Africa). 2000. Guideline for the Compilation of a Mandatory Code of Practice for Underground Railbound Transport Equipment. MRAC Circular unnumbered.

Department of Minerals and Energy (Republic of South Africa). 2000. Proposed Regulations for the operation of surface and Underground Railbound Transport Equipment. MRAC circular unnumbered.

Gold Fields Limited. 1998. Code of Practice GFL 0071 – Undergound Locomotive Practice.

Republic of South Africa. Mine Health and Safety Act, Act 29 of 1996.

RSA Military Standards Steering Committee (RMSS), 1995. RSA-MIL-STD-127: , Volume 1. Ergonomic Design: Anthropometry and Environment.

Wilson, J.R. and Corlett, E.N. 1992. Evaluation of Human work. Taylor & Francis, London.

Appendix 1
Distribution of locomotives

While the distribution of locomotives presented here provides useful statistical information, it is self evident that the data, having originally been produced in 1991, has by now several omissions and errors. In the past decade new locomotives were added, older models disposed of or used for spares while some became redundant as a result of curtailed operations.

Mine	No	Size	Power	Maker
BARBERTON	4	6	Diesel	Funkey
BARBERTON	10	2.5	Battery	Goodman
BARBERTON	4	6	Diesel	Unknown
BARBERTON	6	6	Diesel	Unknown
BEATRIX	28	9	Diesel	Funkey
BEATRIX	52	10	Battery	Goodman
BLYVOOR	2	14	Trolley	Bateman Trident
BLYVOOR	10	5	Battery	Funkey
BLYVOOR		4.5	Diesel	Funkey
BLYVOOR		9.5	Diesel	Funkey
BLYVOOR	5	8	Trolley	General Electric
BLYVOOR	3	14	Trolley	General Electric
BLYVOOR	12	4.5	Trolley	Goodman
BLYVOOR	18	8	Trolley	Goodman
BLYVOOR	3	8	Trolley	Greenbat
BLYVOOR	3	14	Trolley	Greenbat
BUFFELSFONTEIN	2	8	Battery	Bateman Trident
BUFFELSFONTEIN	4	3.6	Diesel	Bateman Trident
BUFFELSFONTEIN	24	3.6	Diesel	Funkey
BUFFELSFONTEIN	54	5.4	Diesel	Funkey
BUFFELSFONTEIN	36	7.3	Diesel	Funkey
BUFFELSFONTEIN	33	8.2	Diesel	Funkey
BUFFELSFONTEIN	4	5	Battery	Goodman
BUFFELSFONTEIN	17	8	Battery	Goodman
BUFFELSFONTEIN	4	12	Trolley	Goodman
BUFFELSFONTEIN	3	15	Trolley	Goodman
BUFFELSFONTEIN	1	5.4	Diesel	Hunslett Taylor
BUFFELSFONTEIN	2	7.3	Battery	Unknown
BUFFELSFONTEIN	9	6	Diesel	Unknown
BUFFELSFONTEIN	10	8.2	Diesel	Unknown
BUFFELSFONTEIN	24	9	Diesel	Unknown
BUFFELSFONTEIN	1	10	Diesel	Unknown
CONS MURCH.	10	2.5	Battery	Funkey
CONS MURCH.	18	6	Battery	Funkey
CONSOLIDATED MODDER	5	6	Battery	Goodman
CONSOLIDATED MODDER	14	5	Diesel	Unknown
CROMORE MOOINOOI	9	6	Battery	Bessinger
DBN ROODEPOORT DEEP	83	5	Battery	Bessinger
DBN ROODEPOORT DEEP	63	5	Battery	Goodman
DBN ROODEPOORT DEEP	42	15	Trolley	Goodman
DEELKRAAL	5	9.1	Battery	Unknown
DEELKRAAL	39	5	Diesel	Anton Type
DEELKRAAL	38	9	Battery	Goodman
DOORNFONTEIN	66	5	Diesel	Anton Type
DOORNFONTEIN	5	6	Diesel	General Electric
DOORNFONTEIN	5	10	Diesel	General Electric

Mine	No	Size	Power	Maker
DOORNFONTEIN	60	2	Battery	Goodman
DOORNFONTEIN	1	4	Diesel	Goodman
DOORNFONTEIN	96	6	Diesel	Funkey
DOORNFONTEIN	2	8	Trolley	Goodman
DOORNFONTEIN	4	12	Trolley	Goodman
DOORNFONTEIN	2	10	Trolley	Greenbat
DOORNFONTEIN	50	3	Diesel	Hunslett Taylor
DRIE CONS	25	60	Diesel	Anton Type
DRIE CONS	14	5	Battery	Bessinger
DRIE CONS	27	5	Battery	Bessinger
DRIE CONS	54	10	Battery	Bessinger
DRIE CONS	9	10	Battery	Funkey
DRIE CONS	6	10	Trolley	Goodman
DRIE CONS	10	10	Trolley	Goodman
DRIE CONS	53	5	Diesel	Hunslett Taylor
DRIE CONS	82	10	Diesel	Hunslett Taylor
DRIE CONS	7	10	Diesel	Unknown
E.R.P.M	6	10	Trolley	General Electric
E.R.P.M	3	3	Battery	Goodman
E.R.P.M	25	6	Battery	Goodman
E.R.P.M	3	12.5	Battery	Goodman
E.R.P.M	78	4	Trolley	Goodman
E.R.P.M	19	8	Trolley	Goodman
E.R.P.M	14	10	Trolley	Goodman
E.R.P.M	3	10	Trolley	Greenbat
E.R.P.M	2	1.5	Battery	Unknown
ELANDSRAND	3	10	Diesel	Funkey
ELANDSRAND	2	10	Trolley	Funkey
ELANDSRAND	1	5	Battery	Goodman
ELANDSRAND	47	8	Battery	Goodman
ELANDSRAND	15	9	Battery	Goodman
ERFDEEL	1	8	Battery	Bateman Trident
ERFDEEL	10	8	Battery	Funkey
ERFDEEL	12	9	Battery	Funkey
ERFDEEL	49	10	Battery	Goodman
ERFDEEL	21	5	Battery	Hunslett Taylor
ERFDEEL	2	8	Battery	Hunslett Taylor
ERFDEEL	6	5	Diesel	Hunslett Taylor
F.S.G.	180	5	Battery	Goodman
FREDDIES		5	Battery	Funkey
FREDDIES	5	5	Diesel	Funkey
FREDDIES	2	8	Trolley	General Electric
FREDDIES	1	10	Trolley	General Electric
FREDDIES	64	8	Battery	Goodman
FREDDIES	8	10	Trolley	Goodman
FREDDIES	72	6	Battery	Hunslett Taylor
FREDDIES	10	10	Battery	Hunslett Taylor
FREDDIES	2	12	Battery	Hunslett Taylor
FREDDIES	1	5	Diesel	Hunslett Taylor
FREDDIES	4	8	Diesel	Hunslett Taylor
GRASS VALLEY CHROME	8	6	Battery	Goodman
GRASS VALLEY CHROME	2	6	Diesel	unknown
GROOTVLEI MINE	2	8	Trolley	General Electric
GROOTVLEI MINE	5	4	Battery	Goodman
GROOTVLEI MINE	50	6	Battery	Goodman

Mine	No	Size	Power	Maker
GROOTVLEI MINE	15	4	Trolley	Goodman
GROOTVLEI MINE	5	6	Trolley	Goodman
GROOTVLEI MINE	4	20	Trolley	Greenbat
GROOTVLEI MINE	25	6	Diesel	Hunslett Taylor
HARMONY	4	6	Battery	Funkey
HARMONY	61	5	Diesel	Funkey
HARMONY	117	6	Diesel	Funkey
HARMONY	129	9	Diesel	Funkey
HARMONY	33	5	Battery	Goodman
HARMONY	78	5	Battery	Goodman
HARMONY	42	5	Battery	Goodman
HARMONY	13	10	Battery	Goodman
HARMONY	13	10	Battery	Goodman
HARMONY	4	10	Battery	Goodman
HARMONY	12	6	Trolley	Goodman
HARMONY	7	10	Trolley	Goodman
HARMONY	21	10	Trolley	Goodman
HARMONY	4	15	Trolley	Goodman
HARMONY	15	15	Trolley	Goodman
HARMONY	4	15	Trolley	Goodman
HARMONY	14	12	Trolley	Greenbat
HARMONY	7	6	Battery	Hunslett Taylor
HARMONY	6	10	Battery	Hunslett Taylor
HARMONY	6	6	Diesel	Hunslett Taylor
HARTEBEESFONTEIN	33	5	Battery	Bateman Trident
HARTEBEESFONTEIN	5	5	Diesel	Funkey
HARTEBEESFONTEIN	42	6	Diesel	Funkey
HARTEBEESFONTEIN	63	5	Battery	Goodman
HARTEBEESFONTEIN	8	8	Battery	Goodman
HARTEBEESFONTEIN	5	10	Trolley	Goodman
HARTEBEESFONTEIN	4	15	Trolley	Goodman
HARTEBEESFONTEIN	2	10	Diesel	Hunslett Taylor
HARTEBEESFONTEIN	42	3.5	Diesel	Unknown
HENRY GOLD	4	6	Battery	Bateman Trident
HENRY GOLD	2	6	Battery	Bessinger
HENRY GOLD	2	6	Battery	Goodman
IMPALA BAF NORTH	79	10	Battery	Bateman Trident
IMPALA BAF SOUTH	83	10	Battery	Bateman Trident
IMPALA BAF SOUTH	1	6	Diesel	Funkey
IMPALA BAF SOUTH	3	10	Battery	Goodman
IMPALA WILD NORTH	105	6	Battery	Goodman
IMPALA WILD SOUTH	70	6	Battery	Goodman
KINROSS MINE	7	6	Battery	Bessinger
KINROSS MINE	57	6	Battery	Funkey
KLOOF	65	5	Battery	Bessinger
KLOOF	11	10	Trolley	Goodman
KLOOF	192	5	Diesel	Hunslett Taylor
KLOOF	33	10	Diesel	Hunslett Taylor
LESLIE MINES	17	6	Battery	Funkey
LESLIE MINES	15	6	Diesel	Funkey
LESLIE MINES	41	8	Diesel	Funkey
LESLIE MINES	2	10	Battery	Goodman
LIBANON	3	5	Battery	Bessinger
LIBANON	19	5	Diesel	Funkey
LIBANON	17	5	Trolley	Goodman

Mine	No	Size	Power	Maker
LIBANON	35	5	Diesel	Hunslett Taylor
LIBANON	46	5	Diesel	Hunslett Taylor
LIBANON	8	5	Diesel	Hunslett Taylor
LIBANON	43	5	Diesel	Hunslett Taylor
MARIEVALE	3	6	Battery	Goodman
MARIEVALE	5	6	Trolley	Goodman
MARIEVALE	7	6	Diesel	Hunslett Taylor
MARIEVALE	1	15	Battery	Unknown
MPONENG	10	10	Battery	Bateman Trident
MPONENG	3	11	Trolley	Funkey
MPONENG	49	5	Battery	Goodman
MPONENG	9	5	Battery	Goodman
MPONENG	150	5	Battery	Goodman
MPONENG	30	8	Battery	Goodman
MPONENG	21	8	Battery	Goodman
MPONENG	37	8	Battery	Goodman
MPONENG	5	10	Battery	Goodman
MPONENG	128	5	Battery	Greenbat
PRESIDENT BRANDT	141	6	Battery	Goodman
PRESIDENT BRANDT	91	10	Battery	Goodman
PRESIDENT BRANDT	1	6	Trolley	Goodman
PRESIDENT BRANDT	9	10	Trolley	Goodman
PRESIDENT BRANDT	1	15	Trolley	Goodman
PRESIDENT BRANDT	18	5	Diesel	Unknown
PRESIDENT STEYN	199	6	Battery	Goodman
PRESIDENT STEYN	3	10	Trolley	Goodman
PRESIDENT STEYN	31	8	Battery	Unknown
PRP	2	6	Battery	Bessinger
PRP	13	6	Battery	Goodman
RPM AMANDEBULT CONS	51	6	Battery	Goodman
RPM AMANDEBULT CONS	3	10	Battery	Goodman
RPM RUSTENBURG CONS	4	6	Battry	Funkey
RPM RUSTENBURG CONS	2	Unknown	Trolley	General Electric
RPM RUSTENBURG CONS	212	6	Battery	Goodman
RPM RUSTENBURG CONS	2	Unknown	Trolley	Goodman
RPM UNION (CONS)	52	6	Battery	Bessinger
RPM UNION (CONS)	17	10	Battery	Goodman
SAAIPLAAS	57	6	Battery	Goodman
SOUTH DEEP	139	5	Battery	Goodman
SOUTH DEEP	27	10	Trolley	Goodman
SOUTH DEEP	64	10	Diesel	Hunslett Taylor
SOUTH ROODEPOORT	1	5	Battery	Bessinger
SOUTH ROODEPOORT	14	5	Diesel	Hunslett Taylor
SPRINGS DAGGA	1	10	Battery	Goodman
SPRINGS DAGGA	2	6	Diesel	Goodman
ST HELENA	54	6	Diesel	Funkey
ST HELENA	23	9	Diesel	Funkey
ST HELENA	30	6	Battery	Goodman
ST HELENA	27	6	Diesel	Hunslett Taylor
ST HELENA	20	10	Battery	Unknown
STAR DIAMONDS	3	5	Diesel	Funkey
STAR DIAMONDS	4	1.5	Battery	Unknown
STILFONTEIN	2	10	Trolley	General Electric
STILFONTEIN	4	15	Trolley	Goodman
TARGET	10	6	Battery	Bessinger

Mine	No	Size	Power	Maker
TARGET	53	13	Diesel	Funkey
TARGET	42	6	Battery	Goodman
TARGET	10	10	Trolley	Goodman
TARGET	47	5	Diesel	Unknown
UNISEL	11	5	Battery	Goodman
VAAL RIVER OPS	1	8	Battery	Bateman Trident
VAAL RIVER OPS	10	3.51	Diesel	Bateman Trident
VAAL RIVER OPS	5	5	Battery	Bessinger
VAAL RIVER OPS	1	5	Battery	Funkey
VAAL RIVER OPS	12	6	Diesel	Funkey
VAAL RIVER OPS	7	10	Trolley	General Electric
VAAL RIVER OPS	6	3	Battery	Goodman
VAAL RIVER OPS	206	5	Battery	Goodman
VAAL RIVER OPS	314	8	Battery	Goodman
VAAL RIVER OPS	9	10	Trolley	Goodman
VAAL RIVER OPS	4	12	Trolley	Goodman
VAAL RIVER OPS	7	15	Trolley	Goodman
VAAL RIVER OPS	2	3	Battery	Greenbat
VAAL RIVER OPS	69	5	Diesel	Hunslett Taylor
VAAL RIVER OPS	9	3.5	Diesel	Unknown
WEST RAND CONS	28	5	Battery	Bessinger
WEST RAND CONS	38	5	Battery	Goodman
WEST RAND CONS	4	15	Trolley	Goodman
WEST WITWATERSRAND	2	5	Battery	Goodman
WEST WITWATERSRAND	17	5	Diesel	Hunslett Taylor
WESTERN HOLDINGS	3	5	Diesel	Unknown
WESTERN PLATS	5	6	Battery	Goodman
WESTERN PLATS	7	7.5	Battery	Goodman
WESTERN PLATS	5	8	Battery	Unknown
WINKELHAAK	21	6	Battery	Bessinger
WINKELHAAK	37	6	Diesel	Funkey
WINKELHAAK	51	8	Diesel	Funkey
WINKELHAAK	14	6	Battery	Goodman
WINKELHAAK	3	27	Trolley	Goodman
WINKELHAAK	1	27	Trolley	Goodman
WITS NIGEL	8	6	Battery	Funkey
WITS NIGEL	1	10	Battery	Funkey
WITS NIGEL	4	5	Diesel	Funkey

Appendix 2
Mines and manufacturers

Table 1 presents the mines assisting the project team by making locomotives available for dimensional evaluation, knowledgeable personnel for task analysis elements and operators for perceptual evaluation.

Table 1.1: Assistance from mines

Mine	Dimensional	Task analysis	Perceptual
Anglo Gold Ltd, Kopanong Mine	X		X
Anglo Gold Ltd, Savuka Mine			X
Anglo Gold Ltd, Tautona Mine	X	X	
Anglo Gold Ltd, Tshepong Mine	X	X	X
Anglo Gold Ltd, West Wits Operations	X	X	
Eastern Platinum Ltd			X
Harmony Gold Mining Company Ltd, Brand 5 Mine	X	X	X
Impala Platinum, Shaft No. 1	X	X	X
Joel Gold Mining Company Ltd	X	X	
Rustenburg Platinum Mines Ltd, Rustenburg Section	X	X	
Placer Dome, South Deep	X	X	

1. Location of Manufacturers

Locomotive Type	PROF Donza (Diesel)
Supplier Name	PROF Engineering (Pty) Ltd
Physical Address	13 Basalt Road Alrode Ext. 7 Alberton
Postal Address	PO Box 124142 Alrode Alberton 1451
Province	Gauteng
Telephone Number	(011) 864 4773/4/5
Fax Number	(011) 864 3321
Email Address	prof@hixnet.co.za

Locomotive type	Funkey (Diesel)
Supplier Name	Dorbyl RSD
Physical Address	Victor Street Industrial Sites Boksburg East
Postal Address	PO.Box 229 Boksburg Johannesburg 1460
Province	Gauteng
Telephone Number	(011) 914 1400
Fax Number	(011) 914 4280
Email Address	neville@rsd.dorbyl.co.za

Locomotive Type	Goodman (Battery and Electric)
Supplier Name	Bateman Trident Locomotives
Physical Address	414 Peddie Street Wadeville Ext. 6 Germiston
Postal Address	PO Box 7198 Albermarie 1410
Province	Gauteng
Telephone Number	(011) 902 6735/6/7/8/9
Fax Number	(011) 902 8988
Email Address	batetrid@icon.co.za

Locomotive type	Scharf (Monorail)
Supplier Name	DBT South Africa (Pty) Limited
Physical Address	Duncanville Vereeniging
Postal Address	PO Box 1509 Vereeniging 1930
Province	Freestate
Telephone Number	(016) 421 3190/1/2
Fax Number	(016) 421 1267
Website	http://www.dbt.co.za

Locomotive type	Walter Becker (Monorail)
Supplier Name	Walter Becker South Africa (Pty) Limited
Physical Address	42 van ECK Street Chamdor Krugersdorp
Postal Address	P.O. Box 1339 Krugersdorp 1740
Province	Gauteng
Telephone Number	(011) 762 5551/9
Fax Number	(011) 762 5550
E-mail	wbsa@mail.global.co.za

Locomotive Type	Rebuilders
Supplier Name	Tau Mining (Pty) Limited
Postal Address	PO Box 1011 Randfontein 1760
Province	Gauteng
Telephone Number	(011) 762 4210
Fax Number	(011) 762 5748

Appendix 3
Dimensional evaluation

1. Locomotive 1

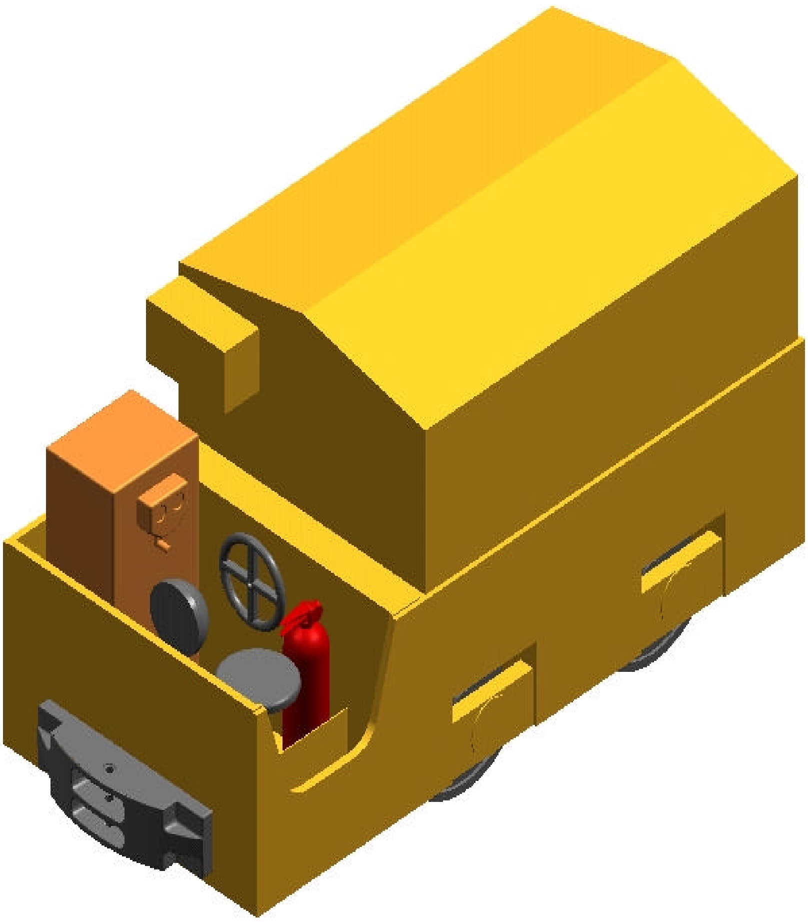


Figure 1.1: 3D CAD representation of the locomotive 1

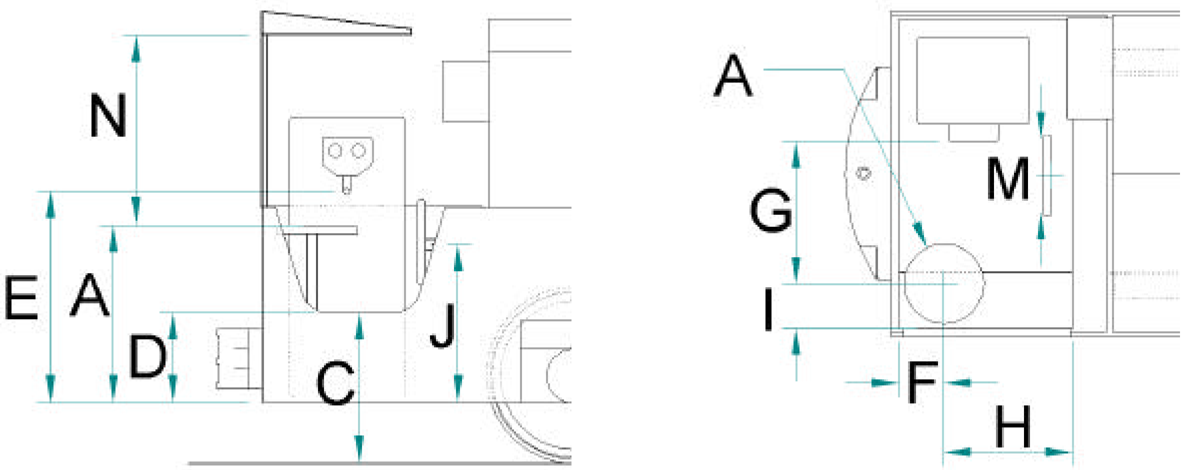


Figure 1.2: Battery powered mine locomotive 1

Table 1.1: Dimensions for battery powered mine locomotive 1

	Manufacturer	Goodman
	Weight class (tons)	**5**
	Mine visited	A
A	Seat height from floor	600
B	Seat dimensions (WxD)	∅300
	Seat material	Wood
C	Surface to entrance height	450
D	Entrance to floor height	320
E	Controller handle height	755
F	Seat to front wall distance	150
G	Seat to controller distance	580
H	Seat to rear wall distance	500
I	Seat to side wall distance	235
J	Park brake height from floor	570
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	200
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	300

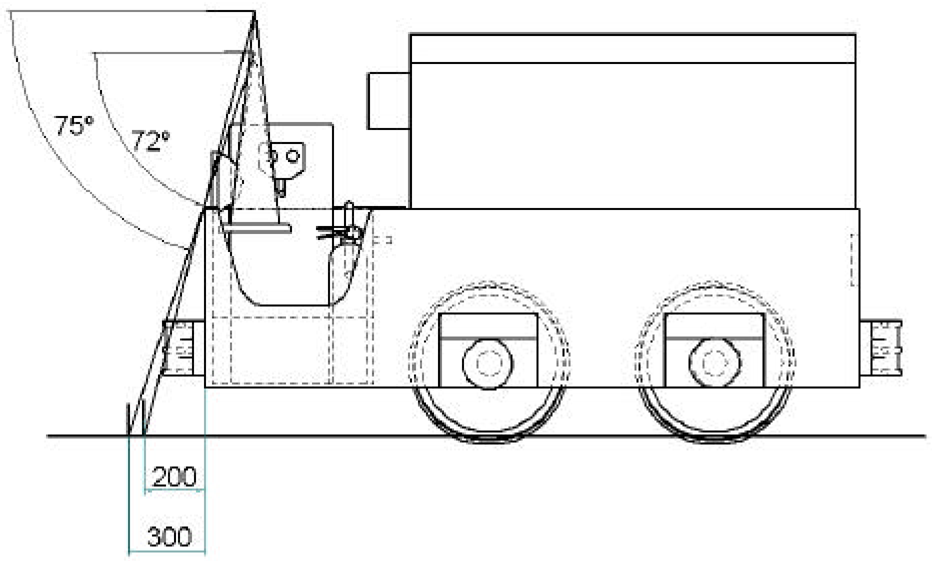


Figure 1.3: Viewing angle and distance for battery powered mine locomotive 1

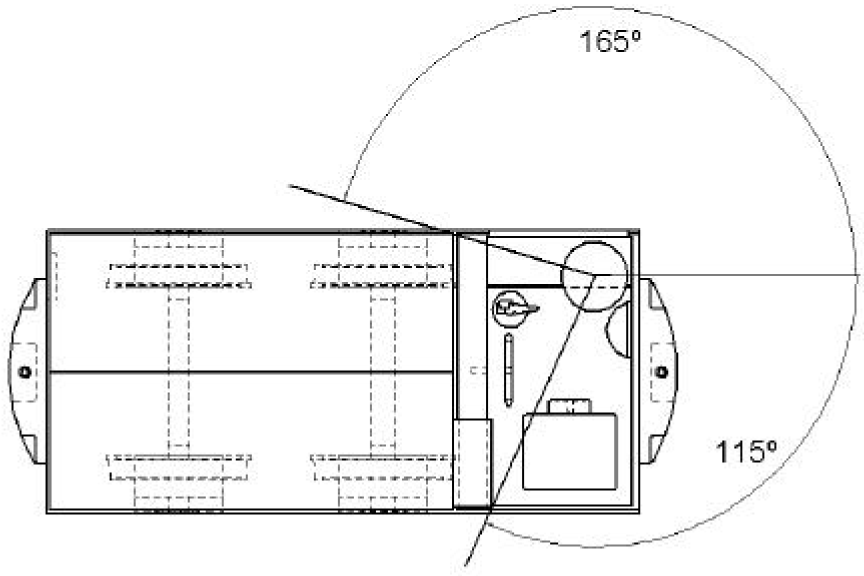


Figure 1.4: Side viewing angle from an aerial plane

1.1 Access

The surface to entrance level was above the recommended height for easy entry into the cab for the 5th percentile up to the 95th percentile male South African. The dedicated storage bin is located along the entrance which partially obstructs access.

1.2 Seat and posture

The wooden seatbase was not height adjustable and did not have back or arm supports. The seat width was too narrow to accommodate the 95th percentile male South African. The height of the seatbase from the cab floor was too high for a comfortable sitting posture for the 5th percentile. The feet of the operator cannot be placed onto the cab floor which results in the operator adopting a semi-standing posture that is unstable for controlling a locomotive.

The operator faces sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. When reversing the locomotive, the operator stands up, which is an unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

1.3 Controls

All the controls were within the reach envelop and visual field of the seated 5th percentile to the 95th percentile male South African. With the exception of the LED indicators for trip and reset which were obstructed from the operator's visual field.

1.4 Visual field

Forward and side viewing angles and distance are excellent when the operator is seated in front of the hoppers. Visual field to the back from the seated posture is restricted.

2. Locomotive 2

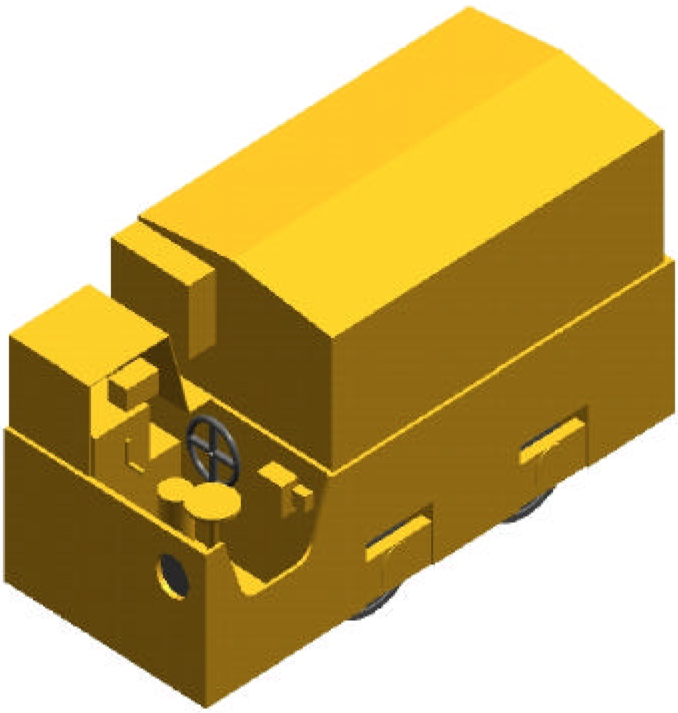


Figure 2.1: 3D CAD representative of locomotive 2

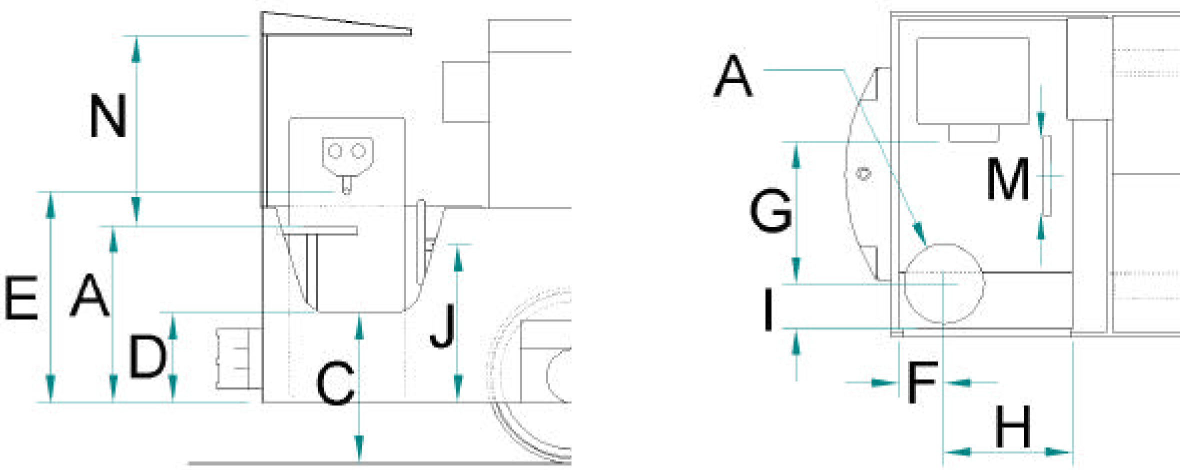


Figure 2.2: Battery powered mine locomotive 2

Table 2.1: Dimensions for battery powered mine locomotive 2

	Manufacturer	Goodman
	Weight class (tons)	**5**
	Mine visited	A
A	Seat height from floor	620
B	Seat dimensions (WxD)	∅ 250
	Seat material	Vinyl covered Cushion
C	Surface to entrance height	520
D	Entrance to floor height	390
E	Controller handle height	685
F	Seat to front wall distance	325
G	Seat to controller distance	380
H	Seat to rear wall distance	385
I	Seat to side wall distance	295
J	Park brake height from floor	580
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	400
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	500

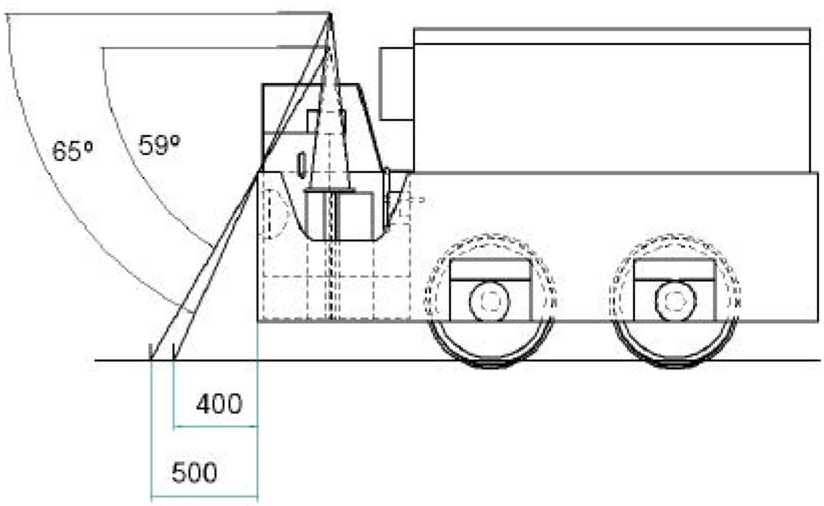


Figure 2.3: Viewing angle and distance for battery powered mine locomotive 2

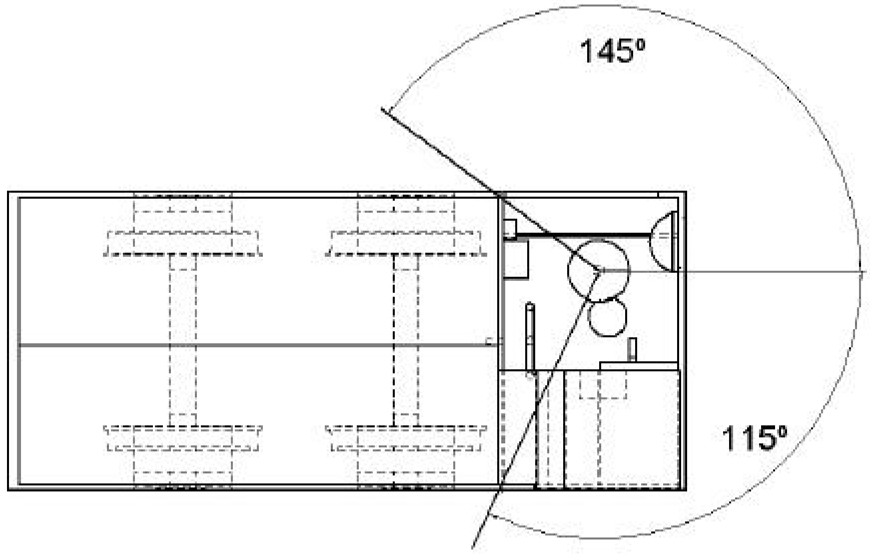


Figure 2.4: Side viewing angle from an aerial plane

2.1 Access

The surface to entrance level was higher than the recommended height for easy access and was without handgrips. The operator steps over the cutout side panel whilst holding onto the ledge of the locomotive when entering into the cab. Three point contact for safe access into the cab was not available. The dedicated storage bin is located across the full width of the entrance further obstructing entry.

2.2 Seat and posture

The seatbase was neither adjustable, nor provided back or arm support. The diameter of the seat was too narrow to comfortably accommodate the 5th percentile up to the 95th percentile male South African. The height of the seat base from the cab floor was too high for comfortable sitting posture. The operator cannot place the feet onto the cab floor and there was no footrest. The operator adopts a semi-standing posture to place the feet onto the cab floor, which is an unstable work posture for controlling the locomotive.

To accommodate the location of the fire extinguisher secured in front of the operator's seat causes the operator to adopt an abducted lower extremity posture. The operator faces sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. When reversing the locomotive, the operator stands up, which is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

2.3 Controls

All the controls are within the reach envelop, for the 5th percentile up to the 95th percentile South African male.

The labelling of the switches for the master controller was illegible with the exception of the emergency controls. Most of the controls were placed within the reach of the 5th to the 95th percentile South African. The exceptions were the placement of the emergency stop button and the main isolator switch which were placed behind the operator on the right hand side. This positioning required an awkward posture in which to apply forces.

The labelling was often illegible and in places was absent. Displays and controls were within the visual field of this operator with the exception of the controls used to be placed behind the operator.

2.4 Visual Field

Forward viewing angle and distance are within the recommended range. The 5th percentile up to the 95th percentile can easily see onto the track. Visual field to the back from the seated posture is restricted.

3. Locomotive 3

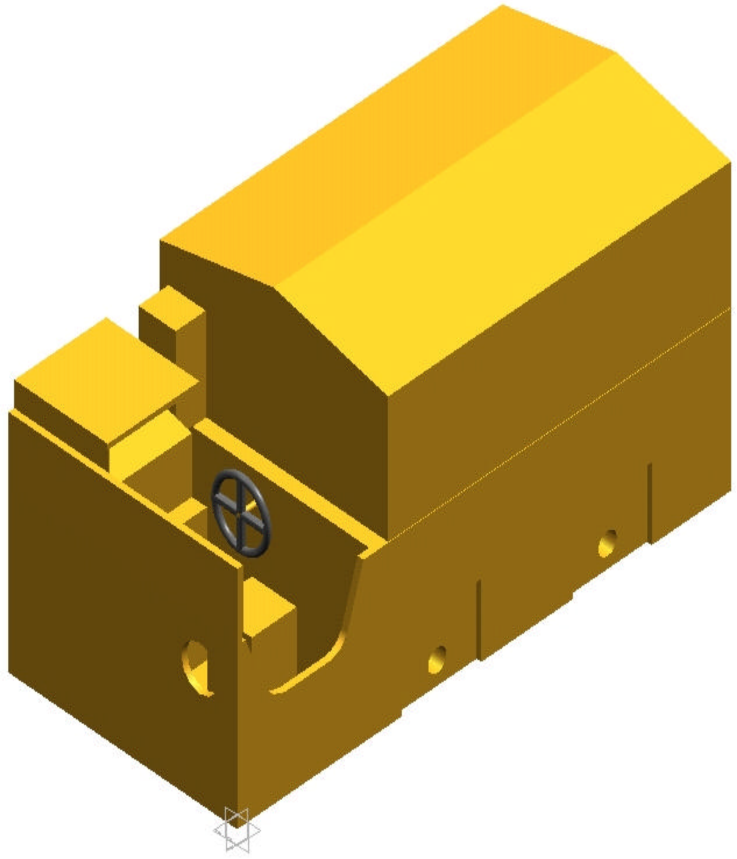


Figure 3.1: 3D CAD representation of the locomotive 3

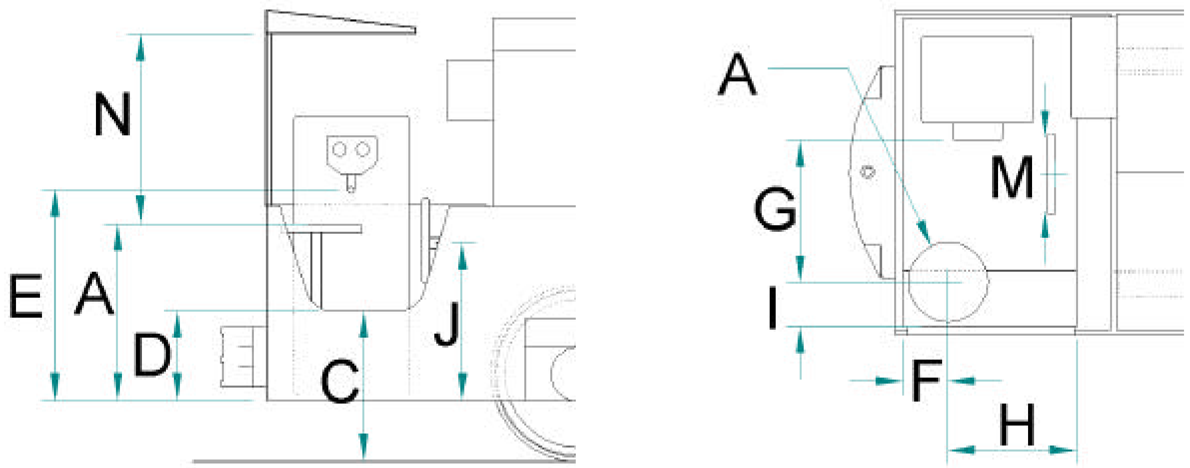


Figure 3.2: Battery powered mine locomotive 3

Table 3.1: Dimensions for battery powered mine locomotive 3

	Manufacturer	**Goodman**
	Weight class (tons)	**5**
	Mine visited	B
A	Seat height from floor	570
B	Seat dimensions (WxD)	240 X 240
	Seat material	Metal
C	Surface to entrance height	530
D	Entrance to floor height	400
E	Controller handle height	635
F	Seat to front wall distance	330
G	Seat to controller distance	540
H	Seat to rear wall distance	420
I	Seat to side wall distance	210
J	Park brake height from floor	600
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	900
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	1400

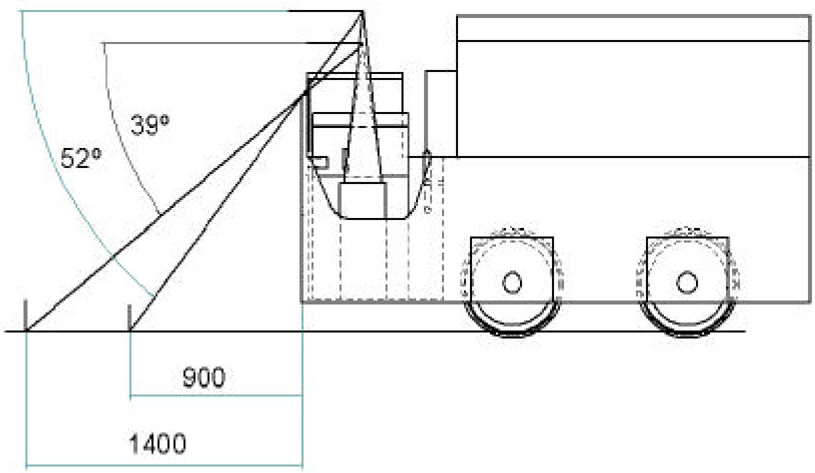


Figure 3.3: Viewing angle and distance for battery powered mine locomotive 3

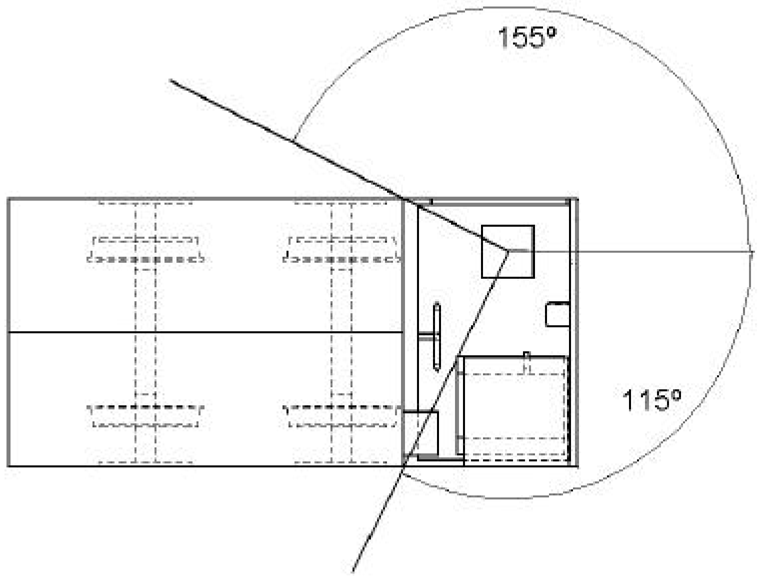


Figure 3.4: Side viewing angle from an aerial plane

3.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator has to step over the cutout entry panel and holds onto the locomotive side panels when entering or exiting the cab. There were no handgrips available to ensure a three-point contact for safe entry into the cab.

3.2 Seats and posture

The square metal seat base was not adjustable in any orientation and did not have back or arm supports. There was however, a rounded surface in the console to be used by the operator to rest his left arm while manipulating the controls. The seat base was too narrow to accommodate the 5^{th} to 95^{th} percentile South African user. The seat height was too high for stable, comfortable sitting posture for the 5^{th} percentile South African male. The 5^{th} percentile male cannot place his feet on the floor when seated and as a result, adopts a semi-standing posture.

The operator is facing sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. The operator stands up when reversing the locomotive, which is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

Workspace in the cab was restrictive for legroom and low sitting configuration for the 75^{th} percentile South African male.

3.3 Controls and displays

All the controls are within the reach envelope of the 5th percentile to 95th percentile South African male. The master controller was legibly labeled and within the visual field, but the two other switches were not labeled.

3.4 Visual angle and distance

Forward and side viewing angles and distance are within the recommended range. The 5th percentile to the 95th percentile male South African can see the track in front of the locomotive from the seated position, but visual field to the rear is restricted such that the operator had to stand when reversing.

4 Locomotive 4

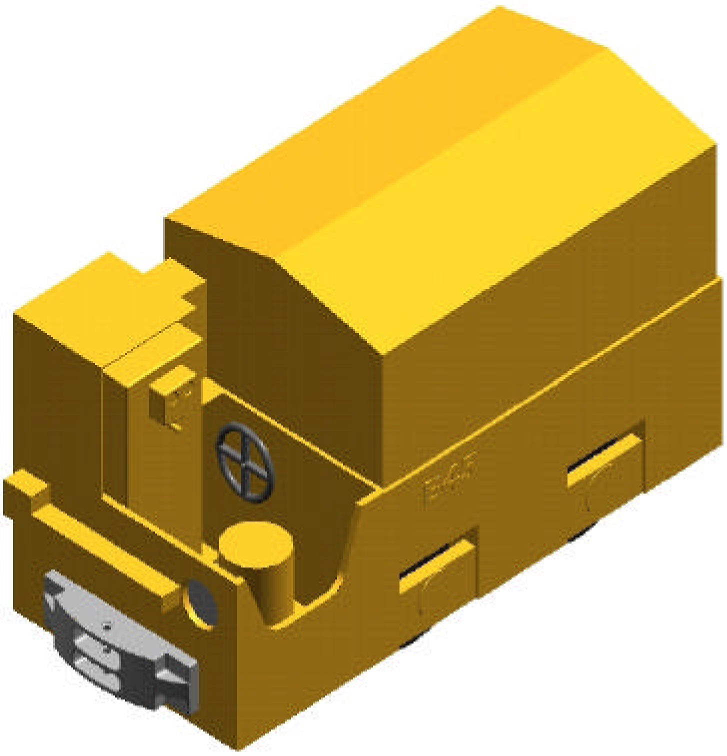


Figure 4.1: 3D CAD representation of the locomotive 4

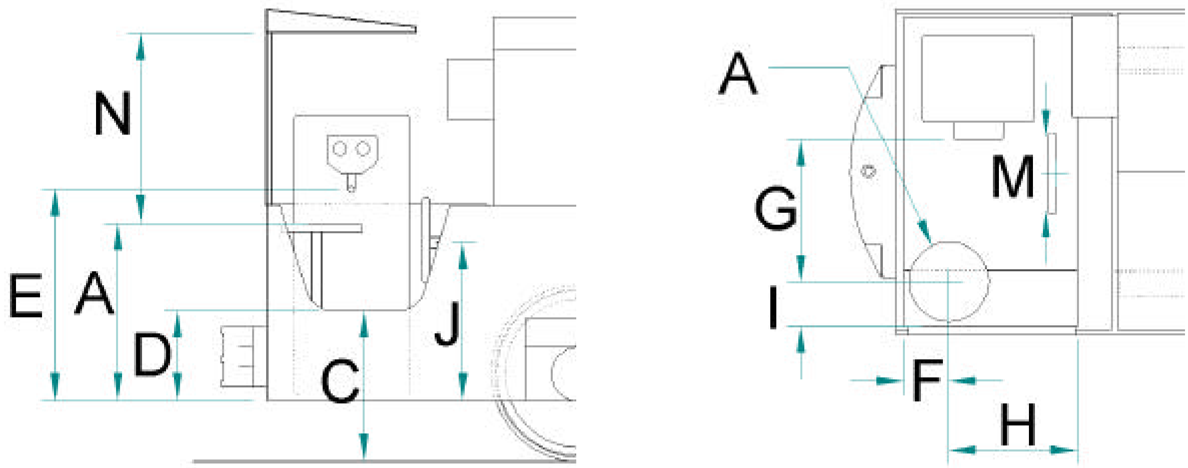


Figure 4.2: Viewing angles and distance for battery powered mine locomotive 4

Table 4.1: Dimensions for battery powered mine locomotive 4

	Manufacturer	Goodman
	Weight class (tons)	**6**
	Mine visited	C
A	Seat height from floor	610
B	Seat dimensions (WxD)	∅ 295
	Seat material	Metal
C	Surface to entrance height	550
D	Entrance to floor height	410
E	Controller handle height	890
F	Seat to front wall distance	240
G	Seat to controller distance	620
H	Seat to rear wall distance	450
I	Seat to side wall distance	140
J	Park brake height from floor	575
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	400
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	500

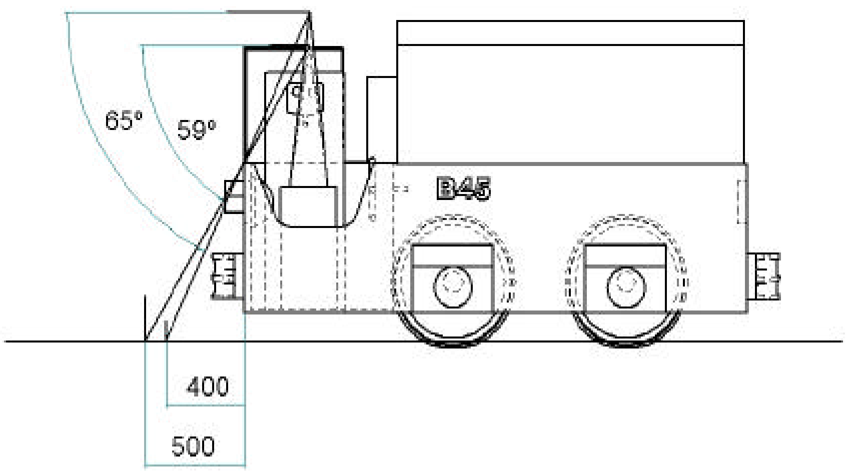


Figure 4.3: Viewing angles and distance for battery powered mine locomotive 4

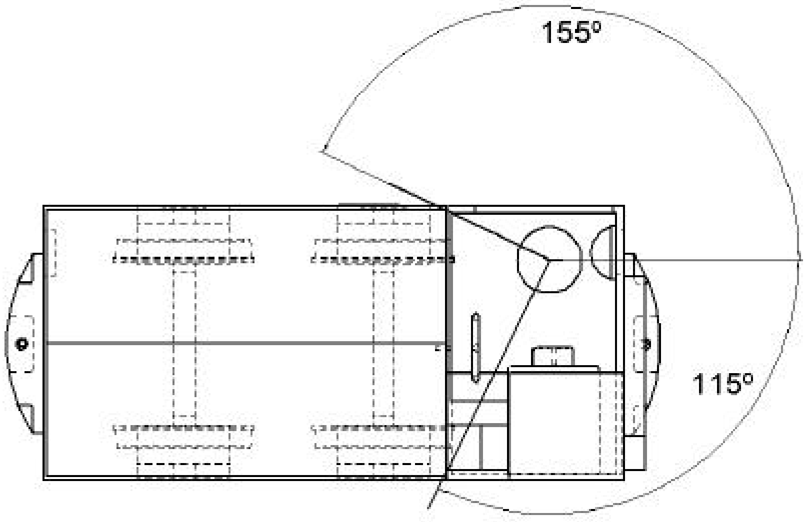


Figure 4.4: Side view angle from an aerial plane

4.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator has to step over the cutout entry panel and holds onto the locomotive side panels when entering or exiting the cab. There were no handgrips available to ensure a three-point contact for safe entry into the cab.

4.2 Seats and posture

The metal seat base was not adjustable in any orientation and did not have back or arm supports. The seat base was too narrow to accommodate the 5^{th} to 95^{th} percentile South African user. The seat height was too high for stable, comfortable sitting posture for the 5^{th} percentile South African male. The 5^{th} percentile male cannot place his feet on the floor when seated and as a result, adopts a semi-standing posture.

The operator is facing sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. The operator stands up when reversing the locomotive, which is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

The left sided body space would be restrictive even for the 5^{th} percentile male. Legroom would be restrictive for the 75^{th} percentile South African male.

4.3 Controls and displays

All the controls are within the reach envelope of the 5th percentile to 95th percentile South African male with the exception of the master controller which would require for the 5th percentile male, an extended reach, beyond the reach envelop. All controls and displays were within the visual field.

4.4 Visual Angle and distance

Forward viewing angle and distance are within the recommended range. The 5th percentile to the 95th percentile male South African can see the track in front of the locomotive from the seated position, but visual field to the rear is restricted.

5. Locomotive 5

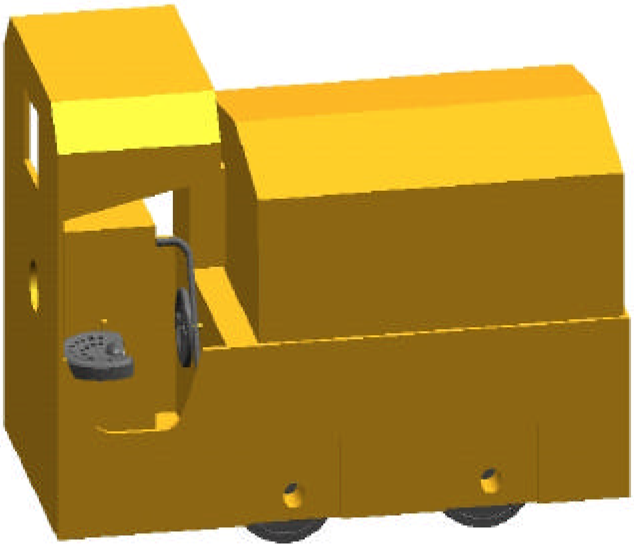


Figure 5.1: 3D CAD representation of the locomotive 5

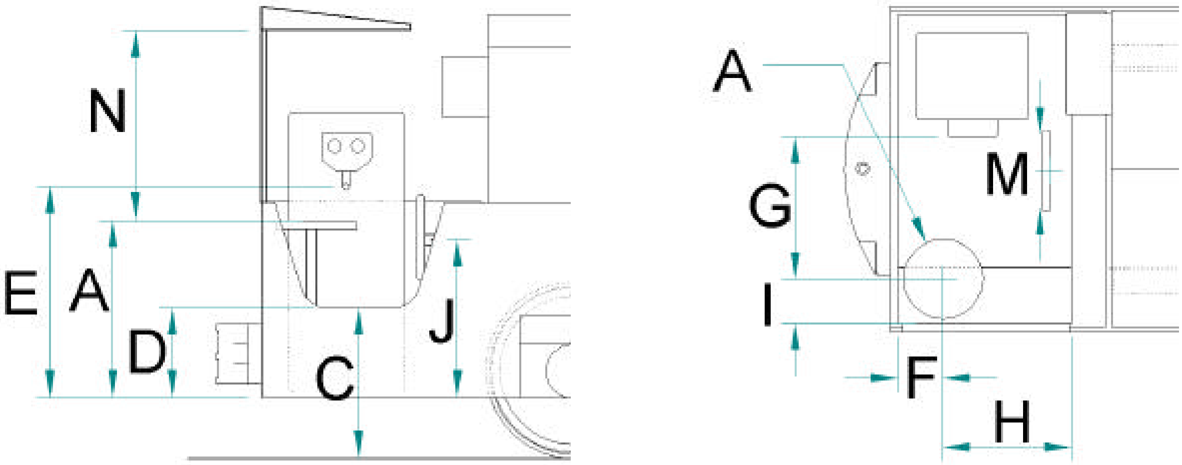


Figure 5.2: Battery powered mine locomotive 5

Table 5.1: Dimensions for battery powered mine locomotive 5

	Manufacturer	**Goodman**
	Weight class (tons)	**6**
	Mine visited	D
A	Seat height from floor	520
B	Seat dimensions (WxD)	400 X 340
	Seat material	Polyurethane
C	Surface to entrance height	540
D	Entrance to floor height	410
E	Controller handle height	440
F	Seat to front wall distance	270
G	Seat to controller distance	430
H	Seat to rear wall distance	440
I	Seat to side wall distance	430
J	Park brake height from floor	600
K	Foot brake height from floor	135
L	Hand brake height from floor	890
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	Yes
N	Canopy to seat height	1185
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	500-1400
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	700-6000

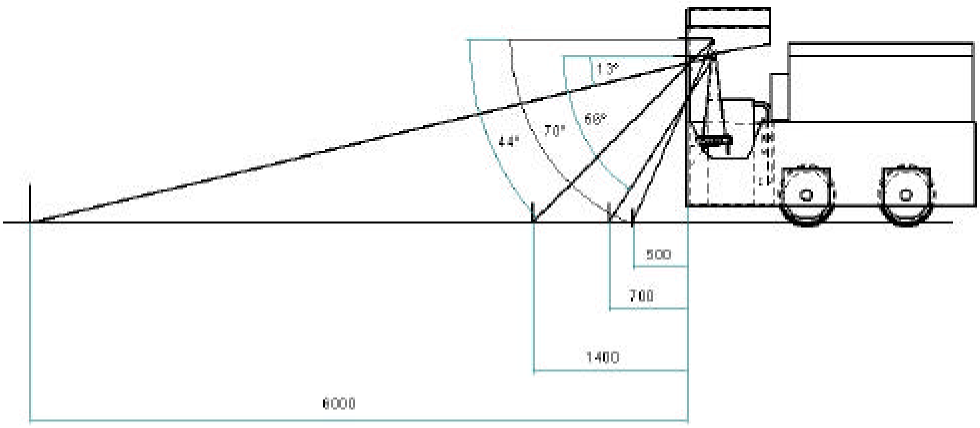


Figure 5.3: Viewing angle and distance for battery powered mine locomotive 5

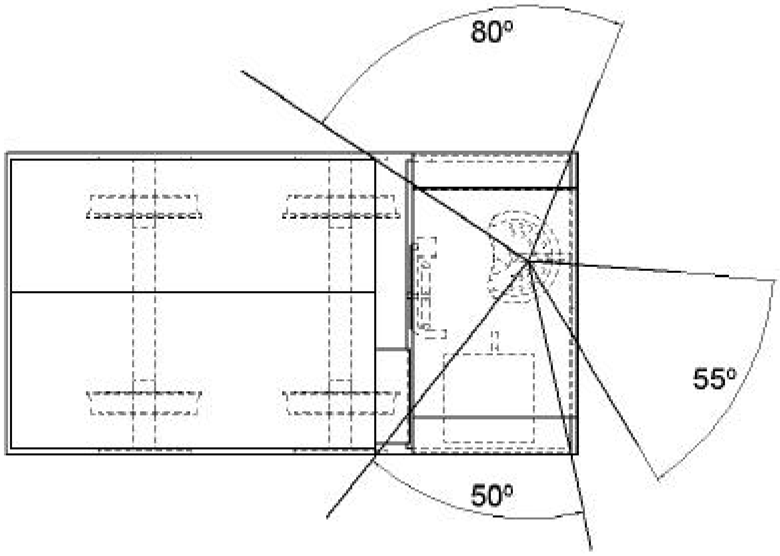


Figure 5.4: Side viewing angle from an aerial plane

5.1 Access

The surface to entrance level was higher than that is recommended for safe access without handgrips. The operator has to step over the cut out side panel to enter into the cab. Handgrips were not available for a three point contact access.

5.2 Seats and posture

A saddle type seat without back or arm support was provided which swivels around the mounting, but it is not height adjustable. The seat height would be too high for the 5^{th} percentile male to place the feet on the cab floor for a stable seated posture. The lamp connector directly behind the operator impeded his head when sitting fully upright. The operator did not face the direction of the locomotive movement. The position of the control panel causes the operator to face backwards. This includes a sustained twisted neck posture when facing towards the direction of forward movement. When reversing the locomotive, the operator leans out of the cab to the right with unsupported lateral flexed trunk or he stands up to face the direction of movement. The latter to postures are not acceptable practices according to the Mine Health and Safety Act, 1996, (Regulation 18.2.1).

5.3 Controls

The hand and foot controls were within easy access for the 5^{th} percentile to the 95^{th} percentile South African male. With the exception of the hand brake which was positioned such that the operator had to swivel the seat or twist his body to access. All controls were operated by the left-hand.

5.4 Visual field

The fully enclosed cab severely restricts forward visual angle and distance. There are blind spots to the left and right corners of the enclosed cab. Visual field to the back from the seated posture was restricted.

6. Locomotive 6

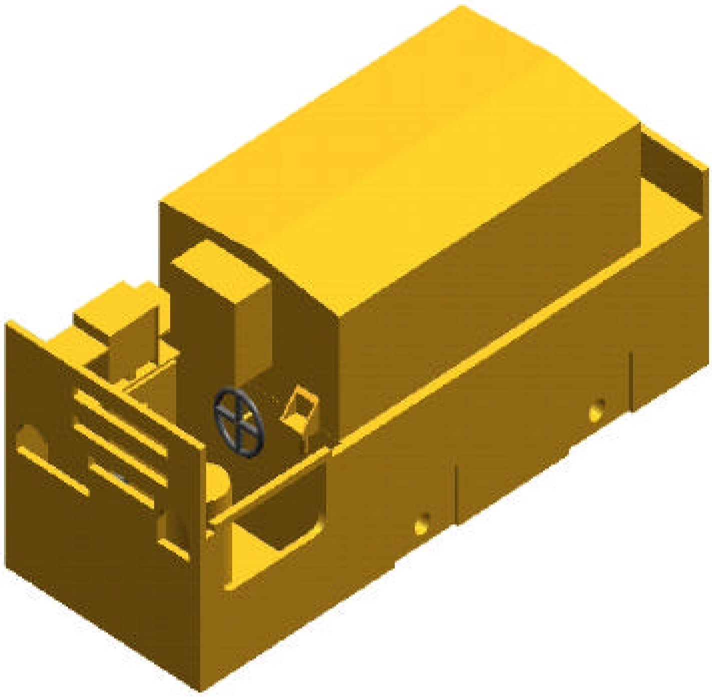


Figure 6.1: 3D CAD representation of the locomotive 6

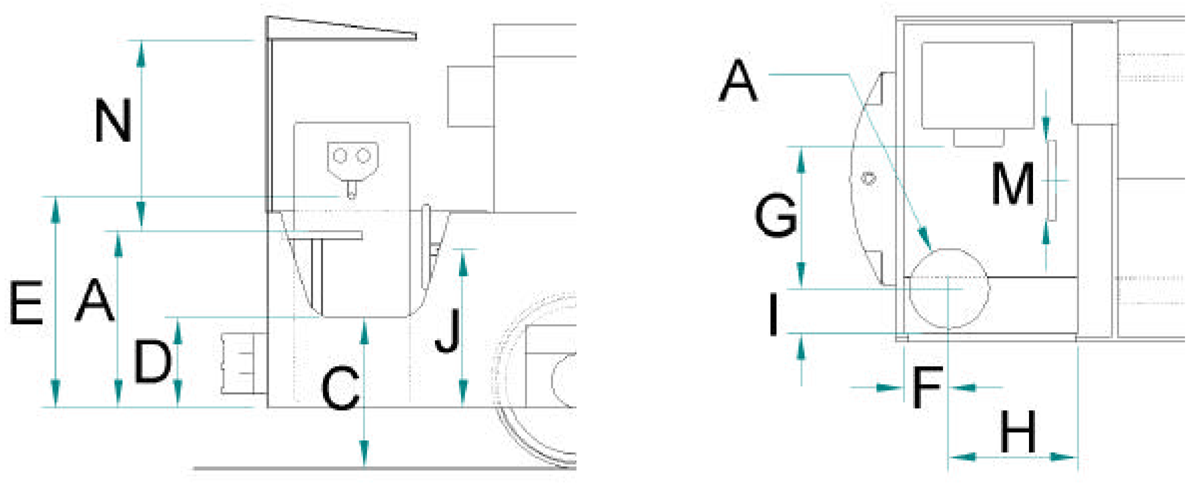


Figure 6.2: Viewing angles and distance for battery powered mine locomotive 6

Table 6.1: Dimensions for battery powered mine locomotive 6

	Manufacturer	Goodman
	Weight class (tons)	**8**
	Mine visited	F
A	Seat height from floor	740
B	Seat dimensions (WxDxH)	∅ 290
	Seat material	Cushion
C	Surface to entrance height	520
D	Entrance to floor height	400
E	Controller handle height	700
F	Seat to front wall distance	235
G	Seat to controller distance	535
H	Seat to rear wall distance	675
I	Seat to side wall distance	245
J	Park brake height from floor	590
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting height	900
	Viewing distance in front of the Locomotive for the 5th percentile sitting eye height	1500

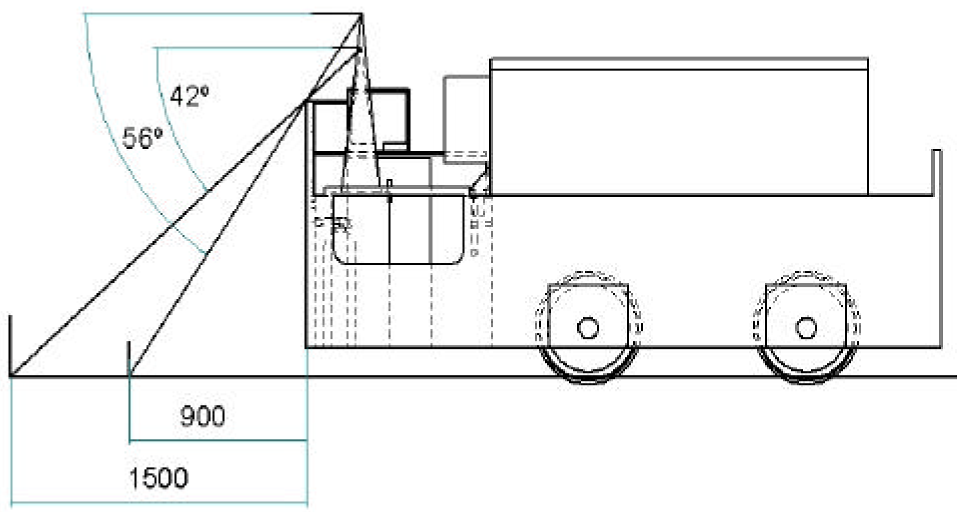


Figure 6.3: Viewing angle and distance for battery powered mine locomotive 6

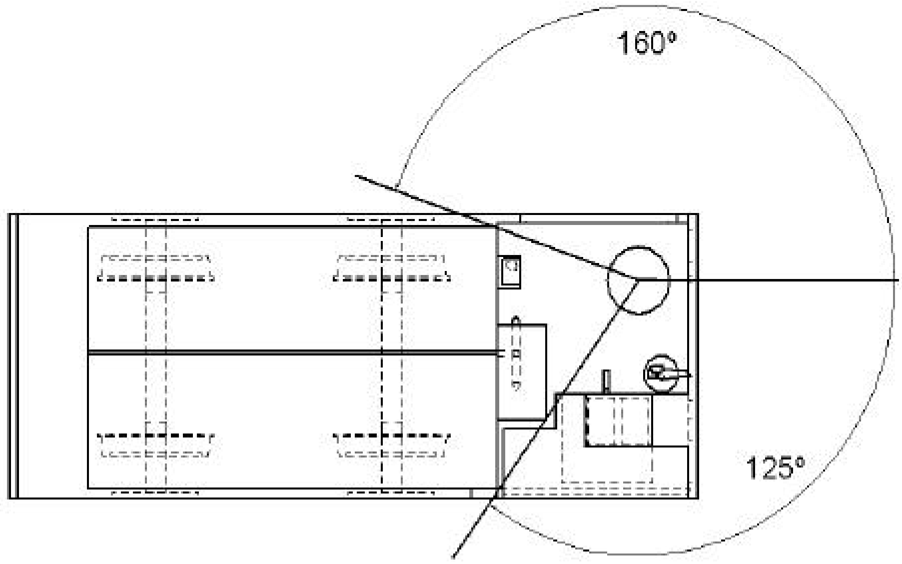


Figure 6.4: Side viewing angle from an aerial plane

6.1 Access

The surface to entrance level was higher than the recommended height for safe access without handgrips. The operator steps over the cutout side panel to enter into the cab. Three point contact for safe entry was not available due to the lack of handgrips. The operator made up of the barrier as a handgrip.

6.2 Seats and posture

The operator is not facing the direction of locomotive movement, but to the rear. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. When reversing the locomotive, the operator stands up or leans out of the cab profile, which were unsafe driving practices.

The round cushioned seat was neither adjustable nor had back or arm supports. The seat height was such that the 5th percentile up to the 95th percentile male South African would have to adopt a semi-standing work posture, which was unstable for comfortable driving of the locomotive. The seat width would accommodate only the 5th percentile South African male comfortably.

6.3 Controls

The controls were within easy reach for the 5th percentile to the 95th percentile male South African. However, manipulation and access to the brake handwheel was impeded by the battery cable that is routed directly over the brake handwheel. A video display to give text command to the operator from the control room was well within visual field.

6.4 Visual field

The visual field to the back from a seated posture was restrictive.

7. Locomotive 7

Figure 7.1: 3D CAD representation of the locomotive 7

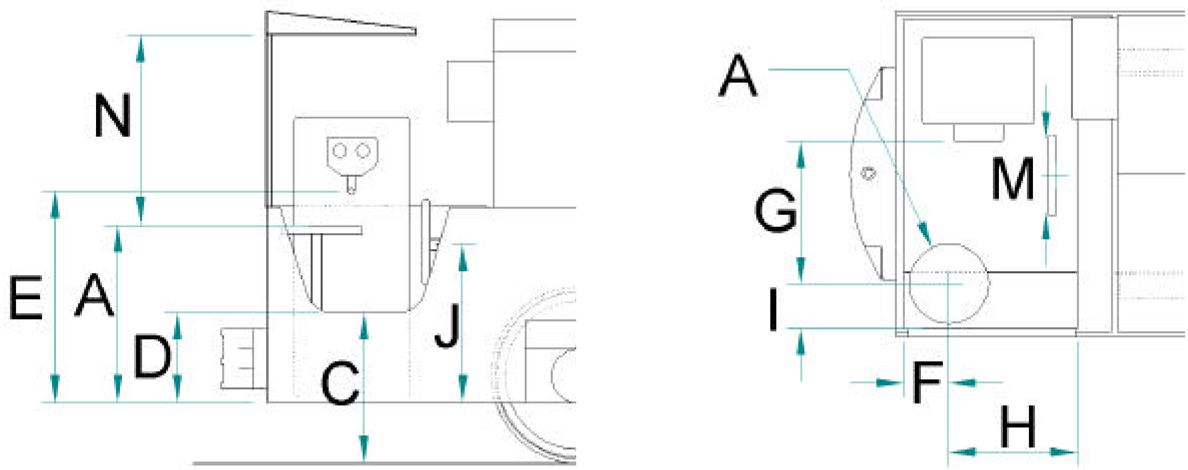


Figure 7.2: Battery powered mine locomotive 7

Table 7.1: Dimensions for battery powered mine locomotive 7

	Manufacturer	Goodman
	Weight class (tons)	**8**
	Mine visited	B
A	Seat height from floor	N/A
B	Seat dimensions (WxDxH)	N/A
	Seat material	No seat
C	Surface to entrance height	545
D	Entrance to floor height	425
E	Controller handle height	940
F	Seat to front wall distance	N/A
G	Seat to controller distance	730
H	Seat to rear wall distance	870
I	Seat to side wall distance	N/A
J	Park brake height from floor	600
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile standing eye height	1000
	Viewing distance in front of the locomotive for the 5th percentile standing eye height	1600

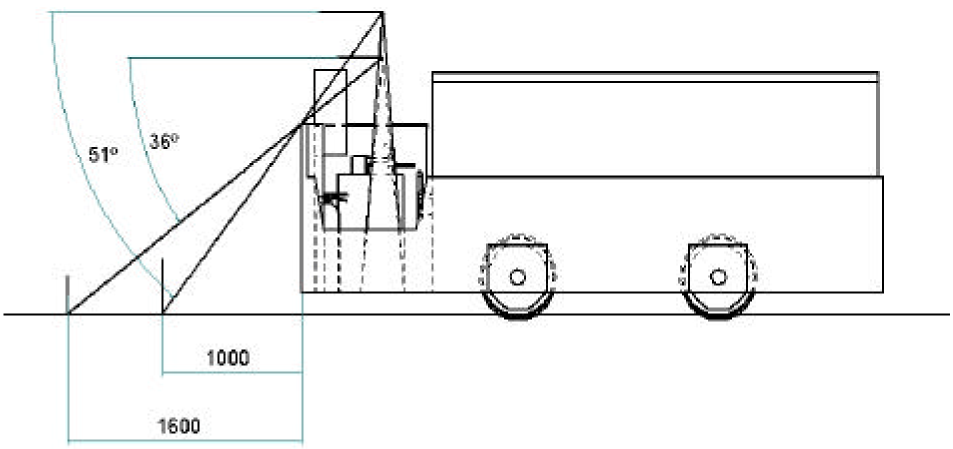


Figure 7.3: Viewing angle and distance for battery powered mine locomotive 7

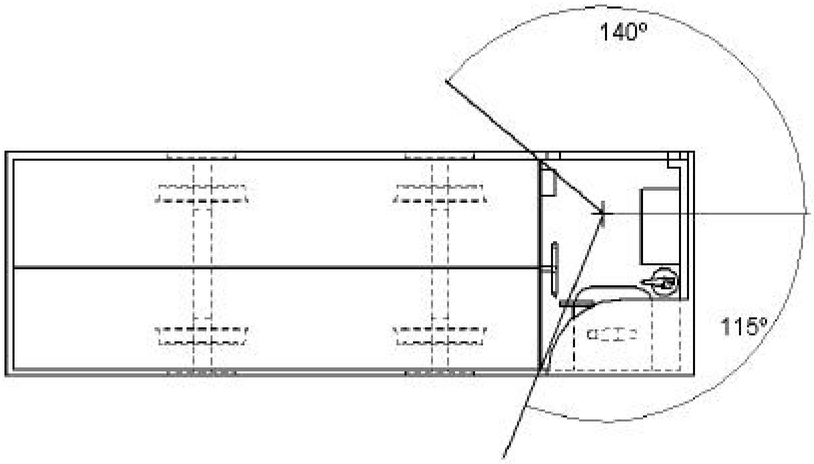


Figure 7.4: Side viewing angle from an aerial plane

7.1 Access

The surface to entrance level was higher than the recommended height for easy entrance. The operator uses the locomotive ledge as handgrip when entering into the cab as there was no handgrip available for a safe three point entry.

7.2 Seats and posture

There was no seat provided for the operator. Thus he must stand while operating the locomotive which is unacceptable practice under the mine regulations. The location of the controls does allow for a forward facing posture. Upon reversing, the trunk and neck would be rotated to the direction of movement and the arm would be extended from the side of the body to operate the controls.

7.3 Controls

The controls located onto the control panel were within the reach envelop from the operator's standing work posture of the 5th to 95th percentile South African male. The location of the main isolator switch and the light switch at the far left corner was too far to reach while operating the locomotive for even the 5th percentile male.

7.4 Visual field

The forward and side viewing angle and distance were within the recommended range. Visual field to the rear was restricted.

8. Locomotive 8

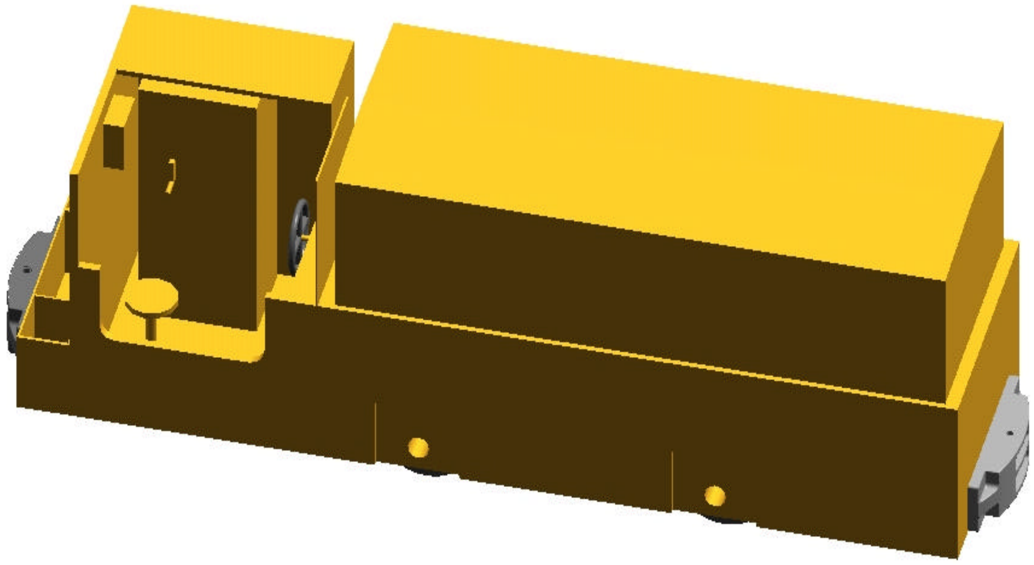


Figure 8.1: 3D CAD representation of the locomotive 8

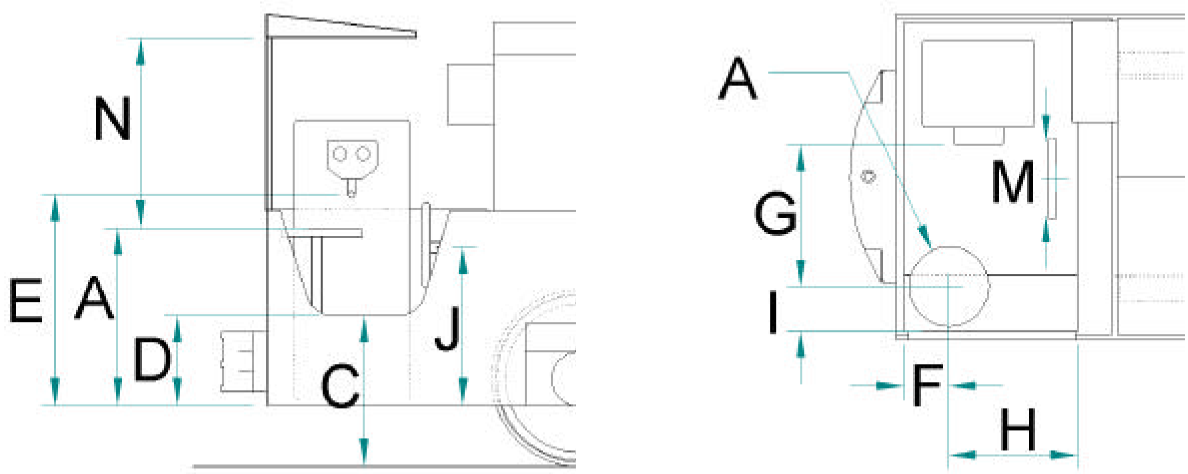


Figure 8.2: Battery powered mine locomotive 8

Table 8.1: Dimensions for battery powered mine locomotive 8

	Manufacturer	Goodman
	Weight class (tons)	**8**
	Mine visited	E
A	Seat height from floor	500
B	Seat dimensions (WxDxH)	∅250
	Seat material	Metal
C	Surface to entrance height	530
D	Entrance to floor height	400
E	Controller handle height	675
F	Seat to front wall distance	300
G	Seat to controller distance	700
H	Seat to rear wall distance	680
I	Seat to side wall distance	50
J	Park brake height from floor	565
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	2300
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	27200

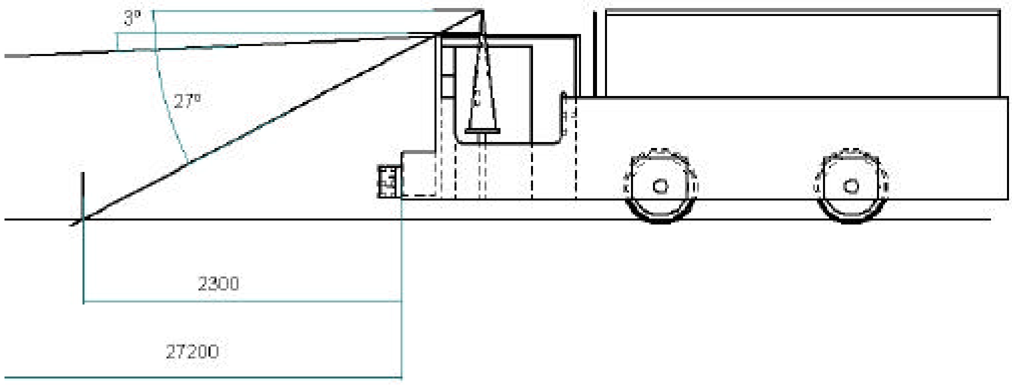


Figure 8.3: Viewing angle and distance for battery powered mine locomotive 8

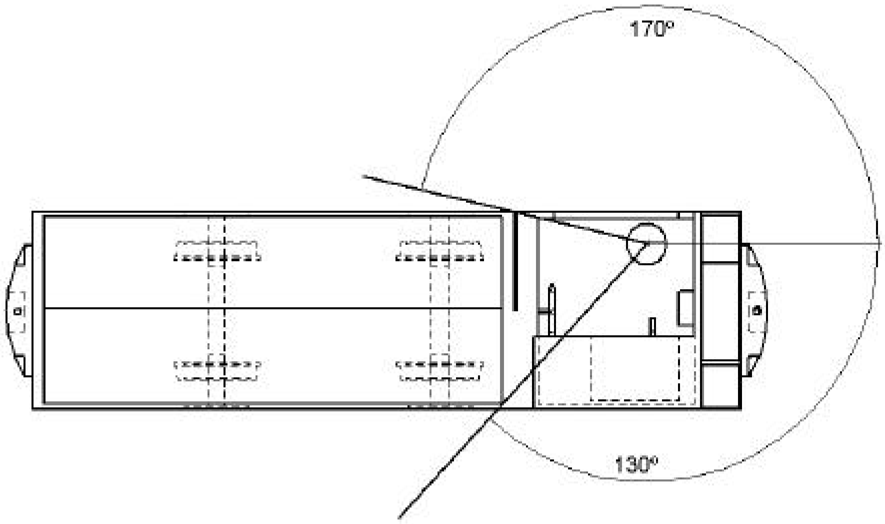


Figure 8.4: Side viewing angles from an aerial plane

8.1 Access

The surface to entrance level was higher than the recommended height. A handgrip bar is provided on the right-hand side of the cutout side panel for the cab, which enables easy access into the cab for the 5^{th} to 95^{th} percentile South African male.

8.2 Seats and posture

The position of the control panel is such that the operator must face sideways. The operator adopts a sustained twisted neck posture when facing towards the direction of the locomotive movement. When reversing the locomotive, the operator stands up or leans out of the cab profile. Standing posture when operating a locomotive is unacceptable driving practice.

The seat height is too high for a traditional sitting posture. The operator would adopt a semi-standing work posture, which is unstable for proper control of the locomotive. The lamp connector is positioned that the operator often contacts it with his trunk.

8.3 Controls

The location of the control panel from the operator's seat was not within the reach envelop of the 50^{th} percentile South African male population.

8.4 Visual field

Forward and side viewing angles and distance were within the recommended range for the 95th percentile male South African. Forward visual field was severely restricted by the front protection plate for the 5th percentile. This operator cannot see in front of the locomotive within the recommended range and therefore cannot safely drive the locomotive. Rear visual field for the 5th percentile to the 95th percentile was restricted.

9. Locomotive 9

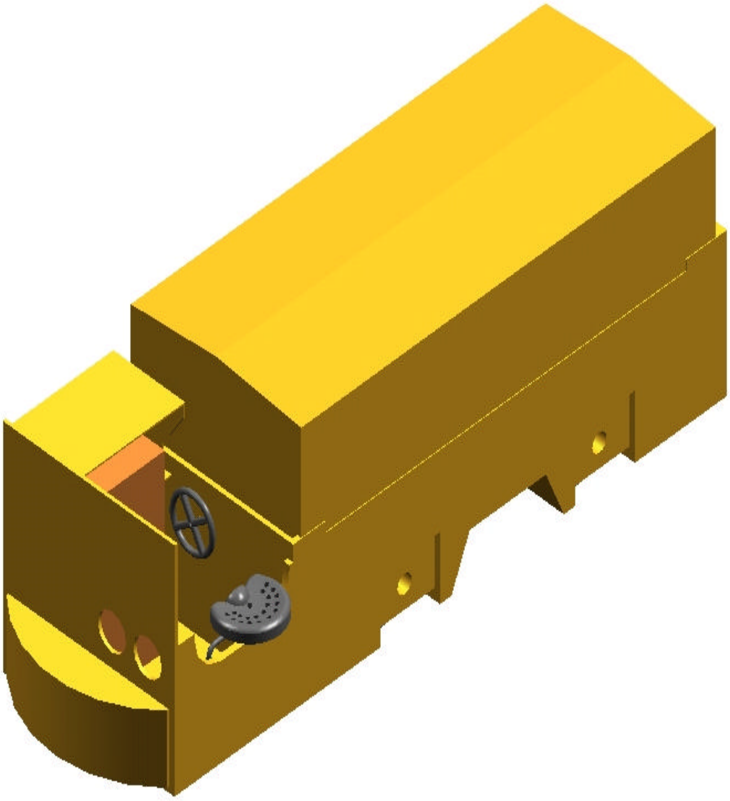


Figure 9.1: 3D CAD representation of the locomotive 9

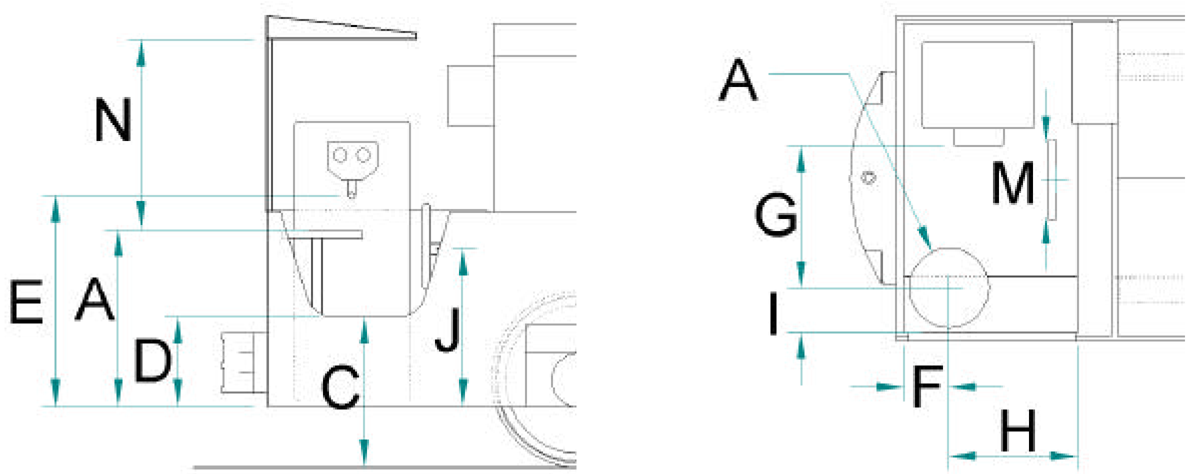


Figure 9.2: Battery powered mine locomotive 9

Table 9.1: Dimensions for battery powered mine locomotive 9

	Manufacturer	Goodman
	Weight class (tons)	**10**
	Mine visited	G
A	Seat height from floor	580
B	Seat dimensions (WxDxH)	400 X 360
	Seat material	Polyurethane
C	Surface to entrance height	615
D	Entrance to floor height	495
E	Controller handle height	780
F	Seat to front wall distance	290
G	Seat to controller distance (seat at furthest backward position)	740
H	Seat to rear wall distance	650
I	Seat to side wall distance	12 (can swivel outside the cabin envelope)
J	Park brake height from floor	585
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake dimensions	∅320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	4300
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	27500

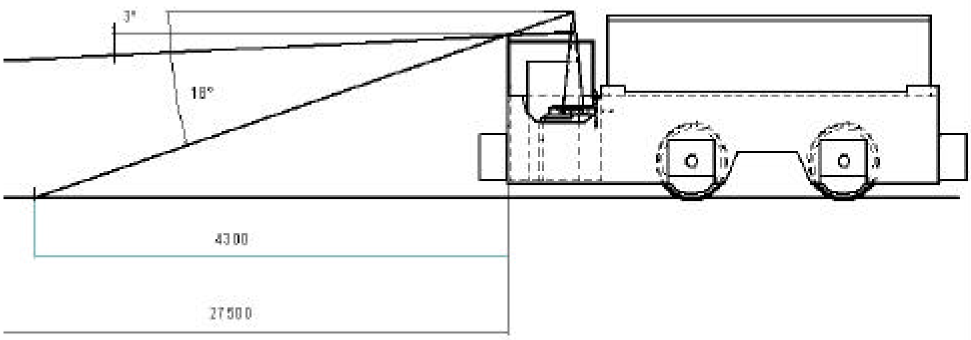


Figure 9.3: Viewing angle and distance for battery powered mine locomotive 9

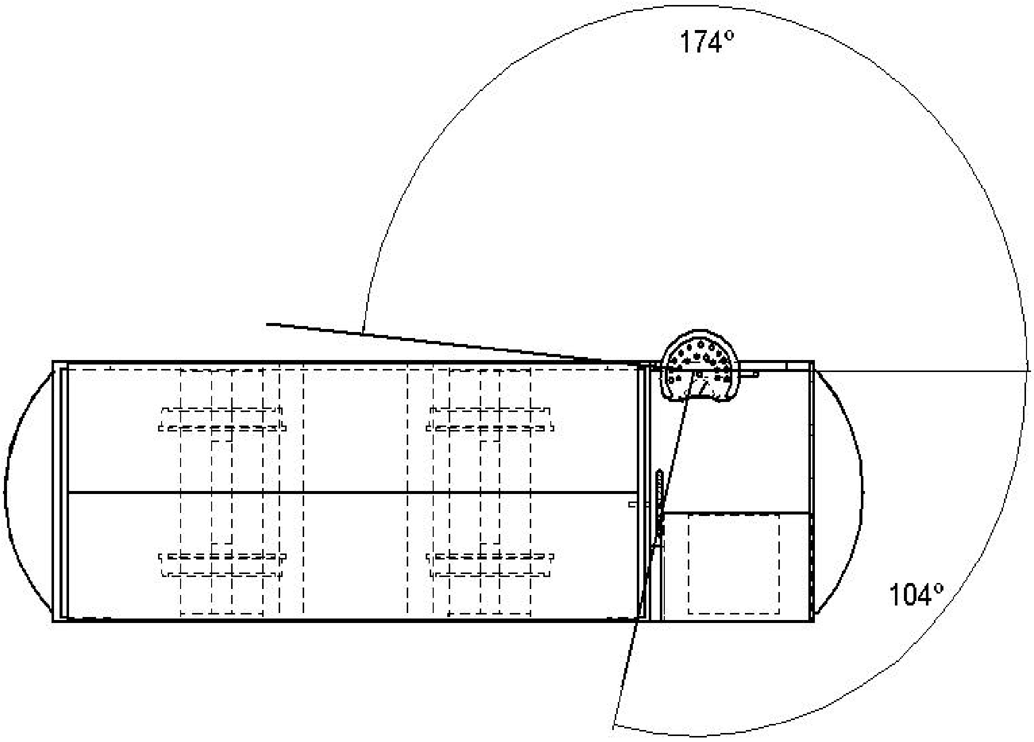


Figure 9.4: Side view angle from an aerial plane

9.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator steps over the cutout side panel to enter into the cab. Three point contact for safe entry into the cab was not available.

9.2 Seat and posture

A swivel type saddle seat with no back and arm support was provided for the operator. The seat swings outside of the locomotive cab profile to allow easy entry. The adjustability to change the horizontal seated position allows for easy access to the controls.

The location of the control panel induces the operator to sit sideways. When facing towards the direction of the locomotive movement, the operator adopts a sustained twisted neck posture. When reversing the locomotive, the operator stands up.

The height of the seatbase from the cab floor was high for comfortable sitting posture for the 5th percentile South African male. The operator adopts a semi-standing posture, which is an unstable posture for locomotion operation. The operator's feet cannot be placed onto the cab floor for a stable seated posture.

9.3 Controls

All controls were within easy reach and manipulation for the 5th percentile to the 95th percentile seated South African male. This was achieved by the horizontal adjustability of the seat for the operator. All controls were clearly labelled.

9.4 Visual field

Forward viewing distance was within the recommended range for the 95th percentile South African male. Forward visual field was severely restricted by the front protection plate for the 5th percentile. He can therefore not safely drive the locomotive. There are blind spots to front corners of protection plate limiting front visual field within a 45 degrees radius. The operator cannot see in front of the locomotive within the recommended range.

10. Locomotive 10

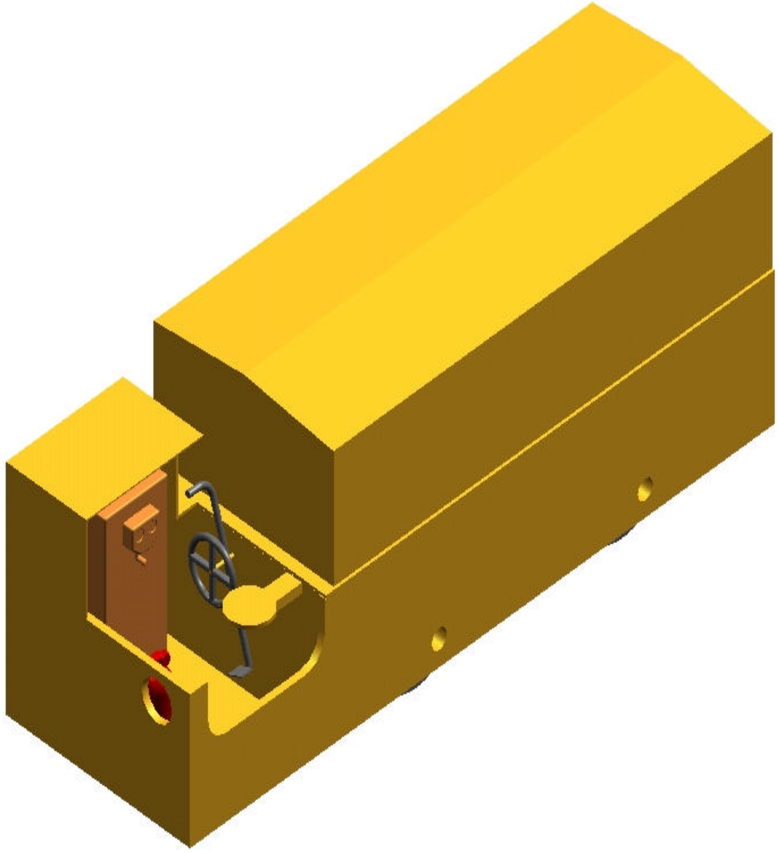


Figure 10.1: 3D CAD representation of the locomotive 10

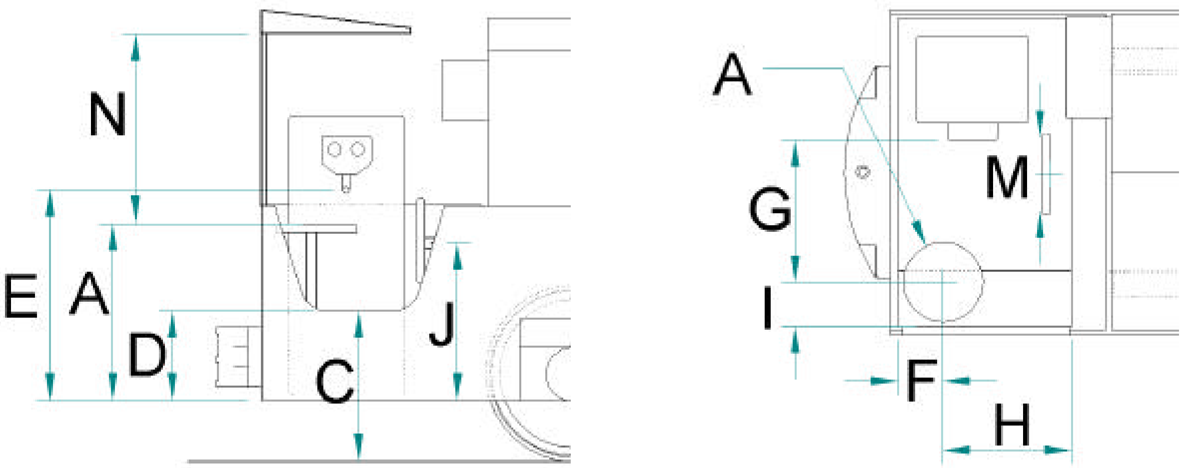


Figure 10.2: Battery powered mine locomotive 10

Table 10.1: Dimensions for battery powered mine locomotive 10

	Manufacturer	**Goodman**
	Weight class (tons)	**10**
	Mine visited	H
A	Seat height from floor	680-740
B	Seat dimensions (WxDxH)	∅265
	Seat material	Wood
C	Surface to entrance height	510
D	Entrance to floor height	410
E	Controller handle height	755
F	Seat to front wall distance	568
G	Seat to controller distance	480
H	Seat to rear wall distance	297
I	Seat to side wall distance	68
J	Park brake height from floor	575
K	Foot brake height from floor	135
L	Hand brake height from floor	890
M	Park brake dimensions	∅ 320
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	600
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	800

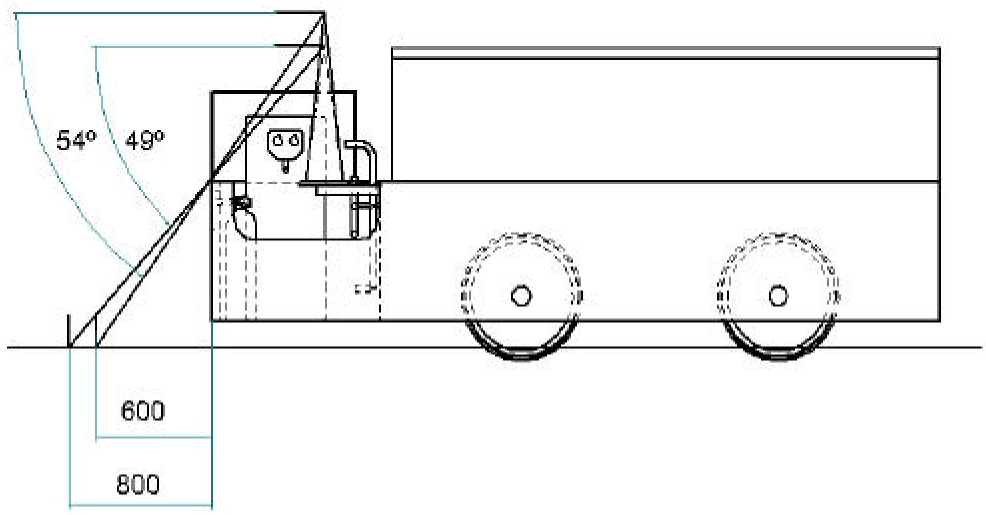


Figure 10.3: Visual angle and distance for battery powered mine locomotive 10

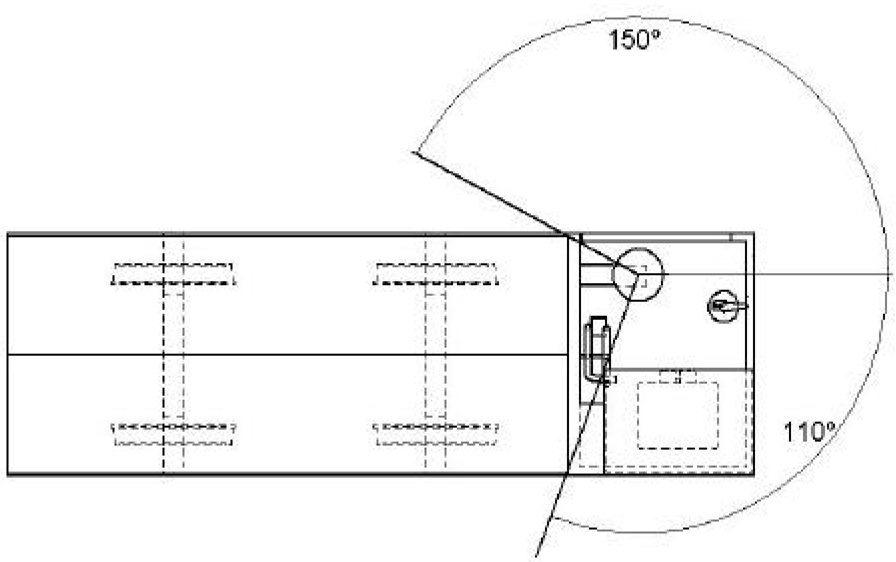


Figure 10.4: Side view angle from an aerial plane

10.1 Access

The surface to entrance level was higher than recommended without handgrips. The operator steps over the cutout side panel and holds onto the locomotive ledge when entering into the cab. Three point contract for safe entering into the cab was not available.

10.2 Seats and posture

The seat was too narrow to accommodate the 5th percentile South African male users. The seat height was adjustable but the range was still too high for comfortable sitting for the 5th percentile up to the 95th percentile male South African. The operator's feet cannot be placed onto the cab floor for a stable seated posture. The operator adopts a semi-standing posture, which is not stable for controlling the locomotive.

The operator does not face towards the direction of the locomotive movement, but to the side of the cab, which includes a sustained twisted neck posture when facing towards the front of the locomotive. To reverse the locomotive the operator must stand up which are against mining health and safety regulations.

10.3 Controls

All the controls were within the reach envelop the 5th percentile to the 95th percentile seated male South African. A hand operated service brake with foot pedal is provided. All displays were legible and within the visual field of the seated operator.

10.4 Visual field

Forward and side viewing angle and distance are within the recommended range. The 5th percentile up to the 95th percentile South African male can see onto the track. Visual field to the rear from the seated posture is restricted.

11. Locomotive 11

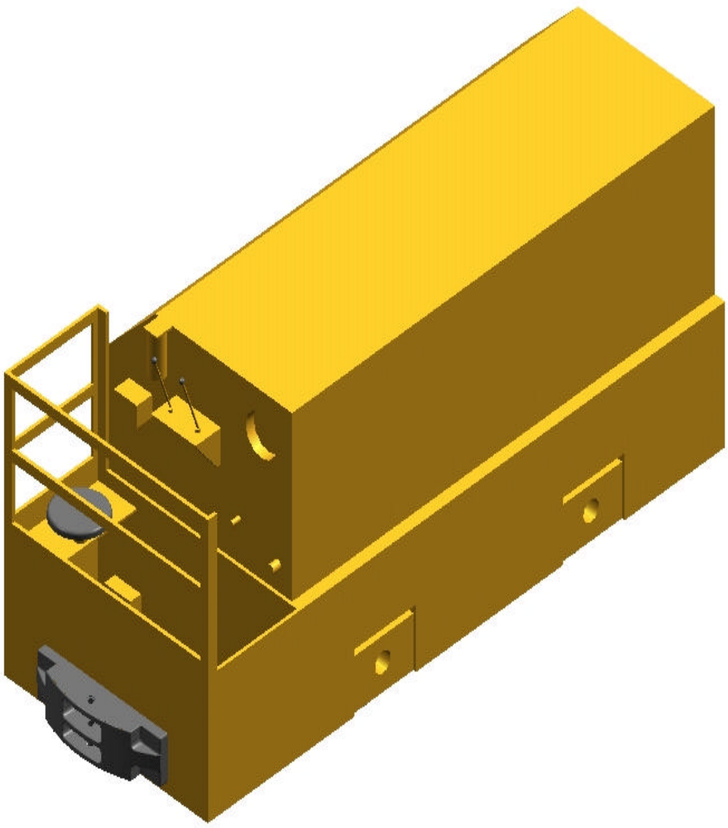


Figure 11.1: 3D CAD representation of the locomotive 11

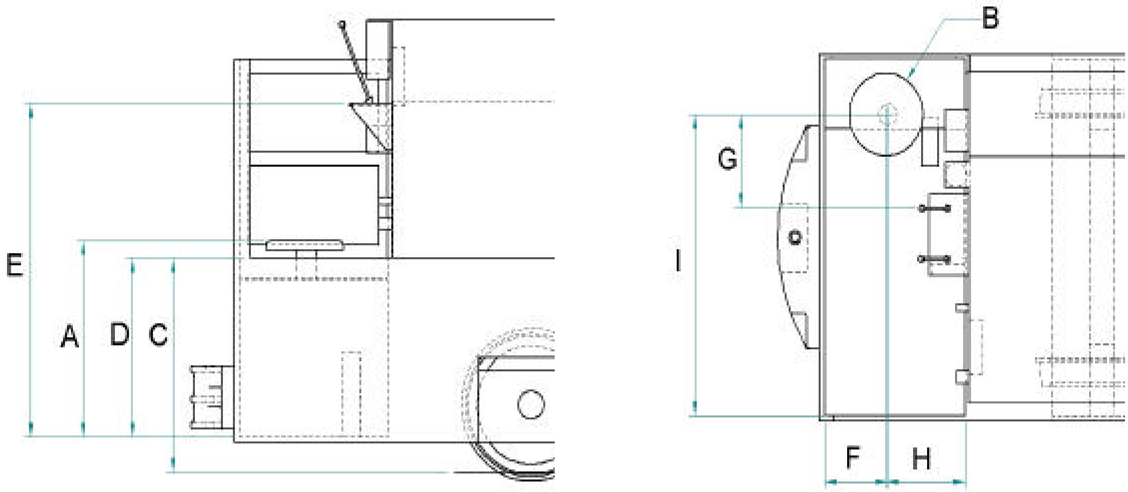


Figure 11.2: Diesel powered mining locomotive 11

Table 11.1: Dimensions for diesel powered mining locomotives 11

	Manufacturer	Hunslett Taylor
	Weight class (tons)	**10**
	Mine visited	?
A	Seat height	660-900
B	Seat dimensions (WxDxH)	∅300
	Seat material	Wood
C	Surface to entrance height	770
D	Entrance to floor height	640
E	Controller handle height	930
F	Seat to front wall distance	310
G	Seat to controller distance	270
H	Seat to rear wall distance	315
I	Seat to side wall distance	960
	Canopy (Yes/No)	No
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	200
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	300

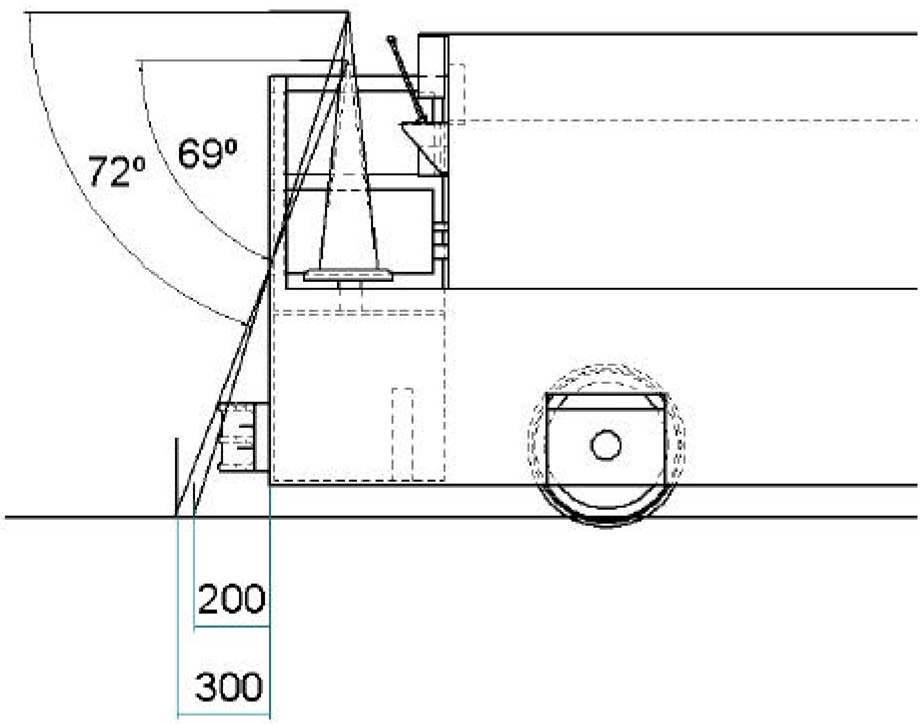


Figure 11.3: Visual angle and distance for diesel powered mining locomotive 11

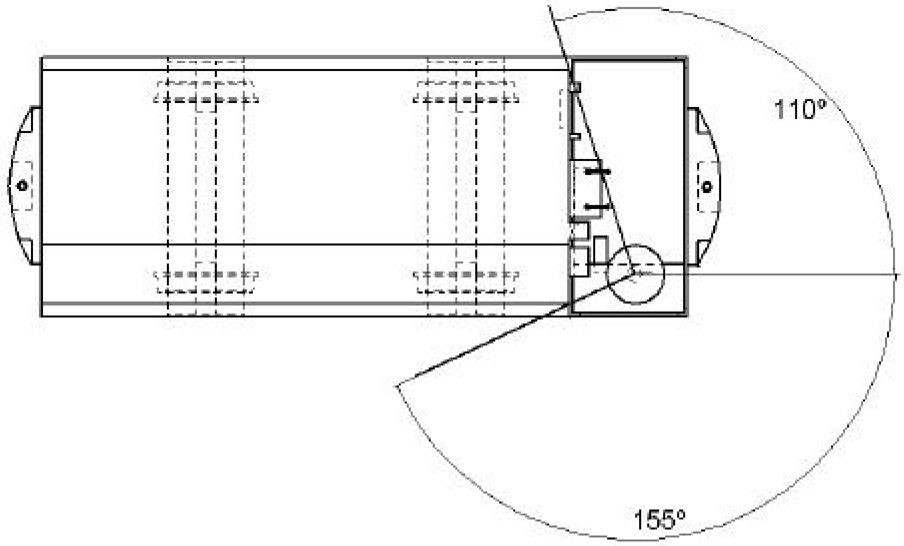


Figure 11.4: Side view angles from an aerial plane

11.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator has to step up onto or over the entry panel, which did not have a cutout. He holds onto the locomotive side panels when entering or exiting the cab, as there were no handgrips available to ensure a three-point contact for safe entry into the cab. Footing on entry is limited due to the tools and equipment being stored on the cab floor.

11.2 Seats and posture

The wooden seat base was height adjustable but did not have back or arm supports. The seat height was too high for the 5th percentile to the 95th South African male to be able to place his feet on the cab floor. The operator places his feet onto ledges on either side of the cab to provide some stability.

The operator is facing sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. The operator stands up when reversing the locomotive, which is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

11.3 Controls and displays

All the controls are within the reach envelope of the 5th percentile to 95th percentile South African male. All controls and displays were legibly labeled and within the visual field.

11.4 Visual angle and distance

Forward viewing angle and distance are within the recommended range. The 5th percentile to the 95th percentile male South African can see the track in front of the locomotive from the seated position, but visual field to the rear is restricted such that the operator had to stand when reversing to have visual access.

12. Locomotive 12

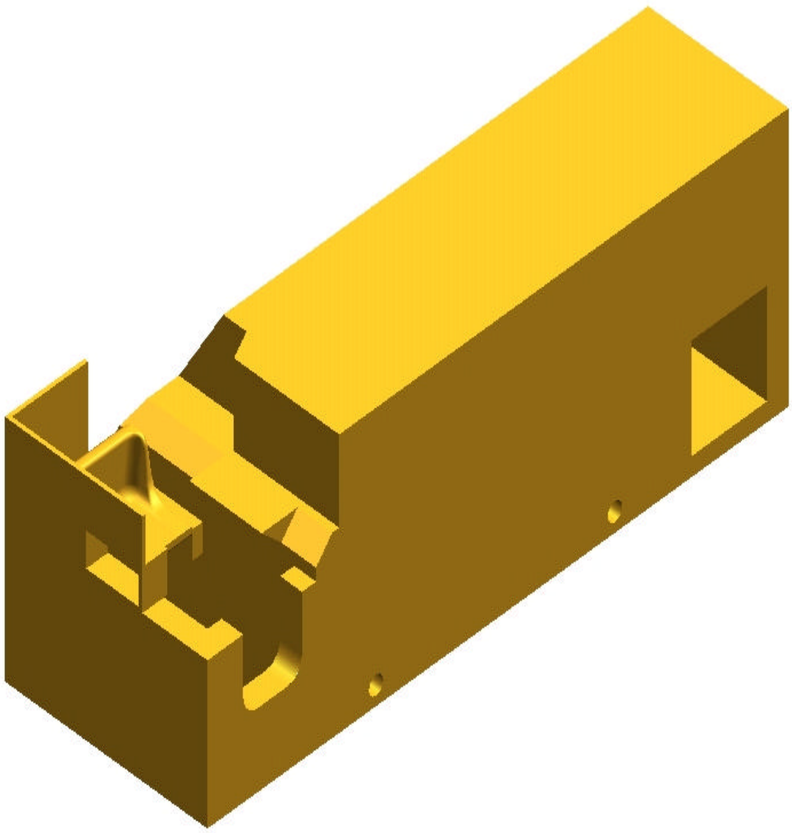


Figure 12.1: 3D CAD representation of the locomotive 12

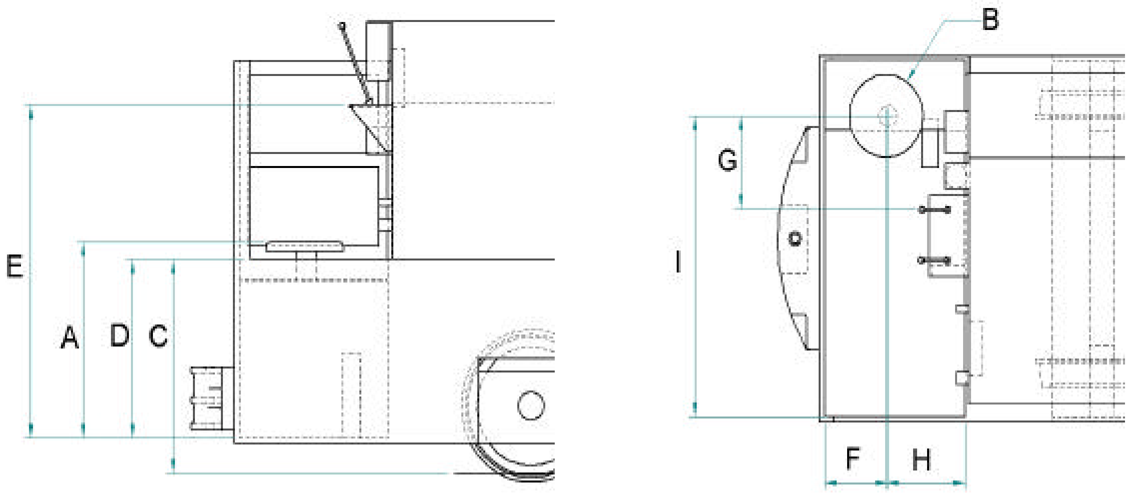


Figure 12.2: Diesel powered mining locomotive 12

Table 12.1: Dimensions for diesel powered mining locomotives 12

	Manufacturer	**Funkey**
	Weight class (tons)	**15**
	Mine visited	?
A	Seat height	660
B	Seat dimensions (WxDxH)	530x370x260
	Seat material	Polyurethane
C	Surface to entrance height	580
D	Entrance to floor height	400
E	Controller handle height	950
F	Seat to front wall distance	335
G	Seat to controller distance	255
H	Seat to rear wall distance	265
I	Seat to side wall distance	895
	Canopy (Yes/No)	No
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	500
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	700

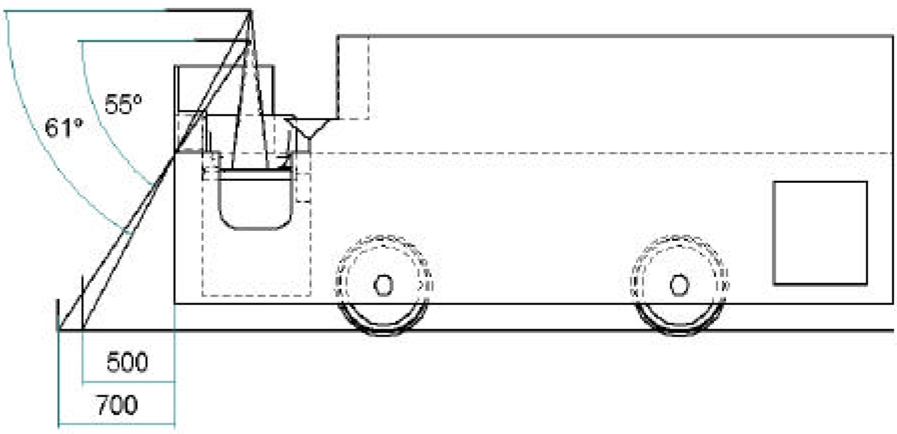


Figure 12.3: Viewing angle and distance for diesel powered mining locomotive 12

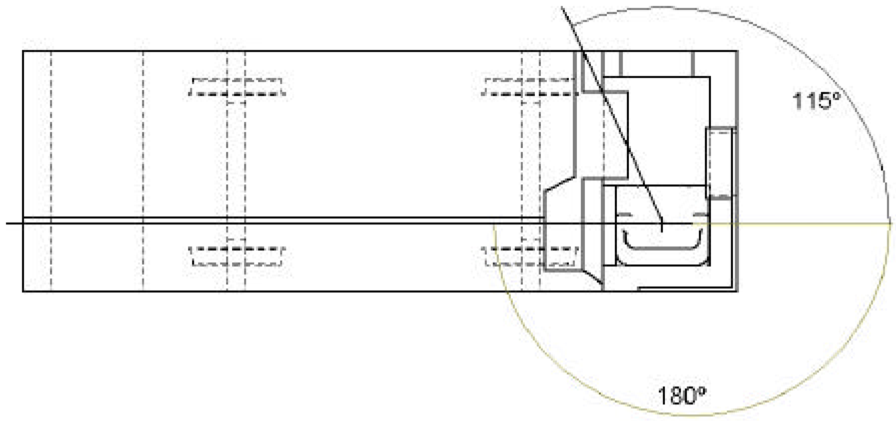


Figure 12.4: Side view angle from an aerial plane

12.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator has to step over the entry panel, which did have a cutout. He holds onto the locomotive side panels when entering or exiting the cab, as there were no handgrips available to ensure a three-point contact for safe entry into the cab.

12.2 Seats and posture

The polyurethane seat was not height adjustable but did have back and arm supports. The seat height was too high for the 5th percentile to the 95th South African male to be able to place his feet on the cab floor. The operator places his feet onto ledges on either side of the cab to provide some stability

The operator is facing sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. The operator stands up when reversing the locomotive, which is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

12.3 Controls and displays

All the controls are within the reach envelope of the 5th percentile to 95th percentile South African male. All controls and displays were legibly labeled and within the visual field.

12.4 Visual angle and distance

Forward viewing angle and distance are within the recommended range. The 5th percentile to the 95th percentile male South African can see the track in front of the locomotive from the seated position, but visual field to the rear is restricted such that the operator had to stand when reversing.

13. Locomotive 13

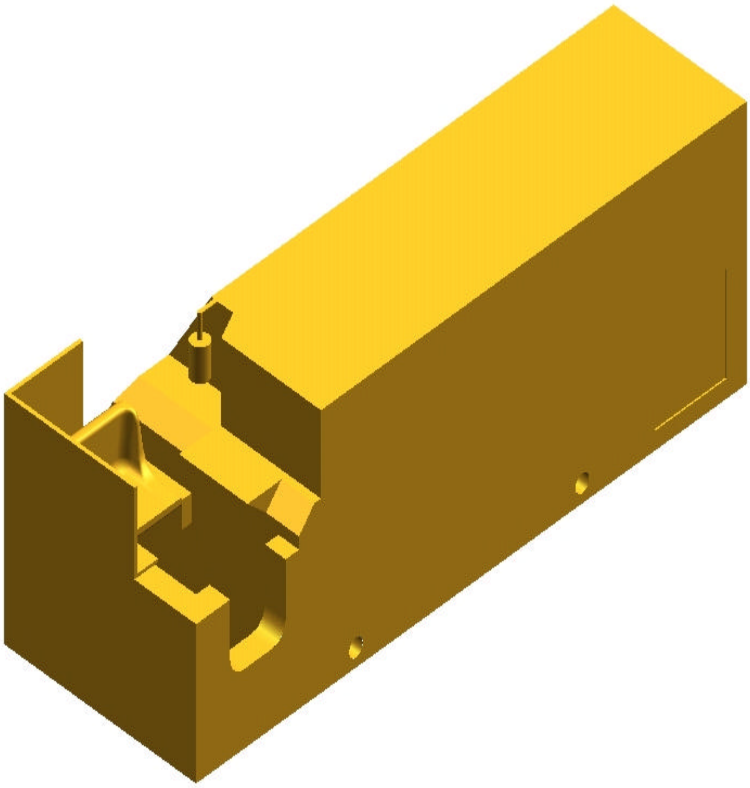


Figure 13.1: 3D CAD representation of the locomotive 13

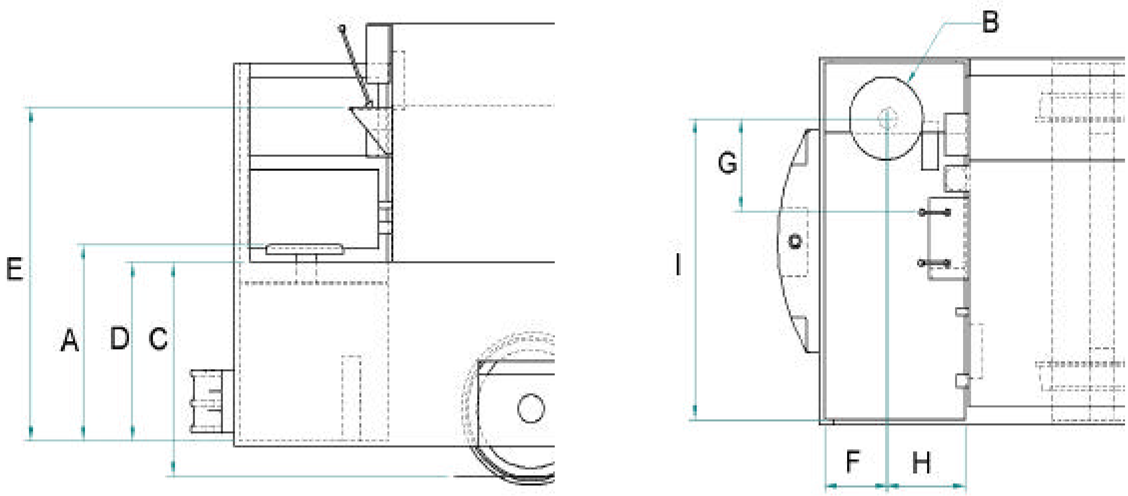


Figure 13.2: Diesel powered mining locomotive 13

Table 13.1: Dimensions for diesel powered mining locomotives 13

	Manufacturer	Funkey
	Weight class (tons)	**15**
	Mine visited	?
A	Seat height	660
B	Seat dimensions (WxDxH)	530x370x260
	Seat material	Polyurethane
C	Surface to entrance height	580
D	Entrance to floor height	400
E	Controller handle height	950
F	Seat to front wall distance	335
G	Seat to controller distance	255
H	Seat to rear wall distance	265
I	Seat to side wall distance	895
	Canopy (Yes/No)	No
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	500
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	700

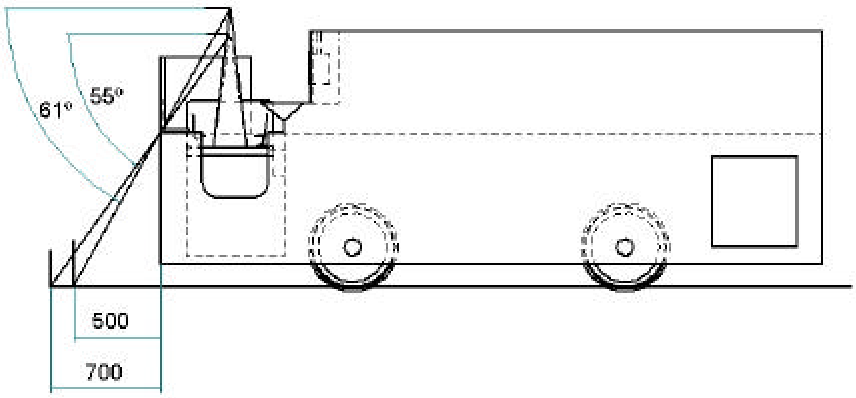


Figure 13.3: Viewing angle and distance for diesel powered mining locomotive

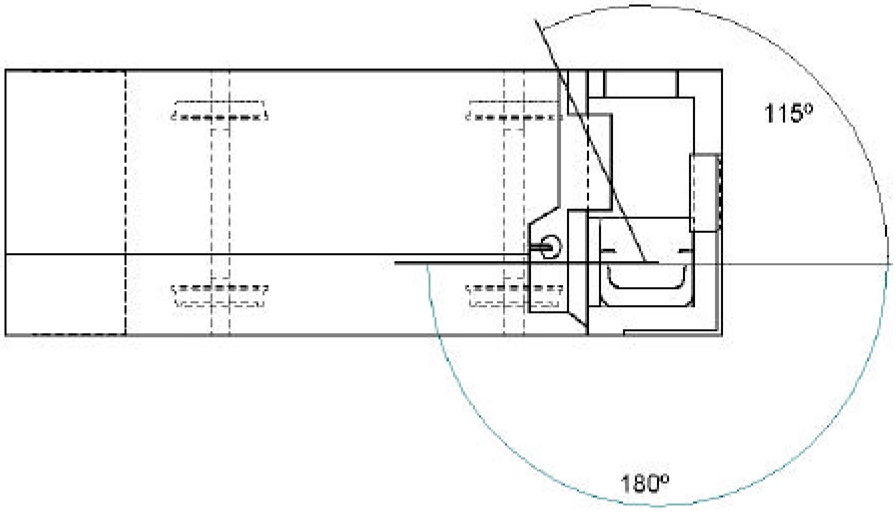


Figure 13.4: Side viewing angle from an aerial plane

13.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator has to step over the entry panel, which did have a cutout. He holds onto the locomotive side panels when entering or exiting the cab, as there were no handgrips available to ensure a three-point contact for safe entry into the cab. No handgrip was provided.

13.2 Seats and posture

The polyurethane seat was not height adjustable but did have back and arm supports. The seat height was too high for the 5^{th} percentile to the 95^{th} South African male to be able to place his feet on the cab floor. The operator places his feet onto ledges on either side of the cab to provide some stability

The operator is facing sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. The operator stands up when reversing the locomotive, which is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.2.1).

13.3 Controls and displays

All the controls are within the reach envelope of the 5th percentile to 95th percentile South African male. All controls and displays were legibly labeled and within the visual field. There were no visual warning lights on the control panel in working order and the labels were eroded or illegible.

13.4 Visual angle and distance

Forward and side viewing angles and distance are within the recommended range. The 5th percentile to the 95th percentile male South African can see the track in front of the locomotive from the seated position, but visual field to the rear is restricted such that the operator had to stand when reversing.

14. Locomotive 14

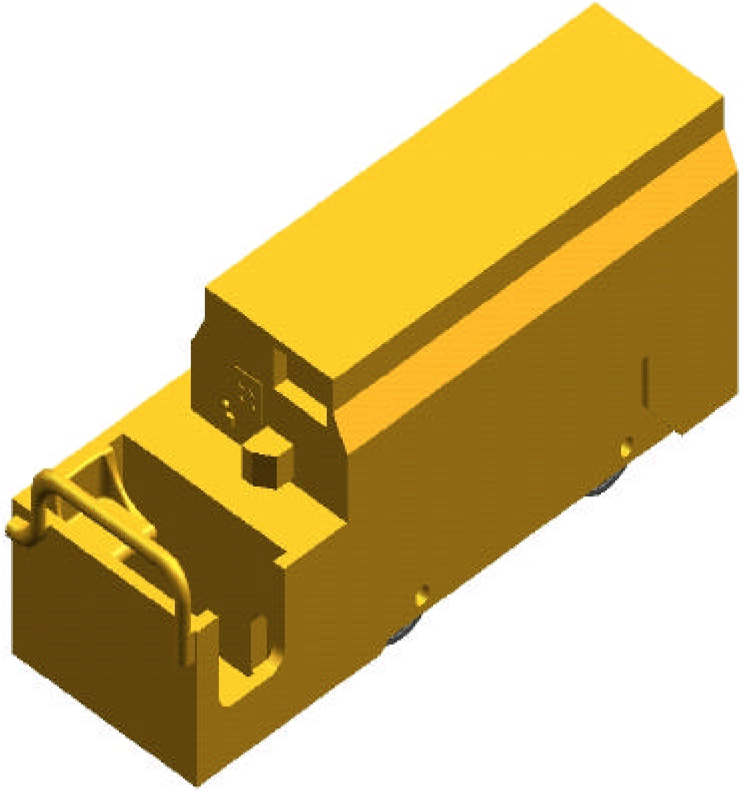


Figure 14.1: 3D CAD representation of the locomotive 14

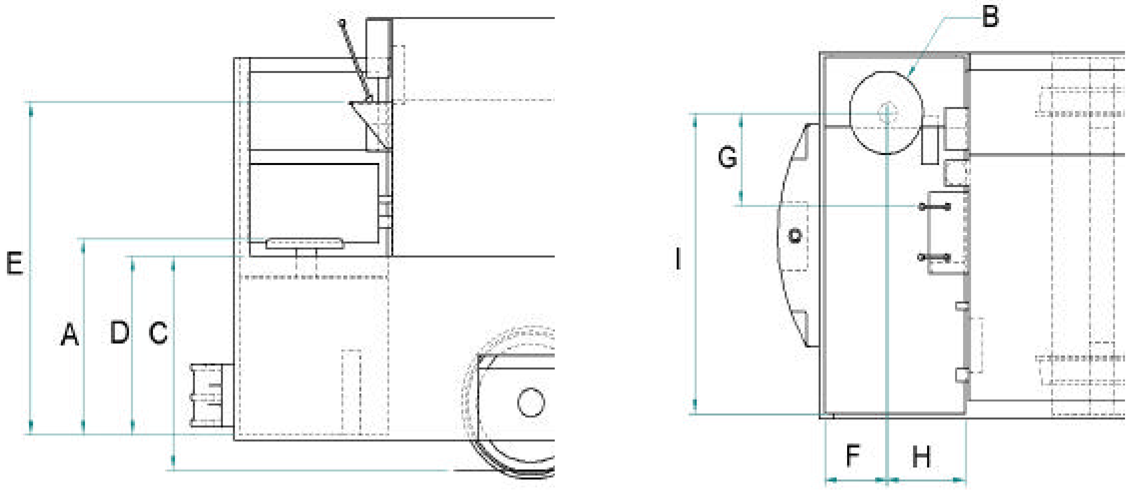


Figure 14.2: Diesel powered mining locomotive 14

Table 14.1: Dimensions for diesel powered mining locomotives 14

	Manufacturer	PROF Donsa
	Weight class (tons)	**15**
	Mine visited	?
A	Seat height	560
B	Seat dimensions (WxDxH)	480x330x250
	Seat material	Polyurethane
C	Surface to entrance height	510
D	Entrance to floor height	295
E	Controller handle height	1030
F	Seat to front wall distance	300
G	Seat to controller distance	630
H	Seat to rear wall distance	240
I	Seat to side wall distance	1015
	Canopy (Yes/No)	No
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	900
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	700

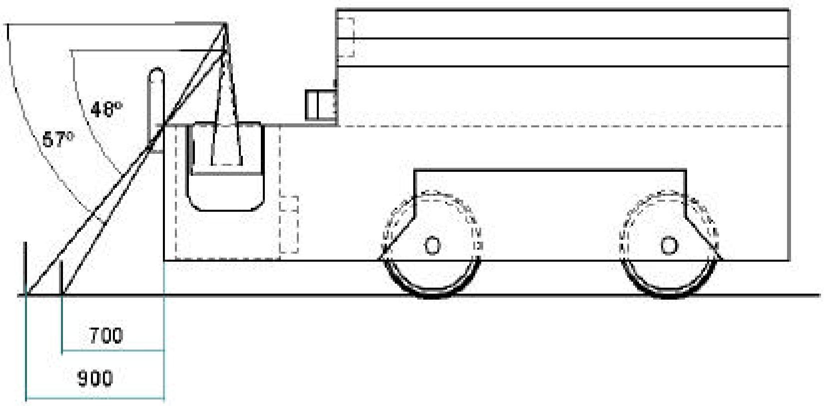


Figure 14.3: Viewing angle and distance for diesel powered mining locomotive 14

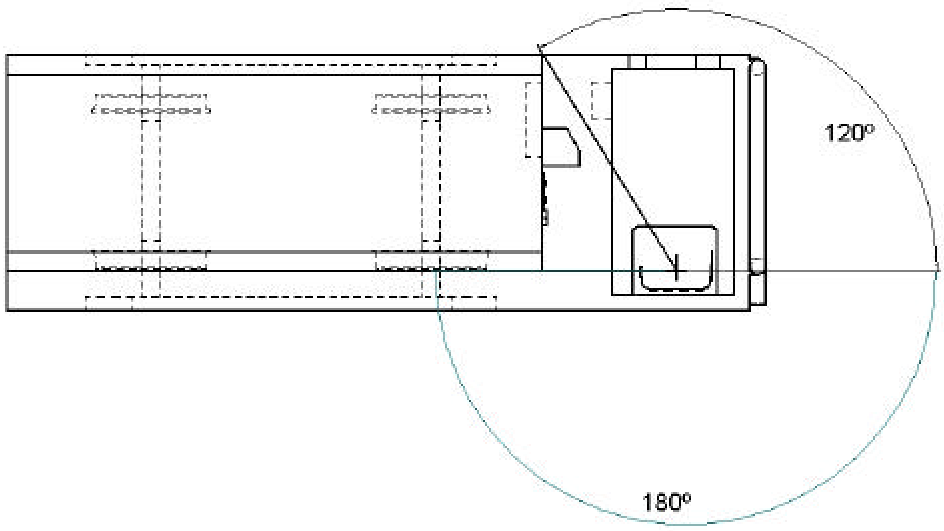


Figure 14.4: Side view angle from an aerial plane

14.1 Access

The access level for higher than the recommended height, however there was cut out in the entry panel and used with the sided bumper rail as a hand rail allowed for safe and easy access.

14.2 Seat and posture

The operator did not face the direction of the locomotive movement which induced a sustained twisted neck posture, towards the direction of movement, when reversing the operator had to lean out of the cab to the left with an unsupported laterally flexed trunk or to stand and face the direction of movement, neither of which are acceptable mine practices. The seat provides adequate back and foot support but no arm support. However the layout of the cab is such that the operator can use the panel to the left-hand side and the bumper rail to the right hand side to rest his arms.

14.3 Controls

The hand and foot controls were within access for the 5th to 95th percentile South African male. The visual display was within visual access.

14.4 Visual field and angles

The angles and distances were within acceptable ranges.

15. Locomotive 15

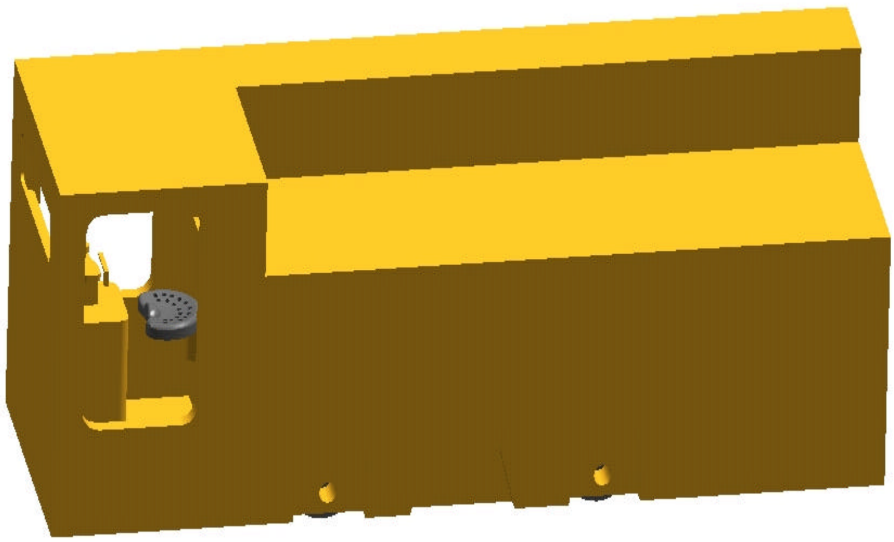


Figure 15.1: 3D CAD representation of the locomotive 15

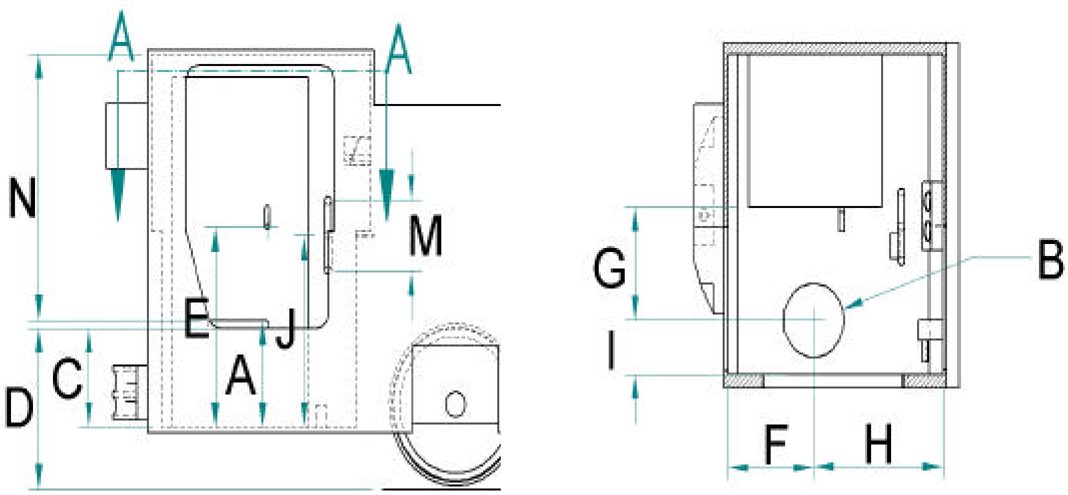


Figure 15.2: Electric powered mining locomotive 15

Table 15.1: Dimensions for electric powered mining locomotives 15

	Manufacturer	**Goodman**
	Weight class (tons)	20
A	Seat height	750
B	Seat dimensions (WxDxH)	400x340
	Seat material	Polyurethane
C	Entrance to floor height	640
D	Surface to entrance height	800
E	Controller handle height	990
F	Seat to front wall distance	620
G	Seat to controller distance	220
H	Seat to rear wall distance	280
I	Seat to side wall distance	635
J	Park brake height from floor	845
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	990
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	2500-6800
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	4200-infinite

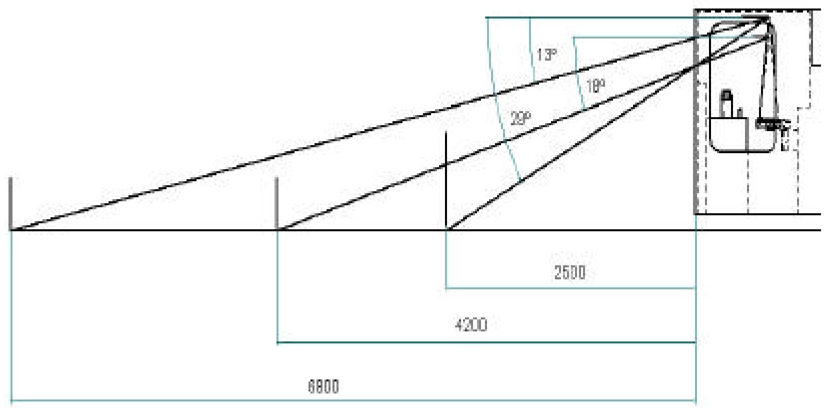


Figure 15.3: Visual angles and distance for electric powered mining locomotive 15

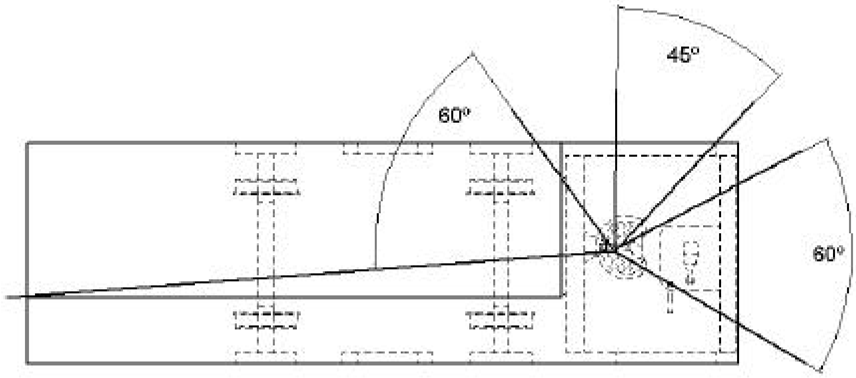


Figure 15.4: Side viewing angle from an aerial plane

15.1 Access

The surface to entrance level was higher than the recommended height and still required the operator to step over the cut out entry panel. There was one handgrip on the left-hand side only which does not allows for a safe three point entry.

15.2 Seats and posture

The saddle type swivel seat base was not adjustable. At its present height the 5th percentile male would have problems with their feet not reaching the ground. There were no back or arm supports. The operator is forward facing at all times, due to the two engine locomotive systems. Occasionally the operator would lean outside the cab with a rotated neck and trunk posture to check for signals. Cab due to the restricted cab roof height, the operators will be in a crouched posture during entry or exit.

15.3 Controls

The forward facing, centred control box is positioned too close to the operator without allowing sufficient leg and foot clearance. As a result the operator adopts a variety of postures including forward facing with feet/legs abducted, rotating the seat to one side, with a rotated spine and the arm operating at from their side or across the body. These are sustained and awkward postures. The instrument panel was within visual access. The controls appear to be designed to be entered to the side of the operator and not front centred.

15.4 Visual field

The forward visual distance is excellent within a 60 degree radius. There are however “blind” spots to the left and right hand angles as all four corners of the enclosed cabs. Due to the height of the window, visual field would be restricted for the 5th percentile South African females when seated.

16. Locomotive 16

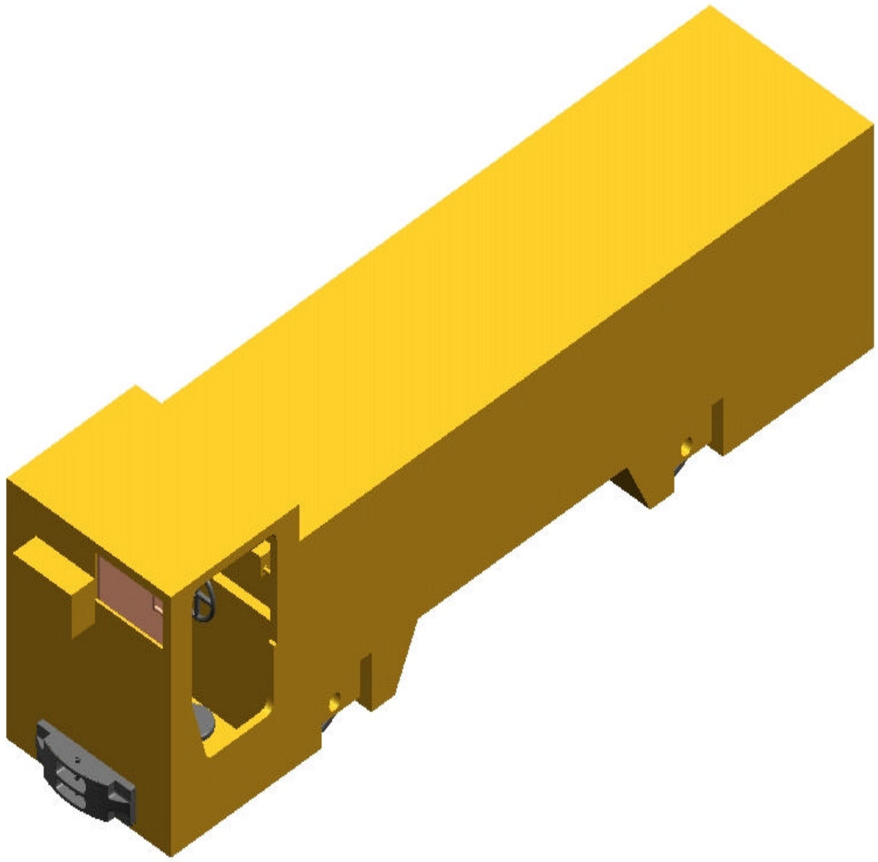


Figure 16.1: 3D CAD representation of the locomotive 16

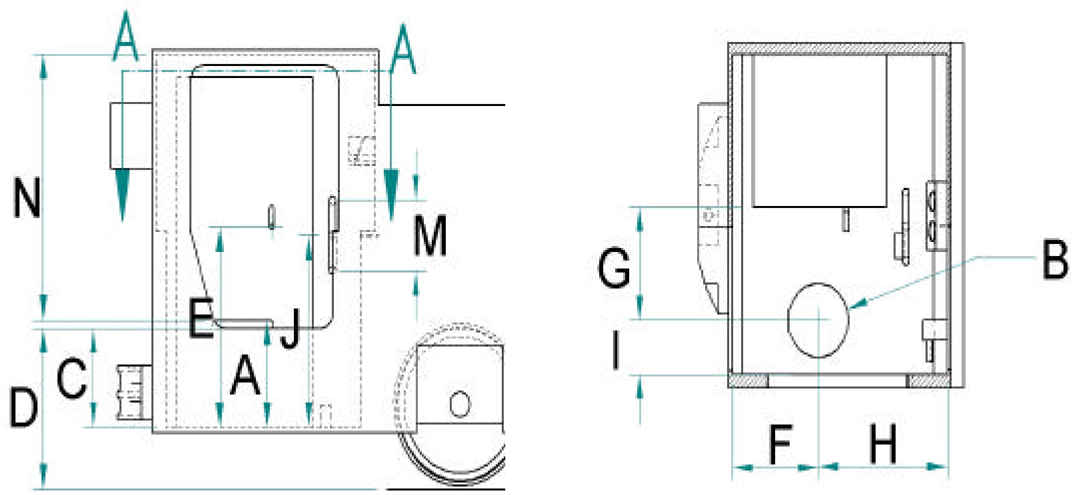


Figure 16.2: Electric powered mining locomotive 16

Table 16.1: Dimensions for electric powered mining locomotives 16

	Manufacturer	**Goodman**
	Weight class (tons)	15
A	Seat height	430
B	Seat dimensions (WxDxH)	∅300
	Seat material	Metal
C	Surface to entrance height	605
D	Entrance to floor height	405
E	Controller handle height	700
F	Seat to front wall distance	540
G	Seat to controller distance	480
H	Seat to rear wall distance	370
I	Seat to side wall distance	220
J	Park brake height from floor	1045
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	1090
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	5400
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	Cannot see the track

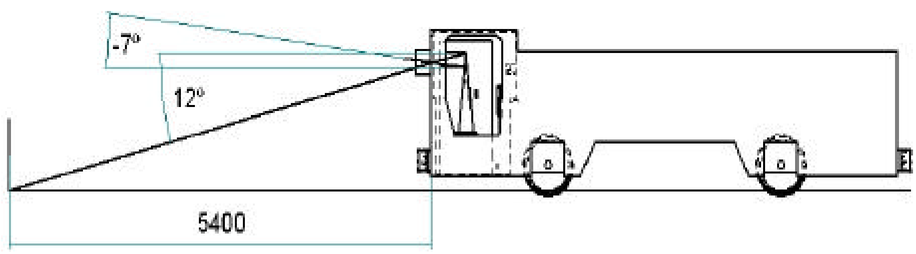


Figure 16.3: Viewing angle and distance for electric powered mining locomotive 16

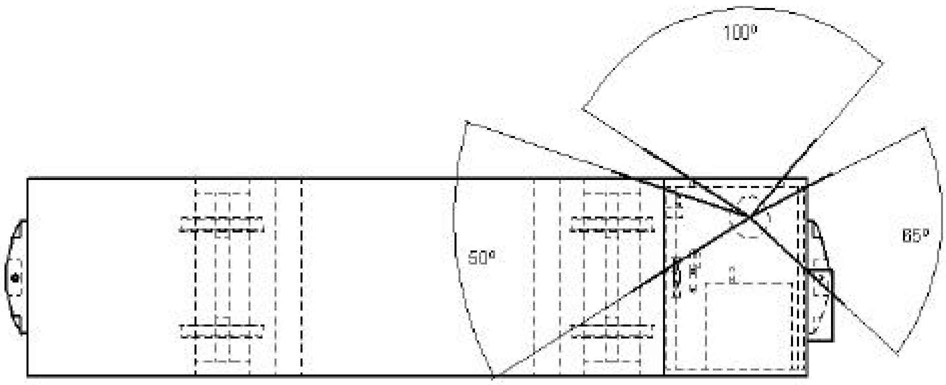


Figure 16.4: Side viewing angle from an aerial plane

16.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. The operator steps over the cut-out panel and holds onto the locomotive ledge when entering in the cab. Three point contact for entering into the cab was not available.

16.2 Seat and posture

The metal seat was not adjustable and did not have back or arm supports. The seat height could comfortably enable sitting posture, with supported feet for the 5th percentile up to the 95th percentile South African male.

The operator faces sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. When reversing the locomotive the drive adopts an awkward rotated body posture in order to see at the back through the rear window of the cab.

16.3 Controls

All the controls are within the reach envelop for the 5th percentile up to the 95th percentile South African male. The instrument panel was within easy access but not direct visual field for the operators.

16.4 Visual field

Forward and side viewing angle and distance did not meet the recommended range for safe operation of the locomotive. The enclosed cab severely restricts visual access only the 95th percentile male operator. The operator cannot see onto the track in front of the locomotive. There are also blind spots to the left and right corners of the enclosed cab.

17 Locomotive 17

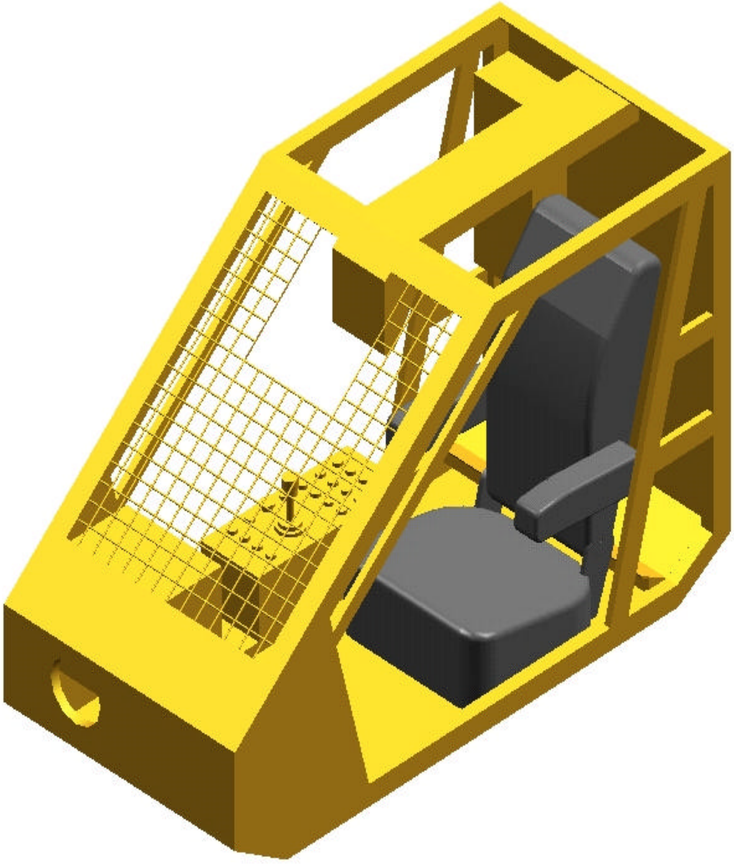


Figure 17.1: 3D CAD representation of the locomotion 17

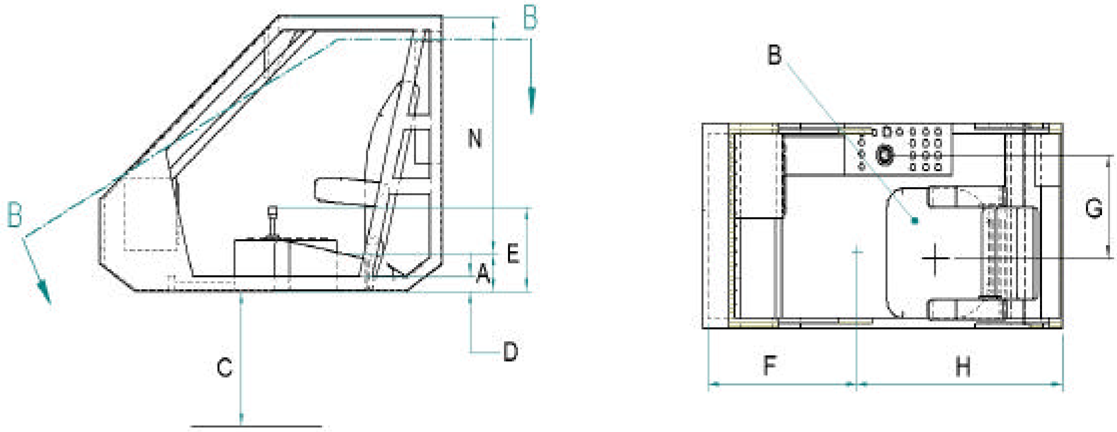


Figure 17.2: Electrical powered monorail mining locomotive 17

Table 17.1: Dimensions for monorail powered mining locomotives 17

	Manufacturer	Becker
A	Seat height	210
B	Seat dimensions (WxDxH)	480x480x630
	Seat material	Vinyl
C	Surface to entrance height	Varies
D	Entrance to floor height	60
E	Controller handle height	335
F	Seat to front wall distance	1105
G	Seat to controller distance	255
H	Seat to rear wall distance	590
I	Seat to side wall distance	240
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake diameter	N/A
N	Canopy to seat height	950
	Viewing distance in front of the locomotive for the 95 percentile sitting eye height	3500
	Viewing distance in front of the locomotive for the 5 percentile sitting eye height	5200

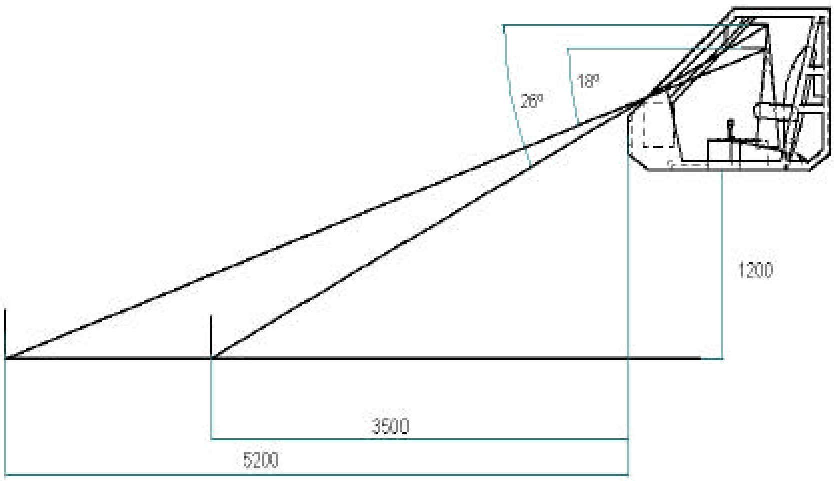


Figure 17.3: Visual angle and distance for monorail powered mining locomotive 17

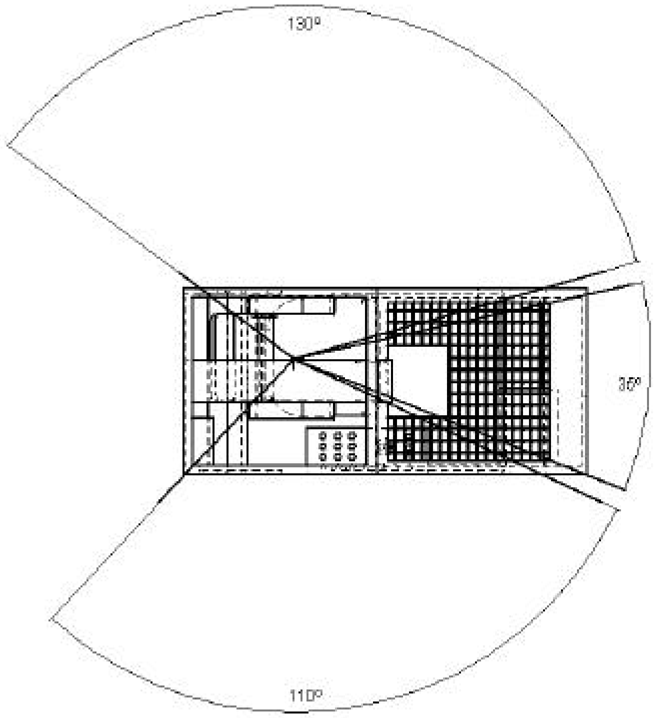


Figure 17.4: Side viewing angle from an aerial plane

17.1 Access

The surface to entrance level was easy for entering into the cab. Handgrips are fitted inside the cab to enable the operator to step into the cab.

17.2 Seat and posture

An automobile type seat is provided for the operator. The seatbase is horizontally adjustable to enable a comfortable sitting posture. The seat has a backrest which could provides lumbar support for the operator but does not accommodate the caplamp battery self rescuer of other equipment attached the minders belt and therefore the backrest is not useful effectively. The seat was generally found to be comfortable. It can accommodate the 5th percentile up to the 95th percentile South African male. The operator faces the direction of the locomotive movement. The operator adopts a crouched posture during entry and exit from the cab.

17.3 Controls

All the controls are within the reach envelop for the 5th percentile up to the 95th percentile South African male. The instrument panel was within easy visual access for the operator.

17.4 Visual field

Forward and side viewing angles and distance are within the recommended range for the 95th percentile South African male. Forward viewing angle and distance are restrictive for the 5th percentile South African male. Visual field to the rear was restrictive. The operator would lean outside the cab with a rotated neck and truck posture to view to the rear.

18. Locomotive 18

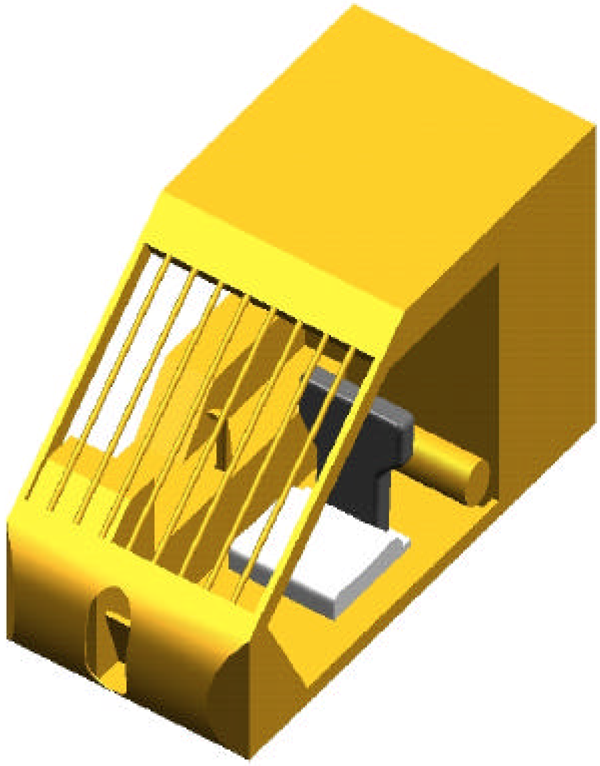


Figure 18.1: 3D CAD representation of the locomotive 18

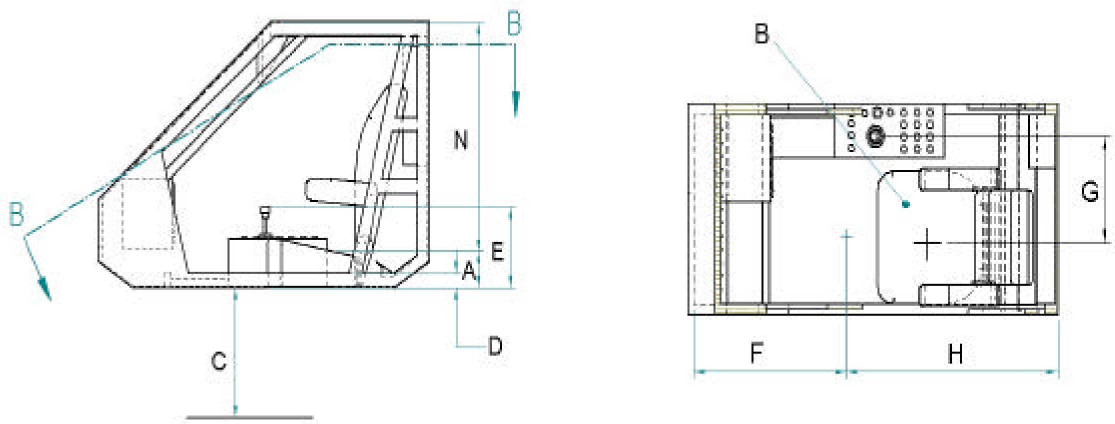


Figure 18.2: Electrical powered monorail mining locomotive 18

Table 18.1: Dimensions for modified powered mining locomotives 18

	Manufacturer	Scharf
A	Seat height	200
B	Seat dimensions (WxDxH)	460x400x450
	Seat material	Polyurethane
C	Surface to entrance height	Varies
D	Entrance to floor height	60
E	Controller handle height	460
F	Seat to front wall distance	890
G	Seat to controller distance	130
H	Seat to rear wall distance	600
I	Seat to side wall distance	310
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake diameter	N/A
N	Canopy to seat height	970
	Viewing distance in front of the locomotive for the 95 percentile sitting eye height	3400
	Viewing distance in front of the locomotive for the 5 percentile sitting eye height	5200

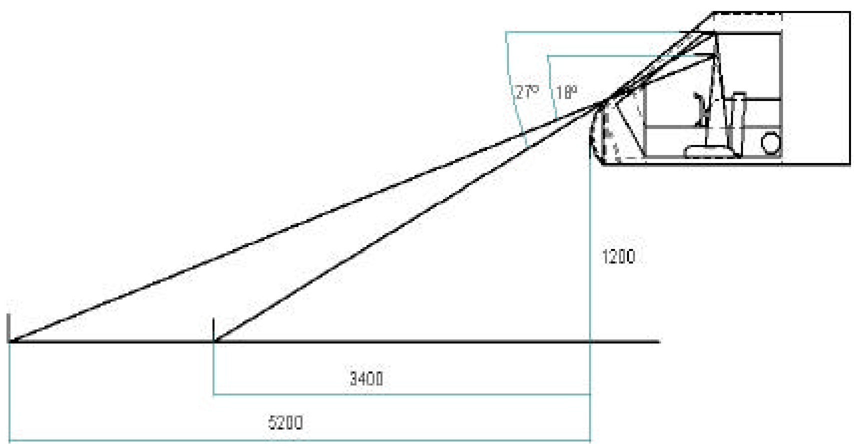


Figure 18.3: Visual angle and distance for locomotive 18

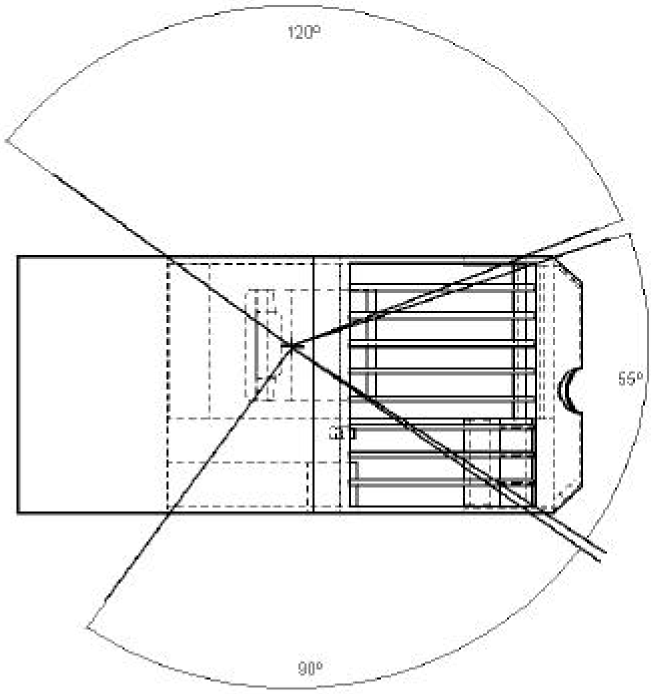


Figure 18.4: Side viewing angle from an aerial plane

18.1 Access

The surface to entrance level was easy for entering into the cab. Handgrips are fitted inside the cab to enable the operator to step into the cab.

18.2 Seat and posture

An automobile type seat is provided for the operator. The seatbase is horizontally adjustable to enable a comfortable sitting posture. The seat has a backrest which could provides lumbar support for the operator but does not accommodate the caplamp battery self rescuer of other equipment attached the minders belt and therefore the backrest is not useful effectively. The seat was generally found to be comfortable. It can accommodate the 5th percentile up to the 95th percentile South African male. The operator faces the direction of the locomotive movement. The operator adopts a crouched posture during entry and exit from the cab.

18.3 Controls

All the controls are within the reach envelop for the 5th percentile up to the 95th percentile South African male. The instrument panel was within easy visual access for the operator.

18.4 Visual field

Forward and side viewing angles and distance are within the recommended range for the 95th percentile South African male. Forward viewing angle and distance are restrictive for the 5th percentile South African male. Visual field to the rear was restrictive. The operator would lean outside the cab with a rotated neck and truck posture to view to the rear.

19. Locomotive 19

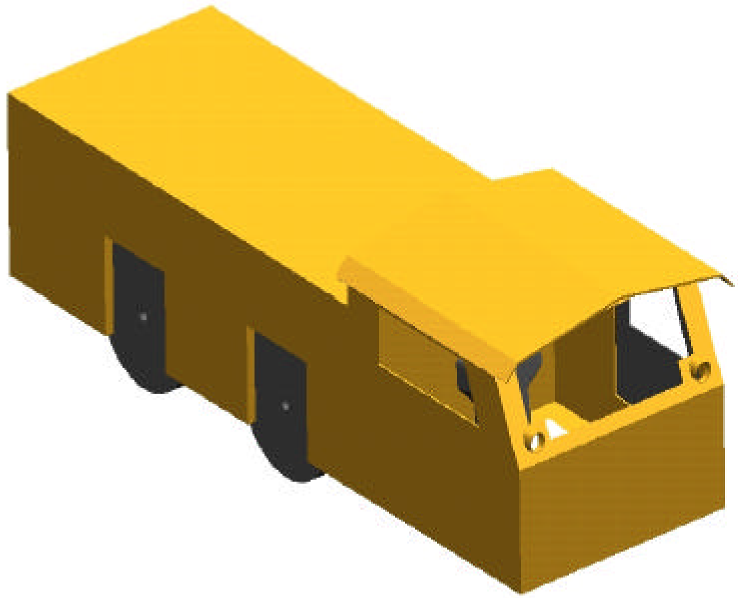


Figure 19.1: 3D CAD representation of the of the locomotive 19

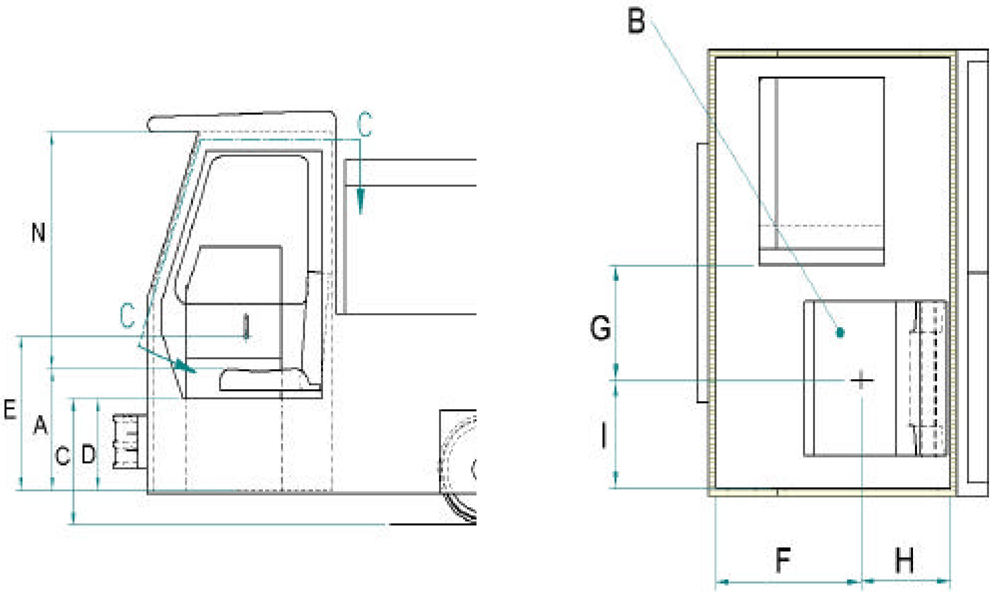


Figure 19.2: Modified mine locomotive 19

Table 19.1: Dimensions for modified mine locomotive 19

	Manufacturer	Modified Goodman battery powered locomotives
	Weight class (tons)	**10**
	Mine visited	H
A	Seat height	240
B	Seat dimensions (WxDxH)	480x410x450
	Seat material	Polyurethane
C	Surface to entrance height	345
D	Entrance to floor height	205
E	Controller handle height	320
F	Seat to front wall distance	845
G	Seat to controller distance	350
H	Seat to rear wall distance	435
I	Seat to side wall distance	560
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	960
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	1600
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	2900

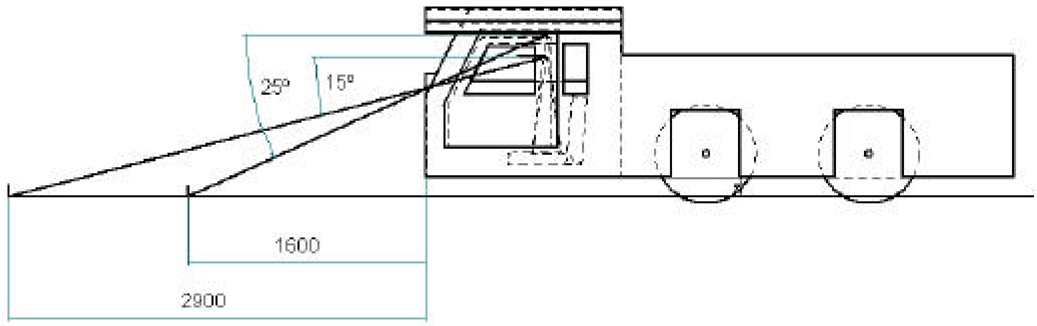


Figure 19.3: Viewing angle and distance for modified mine locomotive 19

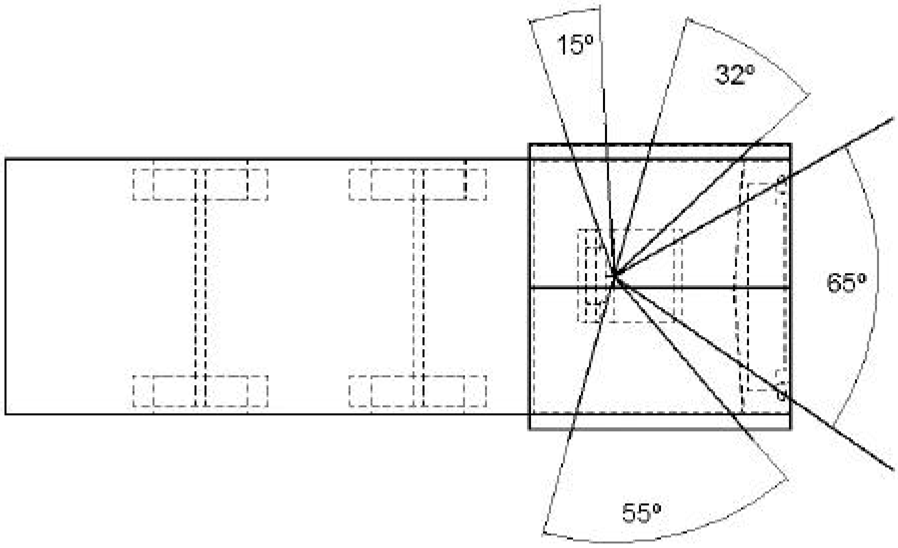


Figure 19.4: Side view angles from a top view

19.1 Access

The surface to entrance level was within the recommended height for easy access without handgrip. Access into the cab was easy for the 5th percentile South African male but restrictive for the 95th percentile male because of the low door height. The operator adopts a crouched posture and can strike the sharp edges of the canopy roof.

19.2 Seat and posture

A T-back polyurethane seat is provided for the operator. The seat is adjustable horizontally to enable comfortable reach distance to the controls. The recess in the seat backrest allows the operator to sit comfortably with the lamp battery, self-rescuer and other protective equipment that are worn on the operator's belt.

19.3 Controls

All the controls are within the reach envelop for the 5th percentile up to the 95th percentile South African male.

19.4 Visual field

Forward viewing angle and distance are within the recommended range. The 5th percentile up to the 95th percentile can see onto the track in front of the locomotive for safe driving of the locomotive. Visual field to the back was severely restricted by the enclosed cab. Side viewing was restricted due to the corners of the enclosed cab.

20. Locomotive 20

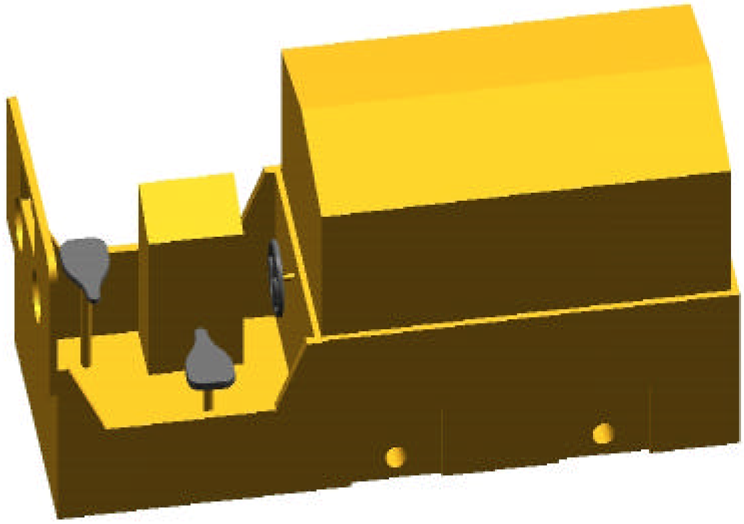


Figure 20.1: 3D CAD representation of the locomotive 20

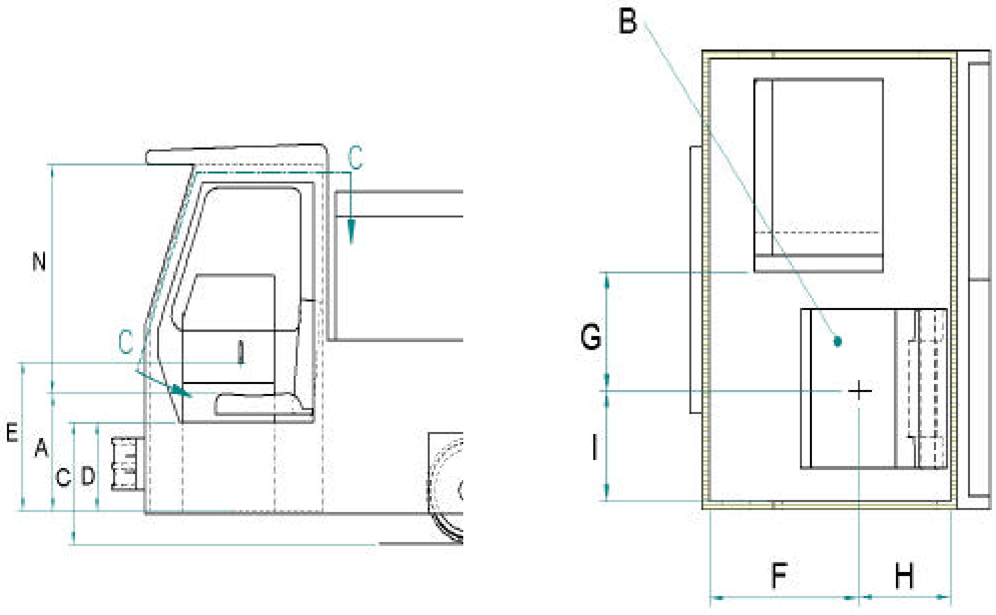


Figure 20.2: Modified mine locomotive 20

Table 20.1: Dimensions for modified mine locomotive 20

	Manufacturer	**Modified Goodman battery powered locomotives**
	Weight class (tons)	**6**
	Mine visited	K
A	Seat height	500
B	Seat dimensions (WxDxH)	Shaped
	Seat material	Steel saddle
C	Surface to entrance height	350
D	Entrance to floor height	220
E	Controller handle height	580
F	Seat to front wall distance	740
G	Seat to controller distance	600
H	Seat to rear wall distance	470
I	Seat to side wall distance	230
J	Park brake height from floor	580
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake diameter	N/A
	Canopy (Yes/No)	No
N	Canopy to seat height	N/A
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	2400
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	4100

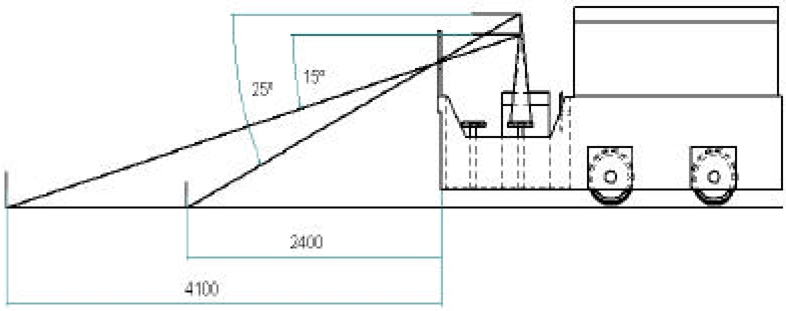


Figure 20.2: Visual angle and distance modified mine locomotive 20

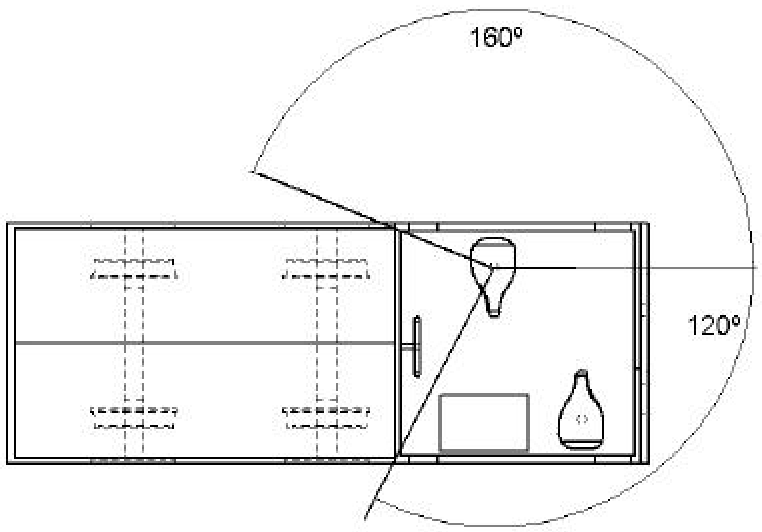


Figure 20.3: Side viewing angles from a top view

20.1 Access

The surface to entrance level was within the recommended height for access. The 5th percentile up to the 95th percentile can easily step into the cab.

20.2 Seat and posture

The saddle type metal seat was not height adjustable and did not have back or arm supports. The seat height required a semi-standing posture for 5th to 50th percentile South African male. The width of the seat was too narrow to accommodate comfortable sitting posture for the 5th percentile up to the 95th percentile South African male. The operator faces sideways. This induces a sustained twisted neck posture when facing towards the direction of the locomotive movement. The operator stands up to view to the rear when reversing the locomotive. Driving the locomotive whilst standing or leaning out of the locomotive profile is unacceptable driving practice according to the Mine Health and Safety Act, 1996 (Regulation 18.21).

20.3 Controls

The controls are not within easy reach for the 5th percentile up to the 95th percentile South African male as it is a training locomotive. The location of the master controller directly in front of the operator, required an extended arm and repetitive arm movements across the midline of the body. This will result in upper extremity fatigue and may precede strain on both the shoulder and the wrist. The instrument panel was within easy visual access for the operator from the seated posture.

20.4 Visual field

The 5th percentile up to the 95th percentile can see the track in front of the locomotive from the seated posture. A cutout in the front panel provided additional forward view. Visual field to the rear was restricted.

21. Locomotive 21

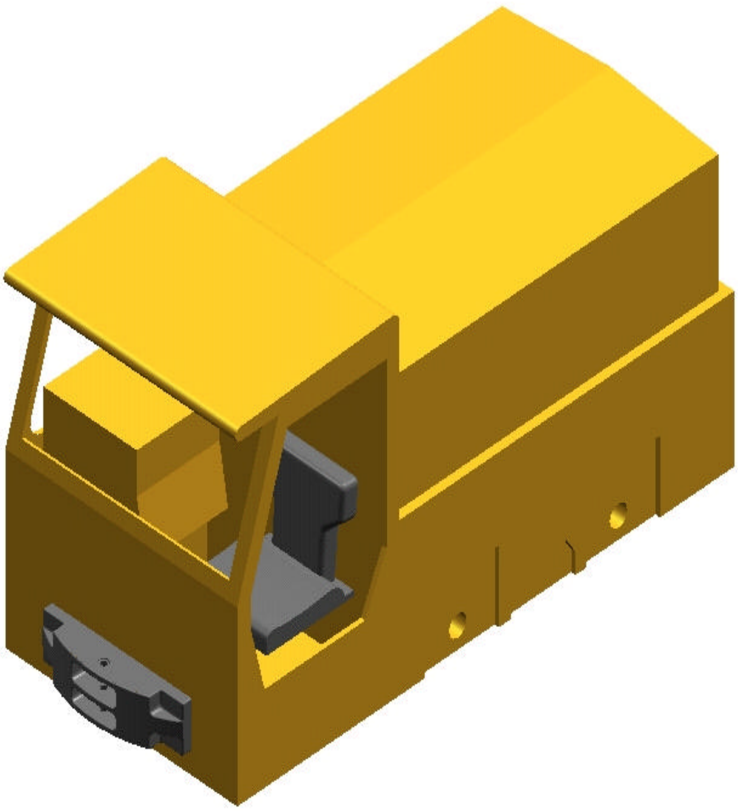


Figure 21.1: 3D CAD representation of the locomotive 21

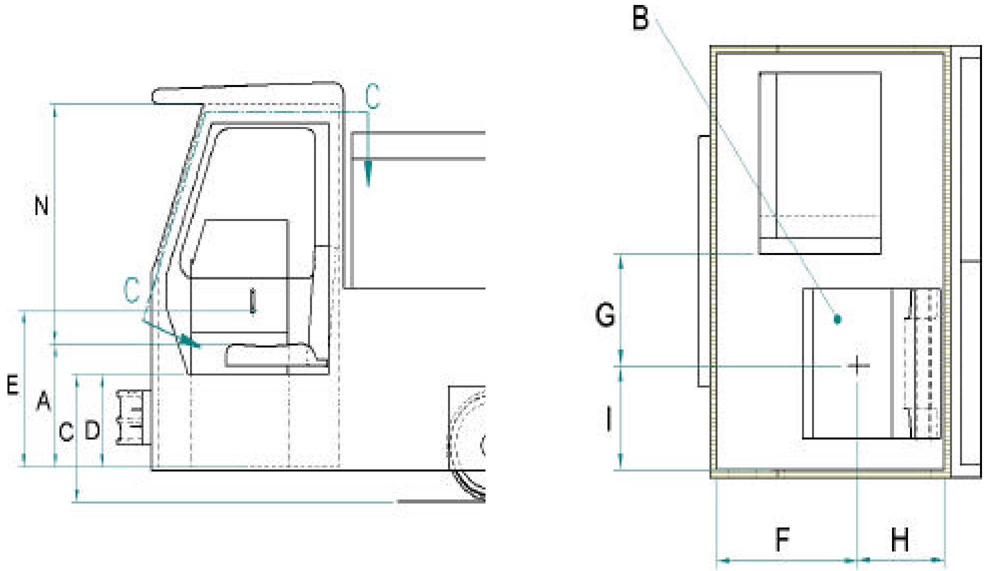


Figure 21.2: Modified mine locomotive 21

Table 21.1: Dimensions for modified mine locomotive 21

	Manufacturer	Modified Goodman battery powered locomotives
	Weight class (tons)	**5**
	Mine visited	J
A	Seat height	475
B	Seat dimensions (WxDxH)	480x410x450
	Seat material	Polyurethane
C	Surface to entrance height	540
D	Entrance to floor height	410
E	Controller handle height	550
F	Seat to front wall distance	470
G	Seat to controller distance	430
H	Seat to rear wall distance	435
I	Seat to side wall distance	340
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	600
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	1060
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	1200
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	1900

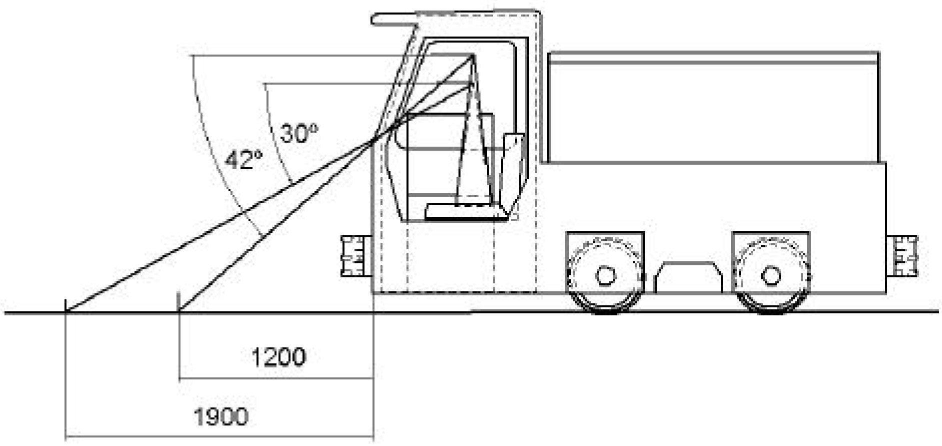


Figure 21.3: Viewing angle and distance form modified mine locomotive 21

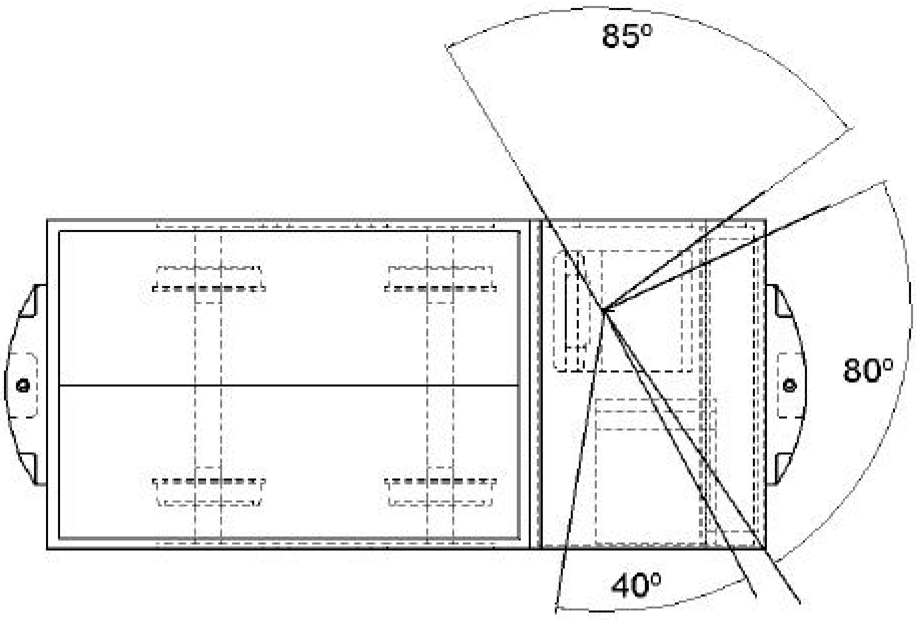


Figure 21.4: Side viewing angles from a top view

21.1 Access

The surface to entrance level was higher than the recommended height. The handgrips provided on the door would assist with a safe access into the cab. The cab doors were of a standard automobile type, including a window and door opening mechanisms.

21.2 Seating and posture

The T-back polyurethane seat was not height adjustable, nor had back or arm support. The height of the seat induced a semi-standing posture. The seat is adjustable horizontally to enable the operator to comfortably reach the controls. The operator seat was found to be comfortable, durable, and it incorporates adequate lumber support to reduce fatigue. The operator orientation was forward facing towards the direction of the locomotive movement.

21.3 Controls

All the controls are within the reach envelop for the 5th percentile up to the 95th percentile. All the instruments are located in directly front of the operator's sitting position in dashboard type configuration.

21.4 Visual field

Forward viewing angle and distance was within the recommended range for safe driving. The operator can see on the track in front of the locomotive from a seated posture. The side and rear viewing was restricted.

22. Locomotive 22

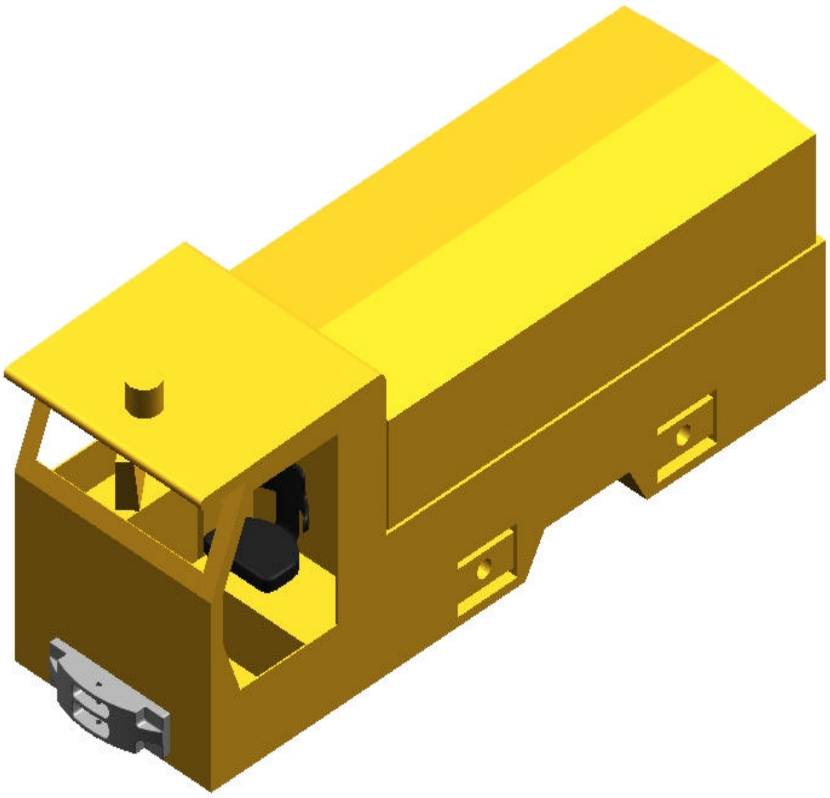


Figure 22.1: 3D CAD representation of the locomotion 22

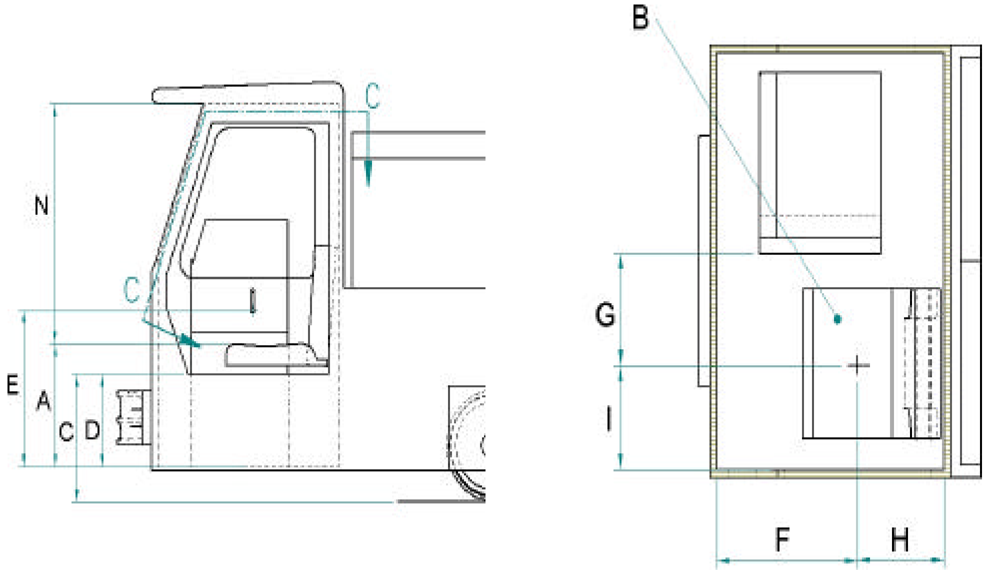


Figure 22.2: Modified mine locomotive 22

Table 22.1: Dimensions for modified mine locomotive 22

	Manufacturer	Modified Goodman battery powered locomotives
	Weight class (tons)	**10**
	Mine visited	J
A	Seat height	570
B	Seat dimensions (WxDxH)	480x355x390
	Seat material	Vinyl covered cushion
C	Surface to entrance height	570
D	Entrance to floor height	435
E	Controller handle height	690
F	Seat to front wall distance	900
G	Seat to controller distance	390
H	Seat to rear wall distance	350
I	Seat to side wall distance	550
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	1015
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	2900
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	5300

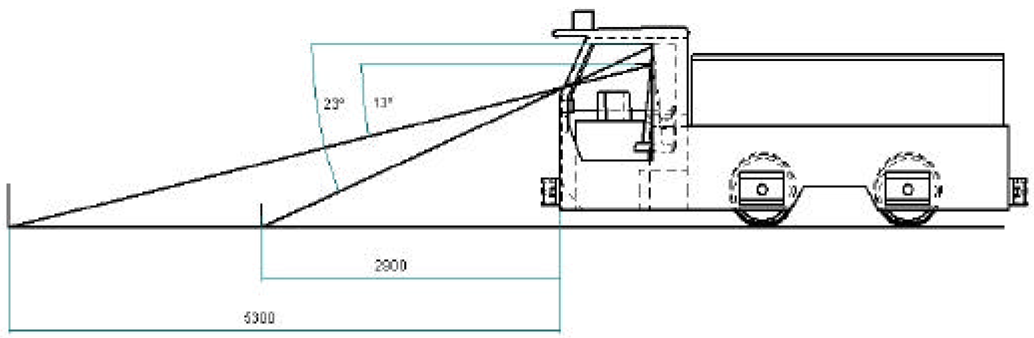


Figure 22.3: Viewing angle and distance modified mine locomotive 22

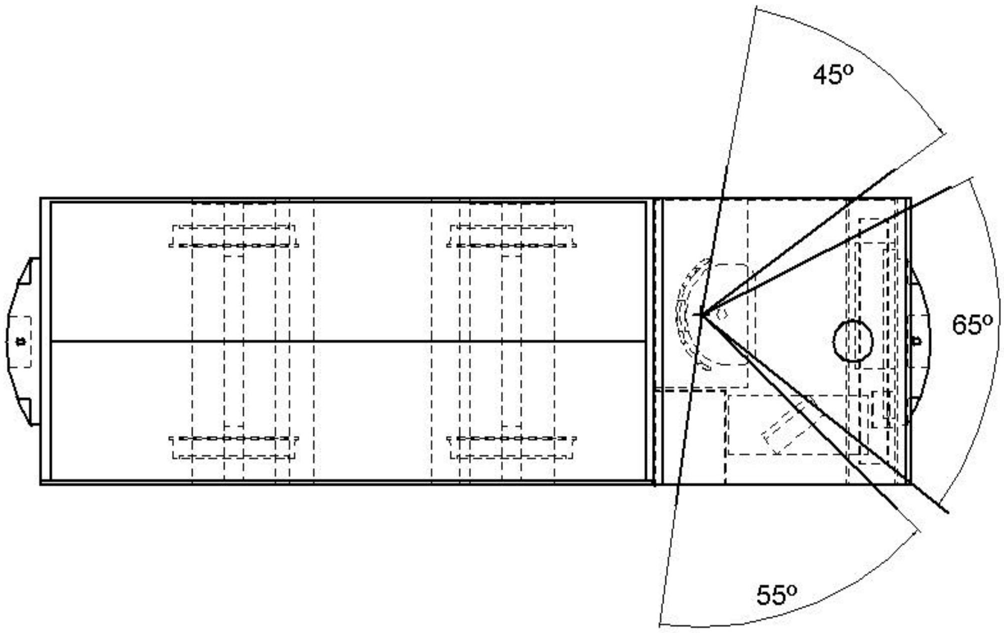


Figure 22.4: Side viewing from a top view

22.1 Access

The surface to entrance level was higher than the recommended height for easy entry without handgrips. Three point contact for safe entering into the cab was not available. A single sliding door was located on the left side of the cab.

22.2 Seat and posture

A T-back polyurethane seat with fixed armrests was found to restrict comfortable sitting posture for the operator with the cap lamp battery and other personal protective equipment attached to the operator's belt. The operator faces forward towards the direction of the locomotive movement. Sit height would require that the 5^{th} to 95^{th} percentile would be sitting with unsupported feet.

22.3 Controls

All the controls are located on a control panel, which is within easy reach for the 5^{th} percentile up to the 95^{th} percentile South African male. All the instruments were within easy visual access for the operator from the seated posture including a clearly labelled, hand-held, docked remote for control of direction and speed.

22.4 Visual field

Forward viewing angle and distance was within the recommended range for safe driving for the 95th percentile South African male. However, the viewing distance for the 5th percentile was not within the recommended range. Visual field to the back is restrictive for the 5th percentile up to the 95th percentile South African male

23. Locomotive 23

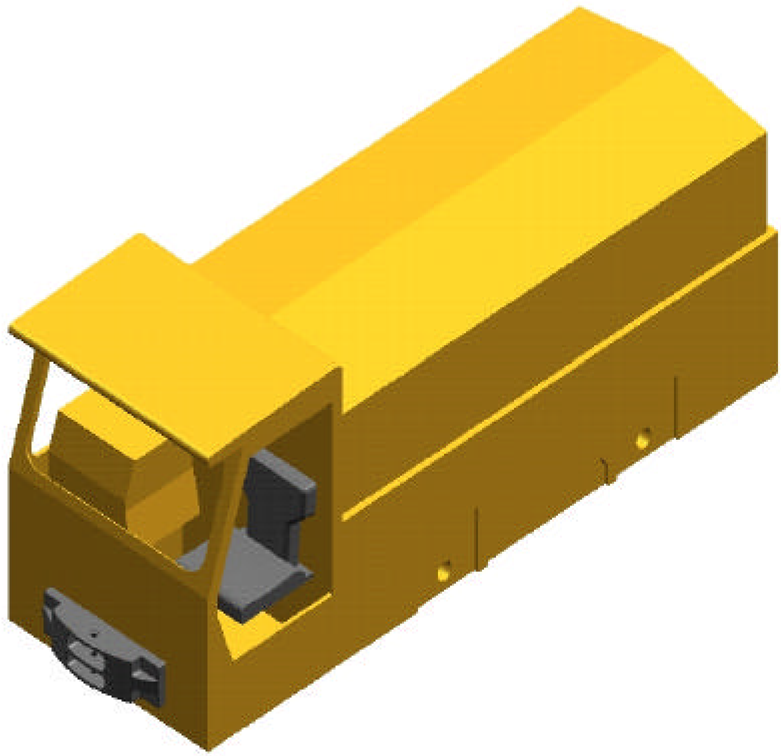


Figure 23.1: 3D CAD representation of the locomotive 23

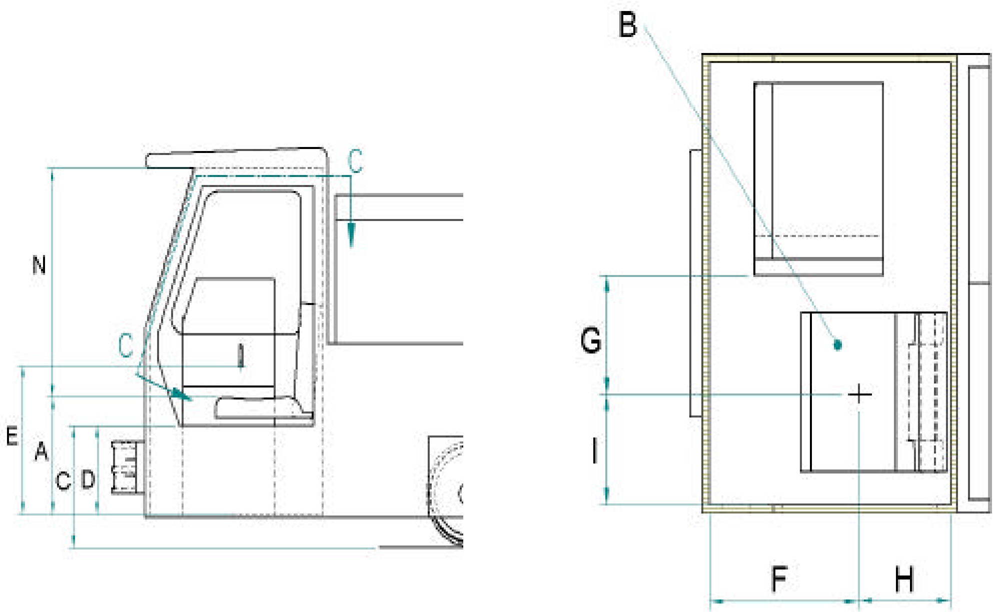


Figure 23.2: Modified mine locomotive 23

Table 23.1: Dimensions for modified mine locomotive 23

	Manufacturer	Modified Goodman battery powered locomotives
	Weight class (tons)	**10**
	Mine visited	J
A	Seat height	475
B	Seat dimensions (WxDxH)	480x410x450
	Seat material	Polyurethane
C	Surface to entrance height	510
D	Entrance to floor height	370
E	Controller handle height	550
F	Seat to front wall distance	350
G	Seat to controller distance	355
H	Seat to rear wall distance	340
I	Seat to side wall distance	410
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	600
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	1020
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	1200
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	1800

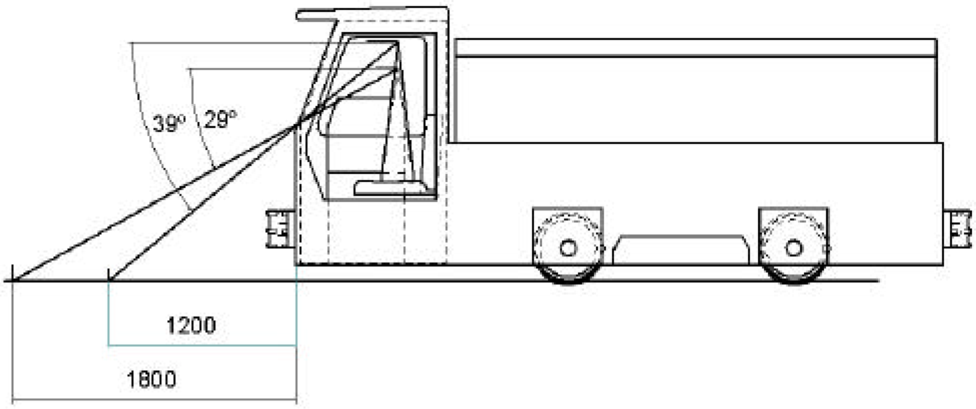


Figure 23.3: Viewing angle and distance for modified mine locomotive 23

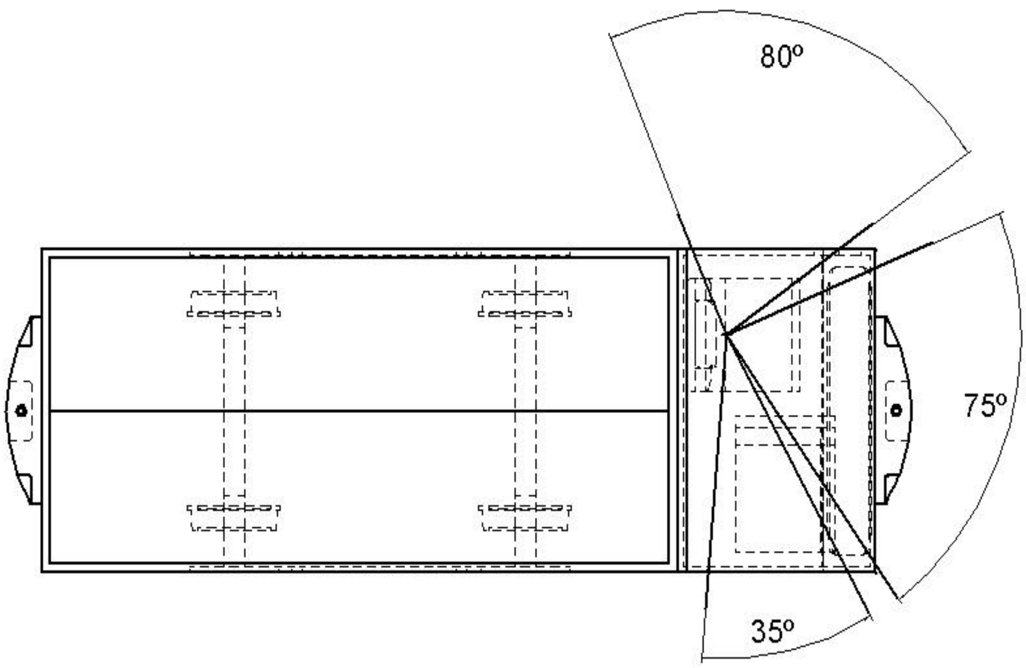


Figure 23.4: Side viewing angle from a top view

23.1 Access

The surface to entrance level was higher than the recommended height for easy entry without handgrips. Three point contact for safe entering into the cab was not available. A single sliding door on the left-hand side of the cab closed the access.

23.2 Seat and posture

A T-back polyurethane seat is provided for the operator. The seat is adjustable horizontally to enable comfortable seat positioning for reach to the controls. The operator faces towards the direction of the locomotive movement. Restricted workspace caused the operator to adopts an awkward rotated body posture when operating controls on the right. The seat height would require the 5th percentile South African male to sit with unsupported feet.

23.3 Controls

All the controls located on the control panel are within the reach envelop for the 5th percentile up to the 95th percentile South African male. The position of the park brake system at the far right, behind the operator required an awkward posture to access the brake.

23.4 Visual field

Forward viewing angle and distance are within the recommended range for safe driving. The 5^{th} percentile up to the 95^{th} percentile can see on the track in front of the locomotive.

24. Locomotive 24

Figure 24.1: 3D CAD representation of the locomotive 24

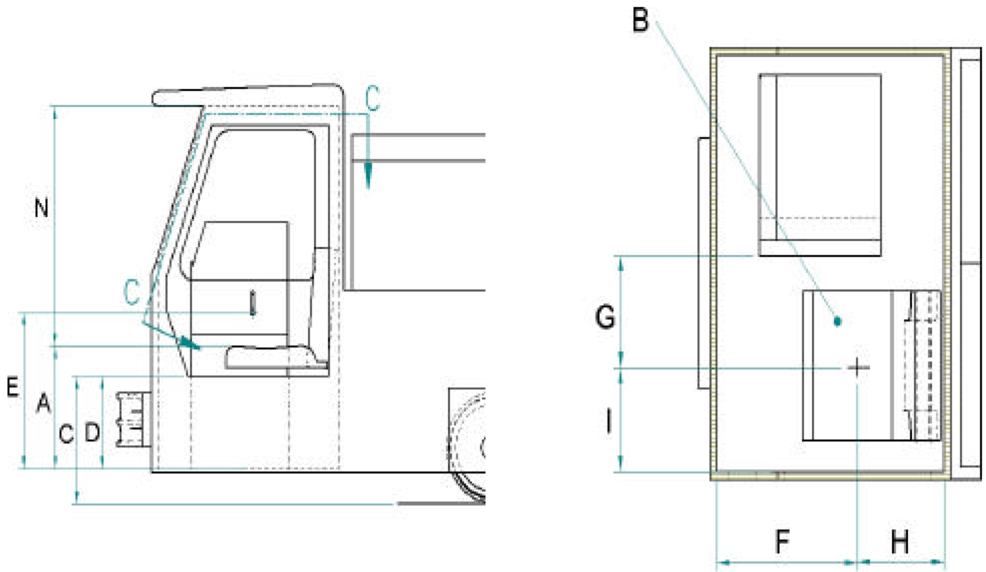


Figure 24.2: Modified mine locomotive 24

Table 24.1: Dimensions for modified mine locomotive 24

	Manufacturer	**Modified Goodman battery powered locomotives**
	Weight class (tons)	**8**
	Mine visited	F
A	Seat height	520
B	Seat dimensions (WxDxH)	480x355x390
	Seat material	Vinyl covered cushion
C	Surface to entrance height	530
D	Entrance to floor height	400
E	Controller handle height	515
F	Seat to front wall distance	520
G	Seat to controller distance	520
H	Seat to rear wall distance	345
I	Seat to side wall distance	300
J	Park brake height from floor	N/A
K	Foot brake height from floor	N/A
L	Hand brake height from floor	N/A
M	Park brake diameter	N/A
	Canopy (Yes/No)	Yes
N	Canopy to seat height	840
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	1500
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	900

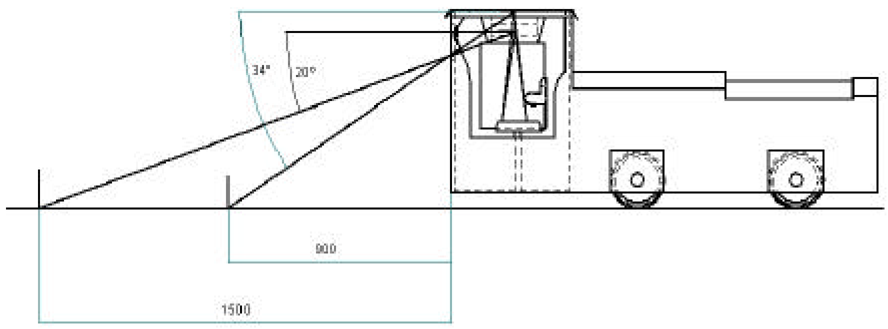


Figure 24.3: Forward viewing angle and distance modified mine locomotive 24

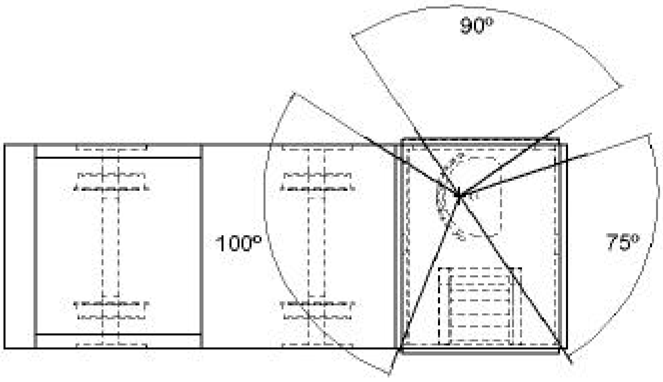


Figure 24.4: Side viewing angles from a top view

24.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrips. Three point contact for safe entering into the cab was not available. When entering the cab, the operator slides up and tilts the door panels for entry/exit. The opened door impedes safe head clearance space when the operator is inside the cab. The operator adopts a crouched body posture to exit.

24.2 Seating and posture

A T-back polyurethane seat with integrated armrests is provided for the operator. The seat mounting is swivel type. It can rotate 360 degrees, which enables the operator to change the viewing direction without adopting strained body posture. The seat height would require a semi-standing posture for the 5^{th} to 95^{th} percentile South African male. In addition the back support does not accommodate the equipment attached to the miner's belt.

24.3 Controls

All the controls and instruments are within the reach envelop for the 5^{th} percentile up to the 95^{th} percentile South African male.

24.4 Visual field

Forward viewing angle and distance are within the recommended range for safe driving. The 5^{th} percentile up to 95^{th} percentile can see the track in front of the locomotive. Visual field to the rear was good. The operator can see a radius of 100 degrees. There are blind spots on the left and right corners of the enclosed cab.

25. Locomotive 25

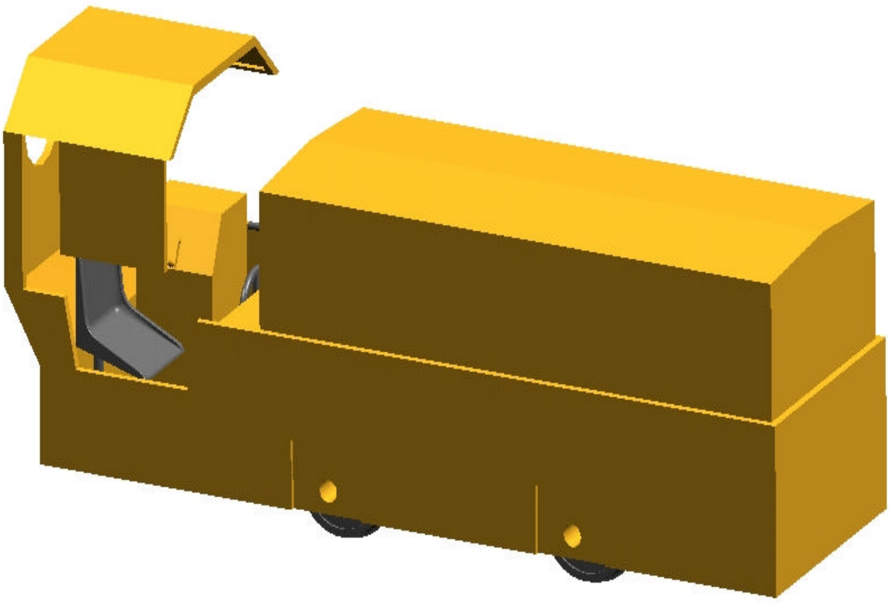


Figure 25.1: 3D CAD representation of the locomotive 25

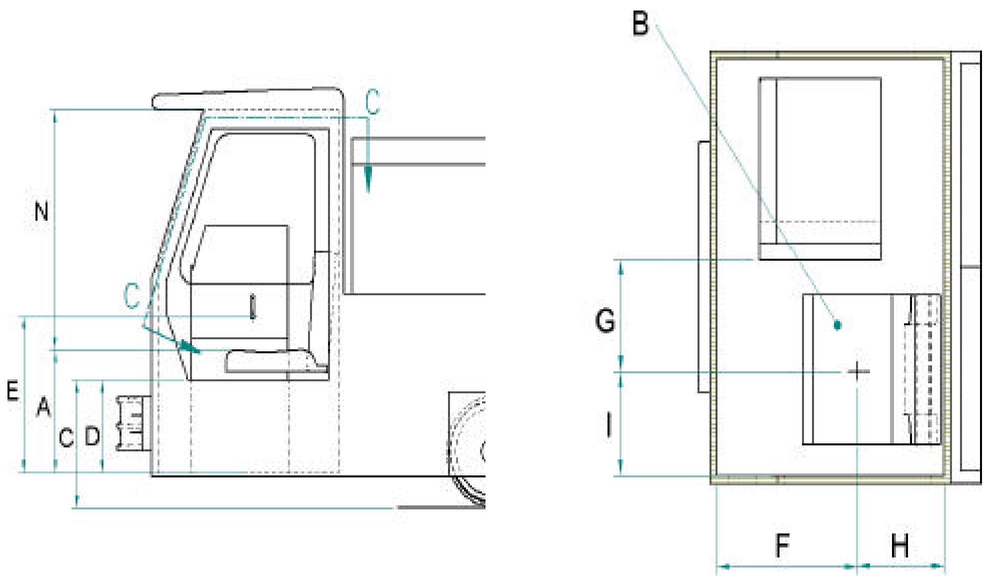


Figure 25.2: Modified mine locomotive 25

Table 25.1: Dimensions for modified mine locomotive 25

	Manufacturer	Modified Goodman battery powered locomotives
	Weight class (tons)	**10**
	Mine visited	I
A	Seat height	430
B	Seat dimensions (WxDxH)	460x400x480
	Seat material	Plastic
C	Surface to entrance height	555
D	Entrance to floor height	425
E	Controller handle height	710
F	Seat to front wall distance	535
G	Seat to controller distance	395
H	Seat to rear wall distance	560
I	Seat to side wall distance	225
J	Park brake height from floor	600
K	Foot brake height from floor	135
L	Hand brake height from floor	890
M	Park brake diameter	∅365
	Canopy (Yes/No)	Yes
N	Canopy to seat height	1220
	Viewing distance in front of the locomotive for the 95th percentile sitting eye height	4200
	Viewing distance in front of the locomotive for the 5th percentile sitting eye height	50500

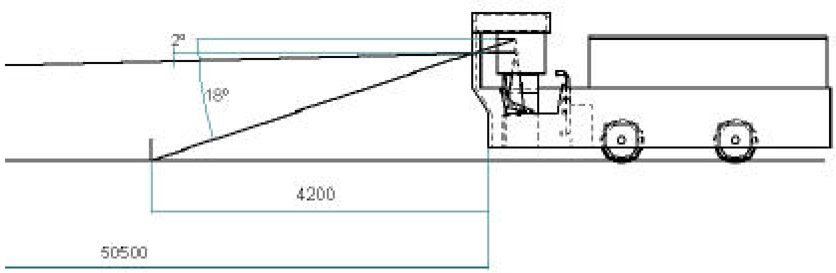


Figure 25.3: Visual angle and distance for modified mine locomotive 25

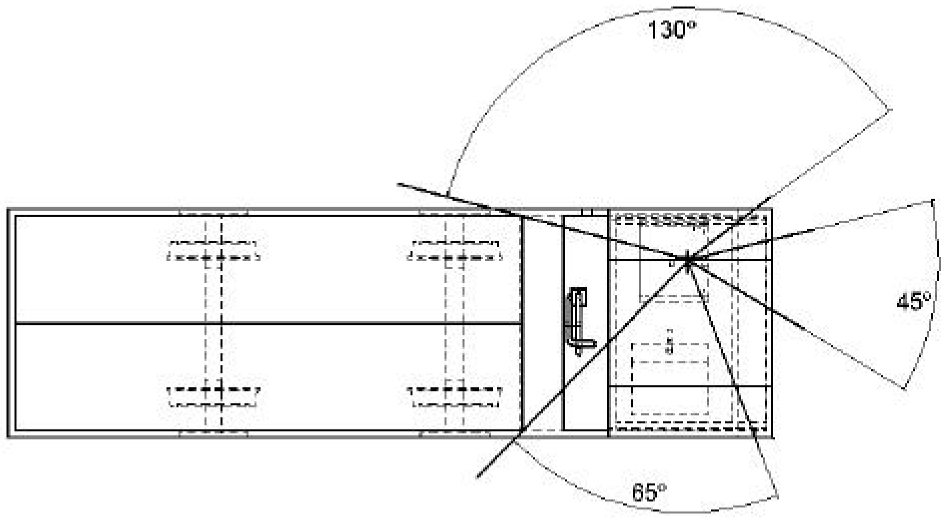


Figure 25.4: Side viewing angles from a top view

25.1 Access

The surface to entrance level was higher than the recommended height for easy access without handgrip. Three point contact for safe entry into the cab was not available.

Exit from the cab was difficult because of the inward-opening entrance barrier, a folding metal grid door that has to held up by the operator while exiting from the cab.

25.2 Seat and posture

The moulded plastic bucket seat was not height adjustable, did not have armrests but did swivel through 360°. The backrest did not accommodate the equipment attached to the miner's belt. The operator was not then able to make use of the backrest.

The operator is oriented sideways and this induces a sustained twisted neck posture when facing towards the direction of movement. The operator leans out of the cab profile when reversing the locomotive which is unacceptable mine practice.

25.3 Controls

All the controls and instrument are within easy reach and manipulation for the 5^{th} percentile up to the 95^{th} percentile South African male. Identification of the controls and instruments was difficult because of the absence of labelling.

25.4 Visual field

Forward viewing angle and distance for the 95th percentile are within the recommended range for safe driving. The 5th percentile cannot see the track in front of the locomotive from the seated position because of the front metal protection plate. As a result of this, the 5th percentile would lean out of the locomotive profile or adopt a semi-standing posture, which are unstable postures for controlling a locomotive. Standing or leaning out of the locomotive is unacceptable driving practices according to the Mine Health and Safety Act, 1996 (Regulation 18.21).

26. Rolling Stock 1

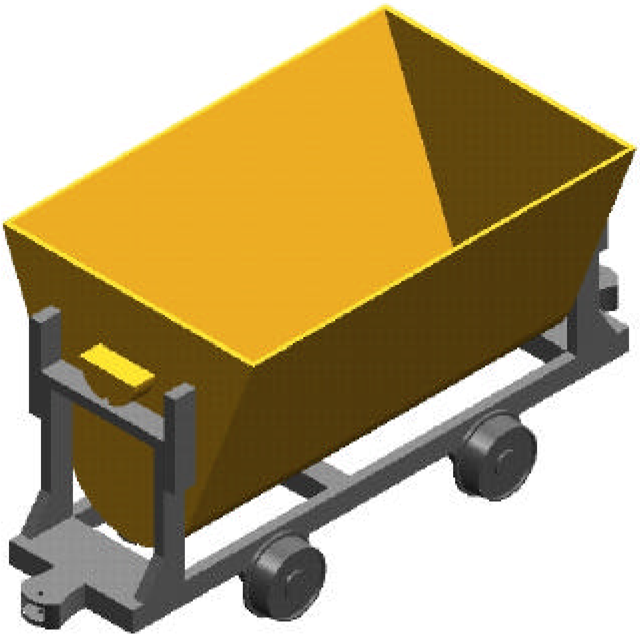


Figure 26.1: 3D CAD representation of the rolling stock

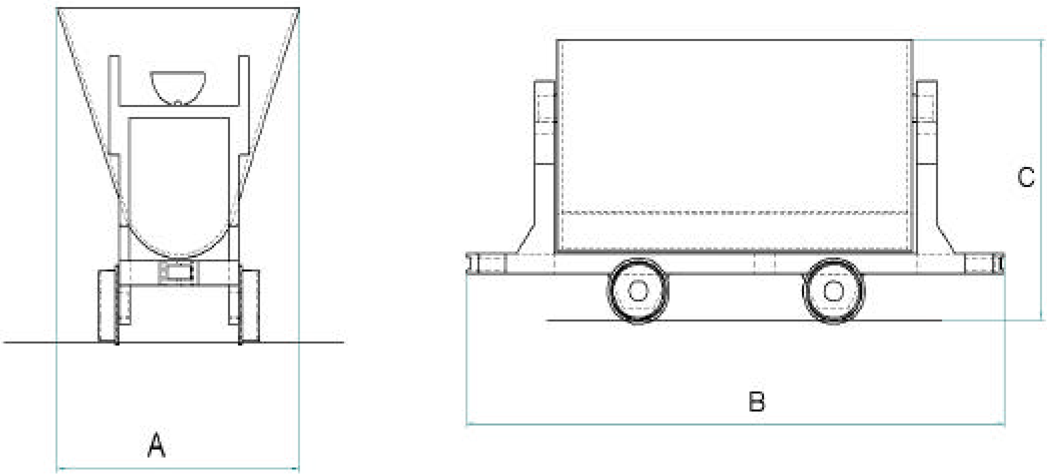


Figure 26.2: Typical Hopper

Table 26.1: Dimensions for rolling stock

Reference	Dimensions	Measurement (mm)
A	Width	690
B	Length	2370
C	Height	1330

The operators manually tilt the hopper when emptying the material. The height of the hopper is higher than the standing shoulder height for the 5th percentile South African male.

27. Rolling Stock 2

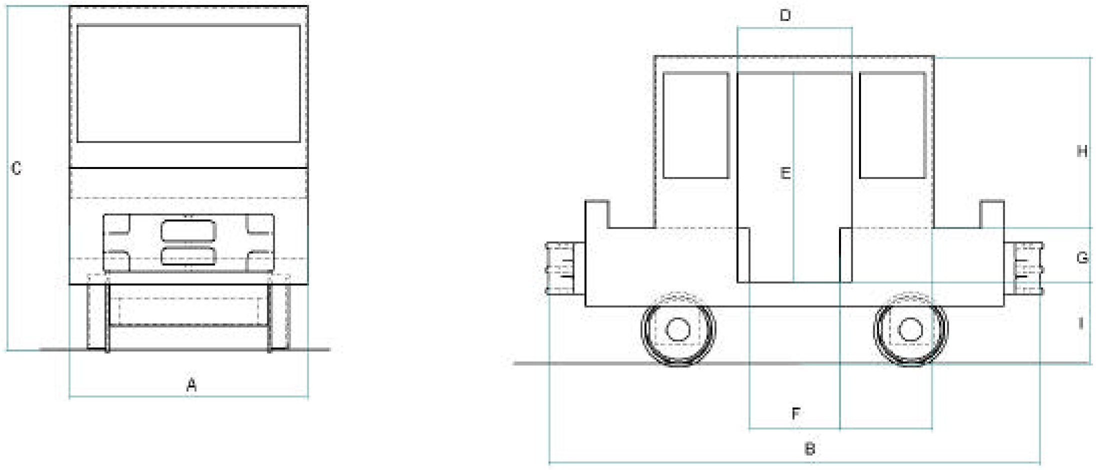


Figure 27.1: Man carriage rolling stock 2

Table 27.1: Dimensions for man carriage rolling stock 2

Reference	Dimensions	Measurement (mm)
A	Width	1540
B	Length	4100
C	Height	1740
D	Door width	355
E	Door height	1060
F	Legroom	420
G	Seat base height above the floor	420
H	Height between the seat base and interior roof	1160
I	Entrance level height from the surface	500

27.1 Access

The surface to entrance level was higher than the recommended height for easy entry with handgrips for 5th percentile up to the 95th percentile South African male.

The width and height of the entrance was lower than the recommended dimensions for unrestricted access. The door width was too narrow for access with the protective equipment worn onto the belt. The operator adopted a crouched posture when entering and exiting.

27.2 Seat and posture

The depth of the bench seat does not provide adequate space for a comfortable seated posture. The users are confined and adopt awkward postures.

28. Rolling Stock 3

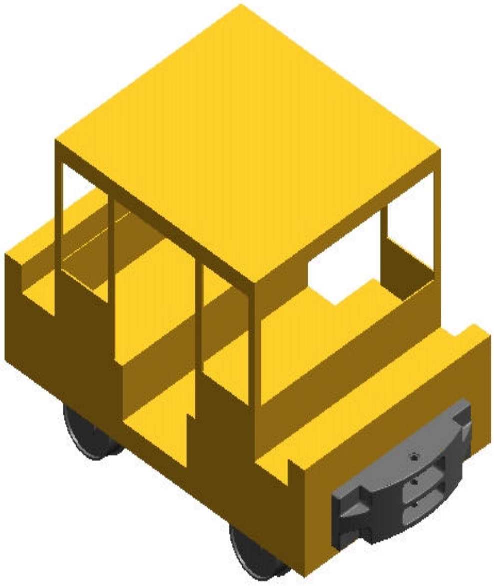


Figure 28.1: 3D CAD representation of man carriage rolling stock 3

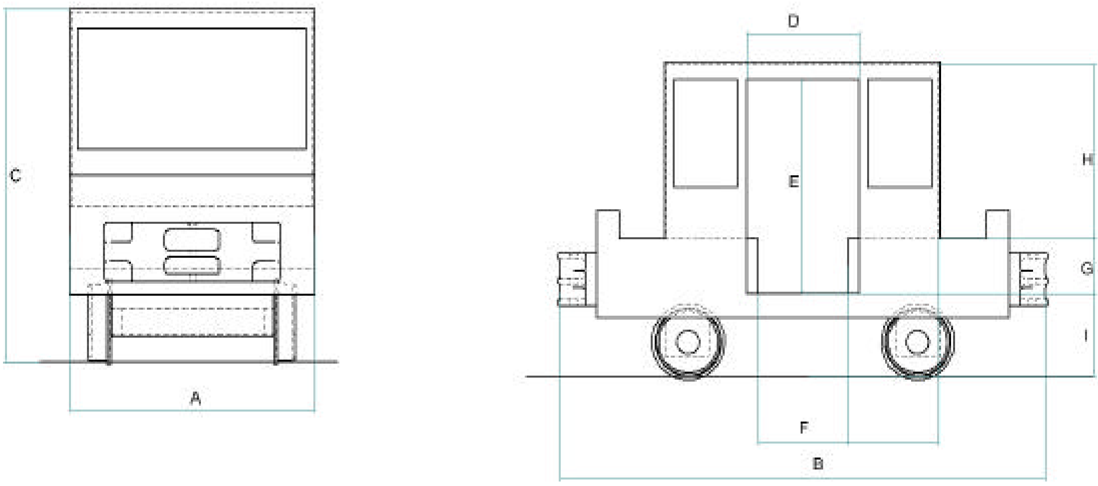


Figure 28.2: Man carriage rolling stock 3

Table 28.1: Dimensions for man carriage rolling stock 3

Reference	Dimensions	Measurement (mm)
A	Width	1120
B	Length	1800
C	Height	1070
D	Door width	490
E	Door height	895
F	Legroom	390
G	Seat base height above the floor	230
H	Height between the seat base and interior roof	730
I	Entrance level height from the surface	350

28.1 Access

The surface to entrance level was within the recommended height for easy access. All the users can enter without the need for handgrips.

The entrance width and height were lower than the recommended dimensions. The user would find access to be restrictive considering that the users wear protective equipment on their belts.

28.2 Seat and posture

The depth of seat would enable comfortable sitting posture for all the users. The interior workspace would accommodate the intended number of users. The 95th percentile South African male can be seated comfortably.

Legroom was found to be adequate for the upright sitting posture.

29. Rolling Stock 4

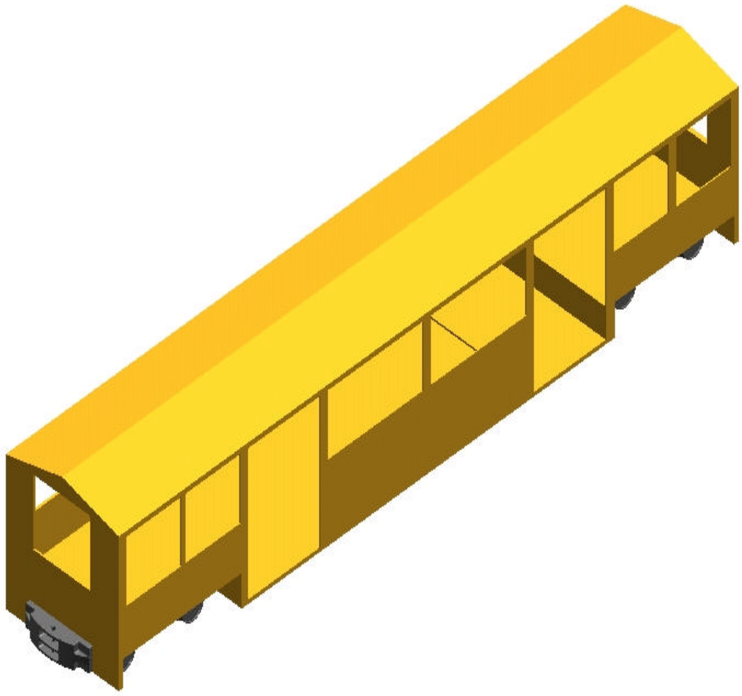


Figure 29.1: 3D CAD representation of the man carriage rolling stock 4

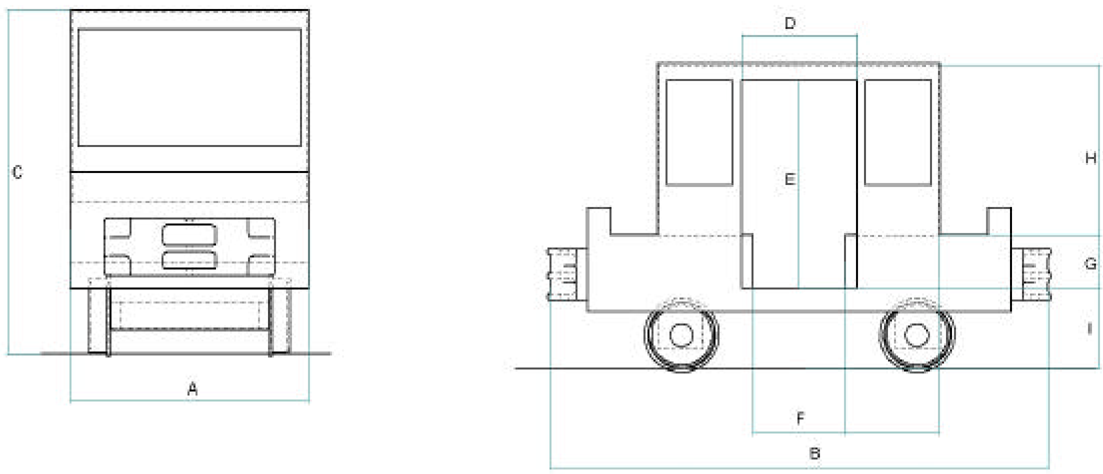


Figure 29.2: Man carriage rolling stock 4

Table 29.1: Dimensions for man carriage rolling stock 4

Reference	Dimensions	Measurement (mm)
A	Width	1425
B	Length	7800
C	Height	1070
D	Door width	900
E	Door height	1310
F	Legroom	390
G	Height between the seat base and interior roof	730
H	Entrance level height from the surface	350

29.1 Access

The surface to entrance level was within the recommended height for easy access. All the users can enter without the need for handgrips.

The entrance width and height are higher than the recommended dimensions. The 5th percentile up to the 95th percentile can easily enter with the cap lamp battery and other protective equipment, which are worn on the user's belt.

29.2 Seat and posture

The depth of the bench seat would enable comfortable sitting posture for the 5th percentile up to the 95th percentile South African male.

The interior space would however not accommodate the intended number of users.

Appendix 4
Detailed task analysis

The following paragraphs present the more detailed level of the task analyses of the locomotive operator tasks. The subtasks and sub-subtasks presented here are derived from the gross tasks presented in paragraph 4 of the main document and are discussed here in the same sequence.

1. Detailed task analysis of the pre-operational procedures

1.1 Inspect safety provisions

The inspection of safety provisions entails physical inspection of the working area to identify potential hazards in the working area to prevent accidents. The operator performs the following tasks:

- inspects the cleanliness of the working environment
- inspects the warning signs and devices
- inspects the potential physical hazards in the area

From an ergonomics point of view, the design of the locomotive would not be greatly influenced by the physical working area. Apart from assessing the physical limitations of the operator when doing these tasks, the tasks requirements were not analysed in more detail.

1.2 Examine the mechanical condition of the locomotive

The purpose of examining the mechanical condition of the locomotive is to ascertain its safe functioning. The following actions are carried out:

- visually inspect the operate locomotive cabin to ensure that it is clean and free from obstructions
- operate directional control handle to ensure that it returns to neutral position and moves smoothly forward and backward
- operate hand brake to ensure that it operates smoothly
- operate brake shoes and attachments for wear and tear
- operate siren push button to ensure that the button return to its original position when released
- examine locomotive drive chain for wear and tear, slackness, and broken links
- inspect motor securing bolts and the condition of the spring
- inspect and ensure that the brake linkage pin is positioned in such a way that the split pin is pushed through and opened on the one side to prevent it from falling out.
- inspect wheel-bearing cover plate to ensure that the bolts on the cover plate are in place and that they are tight
- inspect operator's seat to ensure that it is securely mounted and without damage.

1.3 Inspect the required equipment and tools

The operator inspects the provision and condition of the required equipment and tools carried in the locomotive. This task includes:

- inspecting the fire extinguisher's ensure that it is in a ready to use condition
- inspecting the availability and condition of the required contingency equipment such sprags, chains, and hooks
- inspecting the warning or signalling devices such as peas whistle, siren, triangle and cow bell
- examining the jack and its handle to ensure that it moves smoothly.

From an ergonomics perspective these tasks have considerable influence on the design of the locomotive cabin. Consideration of equipment storage space in the locomotive cab could improve the operator's efficiency.

1.4 Examine the locomotive lights

The Mine Health and Safety regulation states that the locomotive lights should illuminate the rails at least 20 metres from the locomotive to enable the operator identify any dangerous conditions on the track.

The operator performs the following tasks:

- visually inspects the lamp for function
- inspects the lamp for cleanliness
- inspects the lamp for brightness.

1.5 Examine the propulsion mechanism

The propulsion mechanisms for the locomotives used in the South African gold and platinum mines are mainly diesel powered, battery powered or electricity powered. The type of locomotive used determines the operator tasks regarding the examination of the propulsion mechanisms.

Also there are statutory regulations that govern the use of locomotives underground, which the operator must understand when carrying out these tasks. The content and the meaning of these regulations are to ensure that the tasks are carried out safely and effectively. The descriptions of the operator tasks presented here are based on the operational requirements for the types of locomotives used and the governing statutory regulations.

1.5.1 Diesel powered locomotive

A diesel-powered locomotive has an engine, which has a traction generator that provides power to the axle-mounted traction motors. The motors also provide dynamic braking. At the start of each shift the operator performs the following tasks:

- examines the level of water in the water tank
- examines the oil level in the gearbox using the dipstick
- examines oil level in the engine sump using the dipstick
- examines air compressor valve to ensure that all nuts and bolts are tight
- inspects the radiator hoses for any leaks
- examines the fuel supply tap on the fuel tank to ensure that it can open and close
- examines the fuel level in the tank using a dipstick. If the fuel level is found below the required level, he fills up the fuel tank
- examines the smoke box to ensure that the clack valve is free by poking it with a stick. If the smoke box is found clogged up, he washes the smoke box with water until clear water comes out of the smoke box
- examines the condition of belts for the motor fan
- inspects the tension of the belts
- examines the condition of compressor

- inspects the condition of cooling fan

1.5.2 Battery powered locomotives

The battery-powered locomotives has an electric motor usually driving the wheels through a chain drive. The battery is re-charged for at least eight hours at the end of every eight-hour shift to ensure that it has enough power to last for the next shift.

The descriptions of the tasks for the operators regarding the testing of the propulsion mechanism mainly involve the placing of the battery onto the locomotives. These tasks are performed at the battery-charging bay. The operator performs the following tasks:

- aligns the locomotive close to the battery stand, if the locomotive is not properly aligned, to ensure that the battery can be safely manoeuvred from the battery stand onto the locomotive chassis
- places the battery onto the locomotive chassis using the hand winch or a gantry winch.

  When using a hand winch or chain block the operator performs the following tasks:

  - moves the hand winch or chain block to the battery
  - uncoils the cable of the hand winch or release the chain from the chain block
  - attaches the hook fitted at the end of the cable to the hoisting ring bracket in the centre of the battery
  - engages the hooks of the lifting jig to the battery pack (if applicable)
  - engages the ratchet on the hand winch (if applicable)
  - turns the handle of the winch manually in a clockwise direction or pulls the chain block lifting chain to raise the battery above the locomotive chassis
  - when the battery is clearly above the locomotive, then he turns the handle of the winch manually in the anticlockwise to lower the battery and manoeuvres the battery onto the locomotive chassis
  - move the battery into position above the locomotive turns the handle of the winch manually in the anticlockwise or pull the chain block lowering chain to lower the battery and manoeuvres the battery onto the locomotive chassis
  - secures the battery to the locomotive chassis to prevent the battery from sliding off the locomotive chassis using the locking pins or clamps
  - connects the controller cable to the battery to ensure that the positive terminal of controller is connected to the positive of the battery
  - tests the flow of current either using the siren or the locomotive lights. When using a siren, he presses the siren push button so that the siren would sound. If the siren does not sound, the operator uses the locomotive lights to test the flow of current. If the lamps also fail, he inspects the connection between the controller cable and the battery, checks the isolator switch position and then repeats this task until he ensures that there is current flow.

1.5.3 Electricity-powered locomotive

Electrical locomotives are also known as trolley or electric locomotives. They have a roof mounted pantograph or a side mounted collector to receive power provided by an electrified wire. Electrical locomotives are mainly used to transport ore or broken rock over long distances. The operator's tasks regarding the examination of propulsion mechanism are:

- Inspects the voltage reading on the control panel
- Inspects the amperage reading on the control panel
- Inspects the insulation of the pantograph.

2. Detailed task analysis of the operational procedures

2.1 Ingress into and exit from the cab

The task of entering into and exiting from the locomotive cab is influenced by the design of locomotives, particularly the access door height from the ground. The operator enters and exits the cab by either:

- lifting up one leg over the bottom entrance level whilst holding onto the vertical or horizontal edges of the access door
- stepping into cab directly from the ground whilst holding onto the locomotive frame structures
- stepping one foot onto the bottom edge of the entrance level and then lifting the other leg from the ground into the cab

2.2 Start up the locomotive motor or engine

The operator's tasks for starting up the locomotive motor or engine depend on the type of the locomotive being driven. The two types of diesel engines for locomotives used in South African mines are water-cooled and air-cooled engines. The operator tasks for starting up these engines also differ. The task requirements for starting the battery-powered and the electrical locomotive are similar. These tasks are subdivided into pre-start up inspection, start-up and post start-up procedures for all the propulsion types.

2.2.1 Start a diesel locomotive with a direct drive

Conduct pre-start up inspection procedures

The operator performs the following tasks:

- ensures that the locomotive brakes are activated
- ensures that the air brake is off.
- inspects the clutch control is in neutral position.

Conduct start-up procedures.

The operator performs the following tasks:

- opens the throttle slightly.
- pushes in the emergency stop
- opens the fuel tap
- sets decompressor lever
- sets fuel pump in open position
- inspects bleeder cocks
- starts the engine, manually by using a crank handle, pneumatically, electrically or hydraulically using the start control
- releases the crank handle or foot pedal when the engine starts (foot or hand operated)

Conduct post start-up inspection

The operator performs the following tasks:

- inspects the oil gauge for pressure
- inspects the fuel gauge
- inspects pipes for leaks
- inspects the water pump for leaks
- tests the hooter by pressing the hooter button
- depresses the clutch and engages the drive gear
- releases the clutch to move the locomotive
- changes the throttle level to increase or decrease the locomotive speed
- tests brakes with the engine running by driving the locomotive a short distance in both directions (this task has been discontinued).

2.2.2 Starting a diesel locomotive with a hydrostatic drive

Conduct pre start-up inspection

Before the actual starting-up of the engine the operator performs the following tasks:

- inspects the hydraulic fluid in the reservoir by looking at the oil level in the sight glass next to the tank
- inspects to ensure that the delivery line from the oil reservoir to the pump is open
- ensures that the valve below the pump is open
- ensures that the brakes are on
- ensures that the directional control is in neutral position
- inspects the condition of all hydraulic hoses for chafing and wear

Conduct start-up procedures

- ensures that the brake is activated
- ensures that the air brake is off
- ensures that the clutch control is in neutral position
- opens the throttle slightly
- pushes in the emergency stop
- opens the fuel tap on the tank
- sets the fuel pump in the open position
- starts up the engine by pushing down the crank handle, or by activation of the starter control
- releases the crank handle or starter control
- changes the throttle level to increase or decrease the diesel engine speed

Post start-up procedures

After starting up the engine the operator performs the following tasks:

- inspects oil and fuel gauges for pressure
- inspects hoses and hydraulic pump leaks. If leaks are found stops the engine. If no leaks are found, he proceeds
- releases the brake
- opens the throttle slowly to get the desired speed
- moves the directional control in the desired direction of movement
- tests the siren

2.2.3 Starting the battery-powered or electrical locomotive

Conduct pre start-up inspection procedures

The operator performs the following tasks:

- inspects that the brakes are activated with the brake handwheel turned clockwise
- tests the hooter or siren to ensure that it is working.
- inspects the functioning of the locomotive lights.
- tests the braking system by driving the locomotive along a short distance in both directions (this task has been discontinued).

Conduct start-up procedures

A magnetic key (switch key) is used to start battery-powered and electrical locomotives. The key activates the controller to prevent unauthorised use of the locomotive. The operator performs the following tasks:

- inserts the magnetic key into the key slot
- releases the brakes by turning the brake handwheel anti-clockwise
- moves the directional control in the desired direction of movement

Conduct post start-up procedures

After starting the motor of the electrical locomotives, the operator monitors the voltage level, and the amperage.

2.3 Driving off and stopping

Driving off is the task of getting the locomotive into motion. The major operator tasks involved in driving are:

- Communication
- Controlling the locomotive
- Manipulating the ancillary controls
- Observing safety rules
- Stopping the locomotive for other operational tasks and ad hoc tasks.

2.3.1 Communication

The main purpose of communication tasks is to provide instructions, which could be signalling messages or warning messages. The guard uses the pea whistle to give signals to the operator. The operator acknowledges the signal using the siren or hooter and then performs the required action . For example, one long blast or the pea whistle orders the operator to stop the locomotive, two blasts orders the operator to move the locomotive in the reverse direction from a front driven train and three blasts orders him to move the locomotive in the direction of the leading end.

The operator also uses the siren or hooter to communicate or warning signals. The operator sounds the hooter or siren to warn or alert people for a potential danger especially at curves, breakaways, crosscuts and areas with bad illumination.

2.3.2 Controlling the locomotive

The task of controlling the locomotive entails ensuring that the locomotive moves in the required direction at the speed. Also included is the applying of the brakes to stop or reduce the speed of the locomotive.

The operator tasks regarding the control of the locomotive are described below:

- controls direction of movement by manually activating the directional control handle or joystick in the desired direction of movement, that is, either forward or reverse
- controls the speed of the locomotive by applying or releasing the brakes, reducing or increasing the angle of the directional control, or reducing or increasing the throttle level.

2.3.3 Manipulating ancillary controls

The task of manipulating ancillary controls during the driving off process involves operating of the siren or hooter. The operator operates these controls to warn or alert people of oncoming traffic and the accompanying potential danger.

2.3.4 Observing safety rules

The operation of the locomotive underground is governed by the statutory safety regulations and mine's operational policy. The major tasks for the operators are:

- Sounding the warning device before driving off
- Stopping the locomotive at breakaways, crosscuts and areas with bad illumination

2.4 Contingency procedures

Contingency procedures are emergency tasks that the operator performs to keep the locomotive in operation. These tasks include "quick-fix" repairs, and re-railing. Also included is the stopping of locomotive to perform other operational tasks such as removing stop blocks and opening ventilation doors.

2.4.1 Re-railing

Re-railing is the task of placing a de-railed locomotive onto the rails. Firstly, the operator takes the necessary precautions to prevent further incidents or accidents where a derailment has occurred. The operator performs the following tasks:

- places the stop signs ahead and behind the derailed locomotive
- places the warning sign at the start of curve on both sides to ensure visibility
- removes the switch key from the locomotive and places it in a safe place to prevent accidentally operating of the controls during the re-railing process
- places skid sprags under the locomotive wheel to prevent it from moving
- lowers the locomotive jack so that the lifter fits underneath the chassis of the locomotive
- positions the locomotive jack in the centre of the buffer and on solid ground
- inserts a short pinch bar in the hole of the lifting handle
- levers the jack until it takes the weight of the locomotive
- jacks up the locomotive until the de-railed wheels are clear from the tracks
- pushes the de-railed locomotive until its wheels are over the tracks either manually or with mechanical assistive devices
- removes the jack.

3. Detailed task analysis of the post-operational procedures

3.1 Parking the locomotive

At the end of the shift the operator drives the locomotive to the area where the pre-operational procedures were executed.

The task of parking the locomotive is general the same as the normal driving task. The differences are that the operator:

- ensures that the locomotive is properly aligned for easy of filling up the fuel (diesel locomotive), enables easy access for translocating the battery the locomotive chassis to the changing stand or for attaching the battery tender to the locomotive
- ensures that the direction control is in neutral position
- applies the brakes
- removes the magnetic isolator key or locks the directional handle
- switches off the battery isolator switch or stops the engine
- disconnect the electrical plug or closes the fuel taps
- ensures that the skid sprags are placed under the locomotive wheels.

3.2 Cleanliness

The operator ensures that the locomotive is left in a clean condition at the end of the shift by cleaning it and removing litter and putting it in the rubbish bin.

3.3 Preparation of the locomotive for the next shift

The electrical locomotive does not require major preparations. The operator ensures that the pantograph is left in a usable condition and checks that there is no damage to the insulation.

To prepare the diesel locomotive for the next shift, the operator ensures that there is enough fuel in the tank. The major tasks for the operator during the preparation of the locomotive for the next shift involve the battery-powered locomotive. The battery has to be re-charged for at least eight hours at the end of every shift to ensure that it has enough power to last.

Locomotive batteries are usually painted or numbered to identify which batteries are used on night shift and day shift. Locomotive batteries are removed from the locomotive chassis at the end of the shift and placed on charge for the full duration of the next shift.

The task of removing the battery from the locomotive chassis onto the battery stand are reverse functions of placing the battery onto the locomotive chassis from the battery stand (refer to paragraph 1.5.2 in this Appendix). After placing the battery onto the battery stand, the operator performs the battery-charging procedures described below:

- attaches the locking pins to ensure that the battery is secured to the battery stand to prevent it from sliding whilst it is being charged
- inspects loose or burnt connector cables between cells
- inspects the battery cells visually to identify cracked or broken battery cells
- inspects the battery circuit breaker
- inspects the battery water level to prevent damaging the cell plates when charging the battery
- inspects the battery terminals for burns and clogging of dirt. If the battery terminals are found clogged with dirt, the operator cleans the terminals with a brush
- inspects the cell caps to ensure that they are firmly closed
- inspects the charger cable plug to ensure that the contact points are not burnt or damaged
- inspects the female plug of the battery to ensure that the contact points are not damaged or clogged with dirt

- attaches the charger cable to the battery to ensure that charging takes place
- locks the handle on battery plug to ensure that the locking handle secure the cable plug to the female plug to prevent the plug from uncoupling whilst charging
- inspects the charger for proper functioning. This is done by ensuring that the correct voltage reading is displayed. If no the operator inspects the circuit breaker, cable and contact points on the plug and the locking handle to ensure that they are firmly intact.
- when the voltage reading is acceptable, the operator switches on the charger by pressing the starter button.

Appendix 5
Perceptual Questionnaire

The objective of this questionnaire was to obtain information that would be used in improving of the locomotives design. The questionnaire identifies the problems encountered by the mine locomotive operators and subjective views on the modifications that the operators want.

1. Name of the mine: …………………………………………………………………………………….
2. Operator's age:……………………………………………………………………………………..
3. Operator's height : …………………………………………………………………………………….
4. Operator's education level:……………………………………………………………………….
5. Experience driving the locomotive : Months : …………………Years : …………………………...
6. Make and size of the locomotive : ……………………………………..……………………………….
7. Mode of propulsion (battery, diesel or electricity): …………………………………………………….
8. Operator's tasks area (surface or underground)…………………………………………………….

Kindly answer or rate the following:

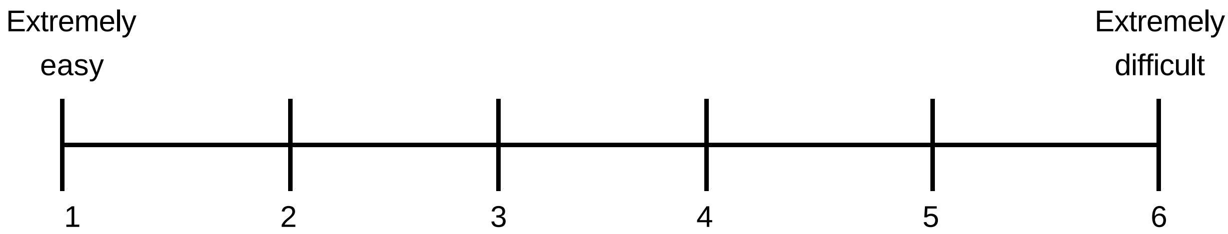
9. Is it easy for you to enter the locomotive? Y / N

Extremely easy … Extremely difficult

1 2 3 4 5 6

Why?
……………………………………………………………………………………………………..
………………………………………………………………………………………………………
…….
………………………………………………………………………………………………………
…….

10. Is it easy for you to exit the locomotive? Y / N


Extremely easy
Extremely difficult
1
2
3
4
5
6

11. Is your seat comfortable? Y / N

Extremely comfortable — Extremely uncomfortable

1 2 3 4 5 6

Why?
……………………………………………………………………………………………….
………………………………………………………………………………………………………
………

12. Is your seat height, too high, too low or just right? (Please indicate the condition that describes your seat height):
………………………………………………………………………………….
………………………………………………………………………………………………………
………

13. Do you have enough space for your legs? Y / N

Extremely enough — Extremely restricted

1 2 3 4 5 6

14. Is it difficult to manipulate the following controls:

- Main controller: ……………………..……………………………………………………….
- Siren: ……………………..…………………………………………………………………..
- Switches : ………………………………………………………………………..………...
- Parking brake wheel : …………..…………………………………………………………..

Extremely easy — Extremely difficult

1	2	3	4	5	6

15. Do you understand the functions of the controls? Y / N

Understand Not understand

1 2 3 4 5 6

16. Do you understand the labels and instructions for the control? Y / N

Understand Not understand

1 2 3 4 5 6

17. Do you understand the meaning of the colours used on the control panel? For example, red, green, yellow, black, and white. Y / N

Understand Not understand

1 2 3 4 5 6

18. Which is the front of your locomotive? (cab area or motor/engine area)

………………………………………………………………………………………………………
……

………………………………………………………………………………………………………
……

19. Do you feel comfortable with your driving position? Y / N

Extremely Comfortable | | | | | Extremely uncomfortable

1 2 3 4 5 6

20. Do you consider driving the locomotive facing towards the direction of movement important? Y / N

Extremely important | | | | | Extremely Unimportant

1 2 3 4 5 6

21. What would you do in an emergency?

……………………………………………………………………………………………………
……

……………………………………………………………………………………………………
……

22. Can you see when reversing the locomotive with the hoppers in front? Y /N

Extremely well | | | | | Extremely poor

1 2 3 4 5 6

23. Can you see when driving the locomotive with the hoppers at the rear? Y / N

Extremely well | | | | | Extremely poor

1 2 3 4 5 6

24. Is it important to see the direction of the locomotive movement when reversing although there is a guard in front? Y / N

Extremely important | | | | | Extremely not important

1 2 3 4 5 6

25. Do you feel safe driving the locomotive? Y / N

Extremely safe Extremely unsafe

1 2 3 4 5 6

26. Are you allowed to drive the locomotive whilst standing? Y / N

……
……

27. Is there noise in the locomotive you are driving? Y / N

Extremely quiet Extremely noisy

1 2 3 4 5 6

28. Can you hear warning signals when the locomotive is moving? Y / N

Extremely well Extremely poor

1 2 3 4 5 6

29. Can the pea whistle signals be misinterpret? Y / N

Misinterpreted Interpreted

1 2 3 4 5 6

Why?

…………………………………………………………………………………………………
……
……

30. Would it be easier to give commands and signals by radio communication)? Y / N

Extremely easy Extremely Difficult

1 2 3 4 5 6

31. Does the locomotive vibrate? Y / N

Extremely high — Extremely low

1 2 3 4 5 6

32. What would you like to be changed in the locomotive?

……

……

……

33. What do you think is the most common causes of locomotive accidents?

……

……

……

34. How often do you re-rail a locomotive and hoppers? (daily, weekly, monthly)

……

……

35. Where do you want to store the equipment and tools that are required for emergency tasks?

………..

………..

36. Do you carry the following items?

ITEM	YES / NO	NUMBER

Guard seat		
Fire extinguisher		
Pea whistle		
Battery lamp		
Coupling pins		
Coupling hooks		
Loco Jack with handle		
Skid sprag		
Red triangle		
Chain		
Guala		

37. General comments

………
……

………
……

………
..

Thank you for answering these questions.

Appendix 6

International locomotive assessment

1. Assessment of deficiencies identified for the local fleet

The assessment involved locomotives from eleven international manufacturers. The purpose of including photographs here is to elucidate pertinent ergonomics aspects only. No other purpose is intended or implied. Credit is given to the companies listed below for use of their promotional material: Clayton Equipment Limited, United Kingdom; DBT Maschinenfabrik Scharf GMBM, Germany; Goodman Equipment Corporation, United States of America; RA Warren Equipment Limited, Canada; Walter Becker GMBH, Germany.

1.1 Access

Access to the cab was identified as a deficiency of the local fleet. Figure 1.1.1 and Figure 1.1.2 shows access steps into the cab of international design that are extremely high. In addition, no handholds are provided to allow for three-point contact during entry or exit. It may be argued that the surrounding structures may be used to hold onto but this is not ideal.

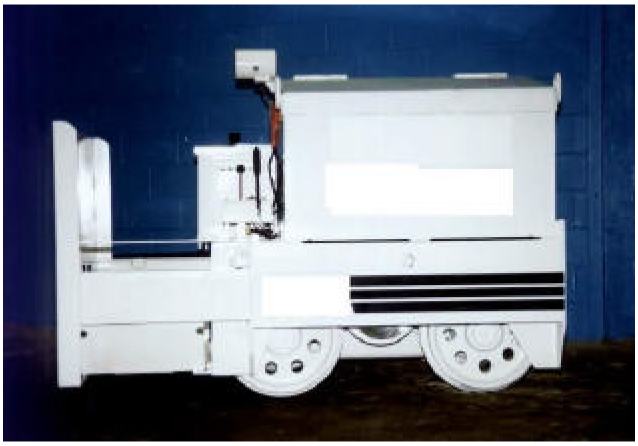


Figure 1.1.1: Battery locomotive (North America)

Figure 1.1.2: Trolley locomotive (Europe)

Figure 1.1.3 shows an enclosed cab with a high access step. However, handholds are available and the configuration is therefor acceptable.

Figure 1.1.3: Battery locomotive (Europe)

Figure 1.1.4: Battery locomotive (North America)

Figure 1.1.5: Trolley locomotive (Europe)

Figure 1.1.4 shows a low access height with an even lower cut-out to provide a foot hold for easy access to the cab. Also note the hand holds on each side of the access opening. A larger trolley locomotive is shown in Figure 1.1.5. A step is provided for entry to the cab. A locomotive with a very low profile (only 1.22 m) is shown in Figure 1.1.6. Entry could be improved by handholds because of the low cab height. Figure 1.1.7 shows a monorail cab that is easy to access because of the low step-in height and adequate handholds on the surrounding structure.

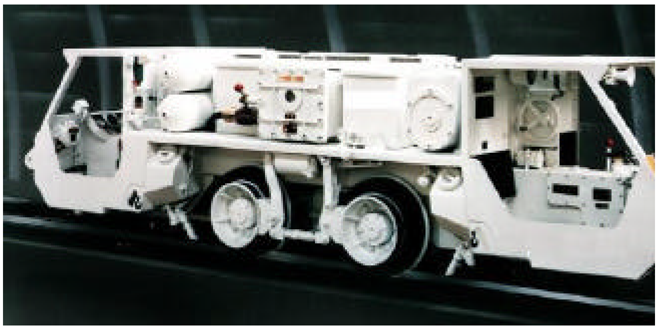


Figure 1.1.6: Battery locomotive (Europe)

Figure 1.1.7: Monorail (Europe)

In general the access to the smaller locomotives had more deficiencies than the larger tonnage locomotives and monorail systems. Ease of access is dependent on the configuration of the cab and, as illustrated here can be improved by proper location of foot holds and hand holds.

1.2 Seating

In the international market seating types and configurations varied from basic structures to automobile type adjustable seating systems. Figure 1.2.1 and Figure 1.2.2 show basic configurations of a hard surface, unadjustable seat. These types were also found in the local locomotive fleet and judged to provide inadequate support (refer to paragraph 6.2 of the main part of the document).

Figure 1.2.1: Trolley locomotive (Europe)

Figure 1.2.2: Trolley locomotive (Europe)

Polyurethane type seats were found on a number of the international designs. Figure 1.2.3 shows a split base and backrest. The backrest folds away to allow access to the cab. The seat is not adjustable but does provide space between the base and backrests for the caplamp battery and self rescuer. However, no lumbar support is provided. A vinyl covered automotive type seat mounted on adjustment rails for horizontal adjustment is shown in Figure 1.2.4. It does not make provision for belt worn equipment.

Figure 1.2.3: Battery locomotive (Europe)

Figure 1.2.4: Battery locomotive (North America)

Another adjustable seat provided as standard equipment in a 20 ton trolley locomotive is shown in Figure 1.2.5. This seat does not provide lumbar support but allows for belt worn equipment. The seat depth is however inadequate to support the thighs, especially for long periods.

Figure 1.2.5: Trolley locomotive (Europe)

It was established that the seat type varied considerably among manufacturers and also among the locomotives of a single manufacturer. Once again the smaller tonnage locomotives, with exceptions, utilised seats with most of the identified deficiencies (i.e. hard surfaces, not adjustable, small contact areas). Larger locomotives generally used ergonomically more acceptable seating equipment. Adjustability of seats are however not standard throughout the international fleet and provision for belt worn equipment was noted on only a few locomotives.

1.3 Body posture and orientation

Body posture and orientation is influenced by the layout of the cab and location of controls and displays. Body orientation to the direction of travel is also important. As with the local locomotives, the international fleet had no standard body orientation nor layouts that would facilitate comfortable and acceptable body postures.

Figure 1.3.1 shows a typical seat orientation (i.e. perpendicular to the direction of movement) of the international fleet. Other examples are presented in Figure 1.1.1, Figure 1.1.2, Figure 1.2.1, Figure 1.2.2, Figure 1.2.3 and Figure 1.2.4.

A forward facing (in the direction of travel) configuration is presented in Figure 1.3.2. Similar orientations is presented in Figure 1.1.3, Figure 1.1.5, Figure 1.1.6, Figure 1.1.7 and Figure 1.2.5.

Figure 1.3.2: Monorail (Europe)

Figure 1.3.1: Diesel locomotive (North America)

Most of the larger tonnage conventional locomotives and all the monorail types used the forward facing seat configuration. Although this configuration was observed even in the 5 ton class (see Figure 1.1.6) most of the small locomotives used the perpendicular orientation.

Figure 1.3.3: Trolley locomotive (Europe)

Figure 1.3.4: Trolley locomotive (Europe)

The body posture required to operate the locomotive effectively is dependent on the layout of the controls and displays. Figure 1.3.3 shows a standard layout for a trolley locomotive. It is predicted that the dispersed layout of this cab would require the operator to adopt awkward body postures to perform the required tasks safely. Another example is presented in Figure 1.3.4. These configurations are inherently no different from some of the examples of the current local fleet. The monorail cab presented in Figure 1.3.5 is of such configuration that the driver is allowed to adopt a stressful posture involving rotation of the trunk and stretching in order to gain visual access to the rear. Use of aids such as mirrors might alleviate this deficiency.

Internationally, there is however also control and display layouts that conform largely to acceptable ergonomics practices. These are discussed in paragraph 1.5 of this appendix.

Figure 1.3.5: Monorail (Europe)

1.4 Workspace

Workspace, particularly legroom was found to be very much dependent on the size of the locomotive. The smaller types would, with the addition of equipment being carried in the cab or on the cab floor, be as restrictive as the current local fleet. The 30 ton trolley locomotive shown in Figures 1.1.5 does however have adequate workspace, so does the monorail examples of Figure 1.1.7 and Figure 1.3.2.

1.5 Control and displays

Control and display best practice is presented in Figure 1.5.1 and Figure 1.2.5. These layouts however lack functional grouping and sound labelling principles but at least the controls are being grouped on an instrument panel in proximity to each other.

Figure 1.5.2: Hand controller (North America)

Figure 1.5.1: Trolley control panel (Europe)

Figure 1.5.2 presents a layout of controls that would be inconsistent with the expectations of the user.

The directional controller is mounted perpendicular to the travel direction and with no labelling the user would have to rely on trial and error to determine direction of control operation to actual direction of travel. This is not an improvement over the current local fleet. In Figure 1.3.4 a handwheel is used as braking control device. In addition to the handwheel, a ratcheted brake lever with handgrip is attached to the handwheel to provide fast operation of the brake. This is preferable to the use of a handwheel only, as was a frequently observed design practice on the local fleet.

From these examples it can be concluded that the international mine locomotives does not universally incorporate sound ergonomics control and display design or layout principles that would be acceptable for the local population. Even “best practice” examples lack the application of basic ergonomics practice.

1.6 Visual Access

Body orientation in relation to the direction of travel and cab structures are attributed to influence visual access to the track, but also to the rear of the locomotive.

Figure 1.3.5 clearly shows how body posture is used to obtain rearward visual access. Most of the international designs allow good visual access to the track. This is achieved by locating the operator close to the end of the locomotive and providing little structural interference to the view to the outside. A good example here is presented in Figure 1.6.1 and Figure 1.6.2. Large aperture viewing access was frequently observed in the international fleet. Examples here include Figure 1.1.3, Figure 1.1.5, Figure 1.1.6, Figure 1.1.7, Figure 1.2.3, Figure 1.3.1, Figure 1.3.2. It should be noted that some of these designs use a vertical glass windscreen or one that is sloping upward and outward. With these configurations the caplamp light can cause annoying reflection and glare in the windscreen and can temporarily blind the operator or reduce the vision to the outside. With downward and outward sloping windscreens the impairment of vision to the outside is reduced. An example is shown in Figure 1.1.5.

Figure 1.6.1: Battery locomotive (Europe)

Figure 1.6.2: Battery locomotive (North America)

1.7 Operator protection

The international fleet of locomotives included both enclosed, semi-enclosed and open cab design. The smaller tonnage locomotives were, as locally, mostly of the open cab design. However, for the larger locomotives, the semi-enclosed to enclosed designs were more abundant. All monorail designs had operator protection structures. Operator protection is an important safety factor and enclosed cabs are therefor the preferred option. The enclosed cab designs and protection structures of the international designs would assist in reducing the perception of hazards arising from the battery retention mechanisms as an identified deficiency of the local fleet.

2. Comparison of international status and ergonomics requirements for the proposed ideal design

The international design status is compared with the requirements for an ideal design as listed in paragraph 7.1 of the main document.

2.1 Adequate space for operators

The international designs would all seem to provide adequate space for the driver with adequate free volume to perform all the required tasks. When looking at new products this assessment could be misleading as additional equipment (e.g. jacks, sprags and fire extinguisher) are added to the available operator space which could reduce the safety and efficiency of operating the locomotive. Space problems, however, are only a serious consideration on the smaller locomotives.

2.2 Adequate communication links

The international designs tend to progress into semi-enclosed and completely enclosed cabs. The completely enclosed cab is arguably not practical, from a communications view, for South African gold and platinum applications. The peawhistle and verbal communication would be ineffective. The completely enclosed cab can only be used within the local mining environment if an effective communication system and procedures are available. However, as short term solution, the advantages of semi-enclosed cabs available internationally should be exploited for the local market.

2.3 Controls and displays

As discussed in paragraph 1.5 of this appendix the control and display layout, arrangement and labelling of the international designs are not optimised even for foreign users. Local drivers, because of language and reading skills, require special representation (e.g. symbols) of internationally accepted terms and descriptions.

Controls and displays are therefor not optimised for the local user population.

2.4 Access

Refer to paragraph 1.1 of this appendix.

2.5 Body orientation

There can be no doubt that body orientation in the direction of travel is the preferred position for a locomotive driver. The monorail designs and larger conventional rail locomotives all adopted this orientation.

2.6 Protection and safeguards against hazards

The safety features and protection provided by the international designs are deemed superior to that of the local fleet. It could in part be attributed to the abundance of semi-enclosed cabs found internationally. The use of rubber and polymer wheels to improve traction but potentially reducing whole body vibration are also noteworthy. Except for fully enclosed cabs, noise exposure for the driver remains a challenge, especially to maintain effective communication.

2.7 Adequate illumination

Illumination is an important component of adequate visual access for performing the driver tasks. This can include illuminating for inspection and operational tasks. No special features other than reduction of inspection task intensity as result of engineering progress was observed.

2.8 Seating

A variety of seating equipment was noted for the international design. Provisions for belt worn equipment on seats were rarely observed. The South African designed T-back seat providing lumbar support and which makes provisions for belt worn equipment is to be preferred equipment on all locomotives.

2.9 Emergency systems

Although the safety considerations, including emergency escape provisions, of the enclosed cab was included in most designs, some examples where access to and from the cab is severely restrictive were judged to be unacceptable for the South African environment.

2.10 Fail safe design, simplest design, minimise human error

These factors could not be fully assessed as they are related not only to sound engineering practice but also to effective integration of operator expectations, operator skills and experience, accepted stereotypes, environmental influences, local procedures and practices and statutory requirements. It also relates to control and display application and labelling. These aspects should be carefully considered and quantified for the local user population before international designs are accepted as fail safe, simple and able to minimise human error.

Appendix 7
Ideal design layout drawings

Figure 1 and Figure 2 present the major dimensions for the ideal locomotive design.

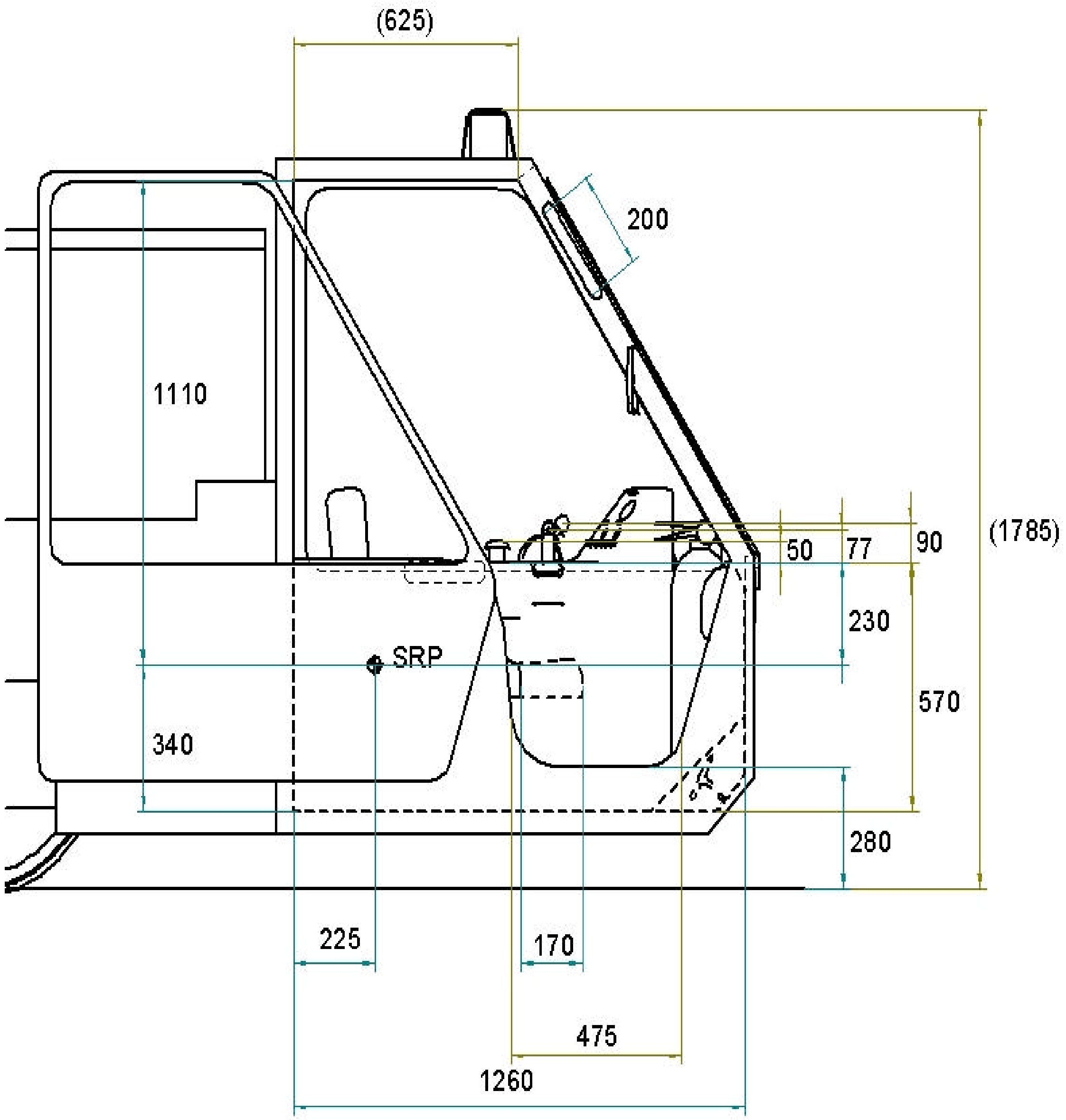


Figure 1: Dimensions – side view

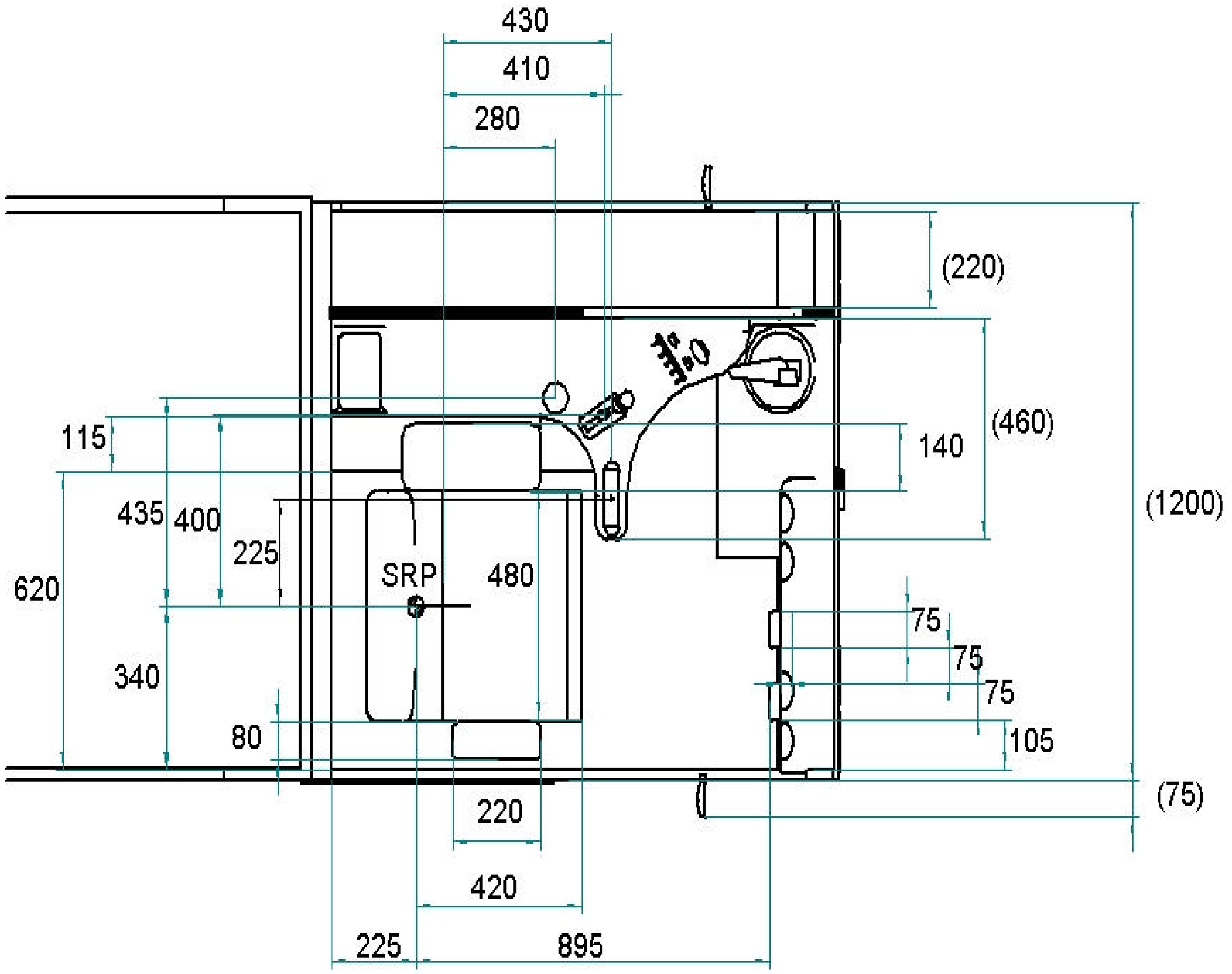


Figure 2: Dimensions – top view

Appendix 8
Practical design layout drawings

Figure 1 and Figure 2 present the major dimensions for the practical design of the locomotive and the guard car.

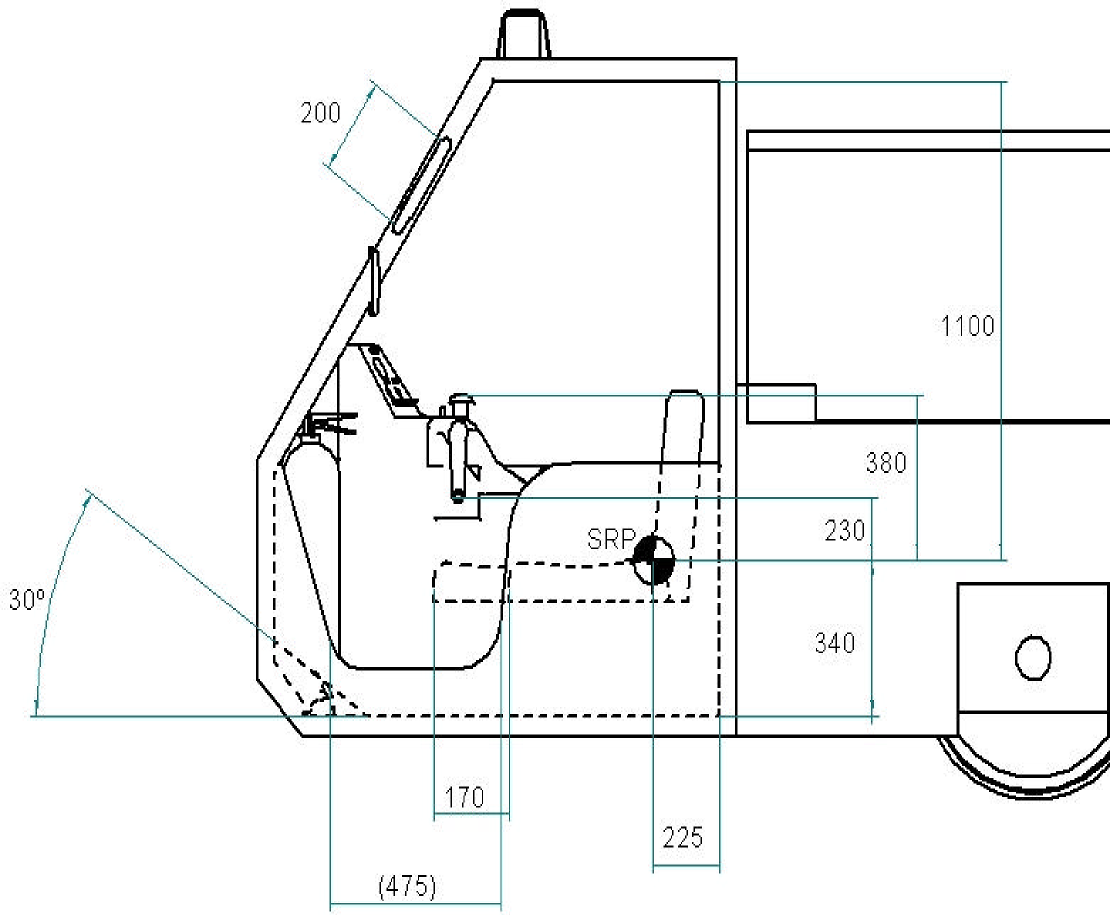


Figure 1: Dimensions – side view

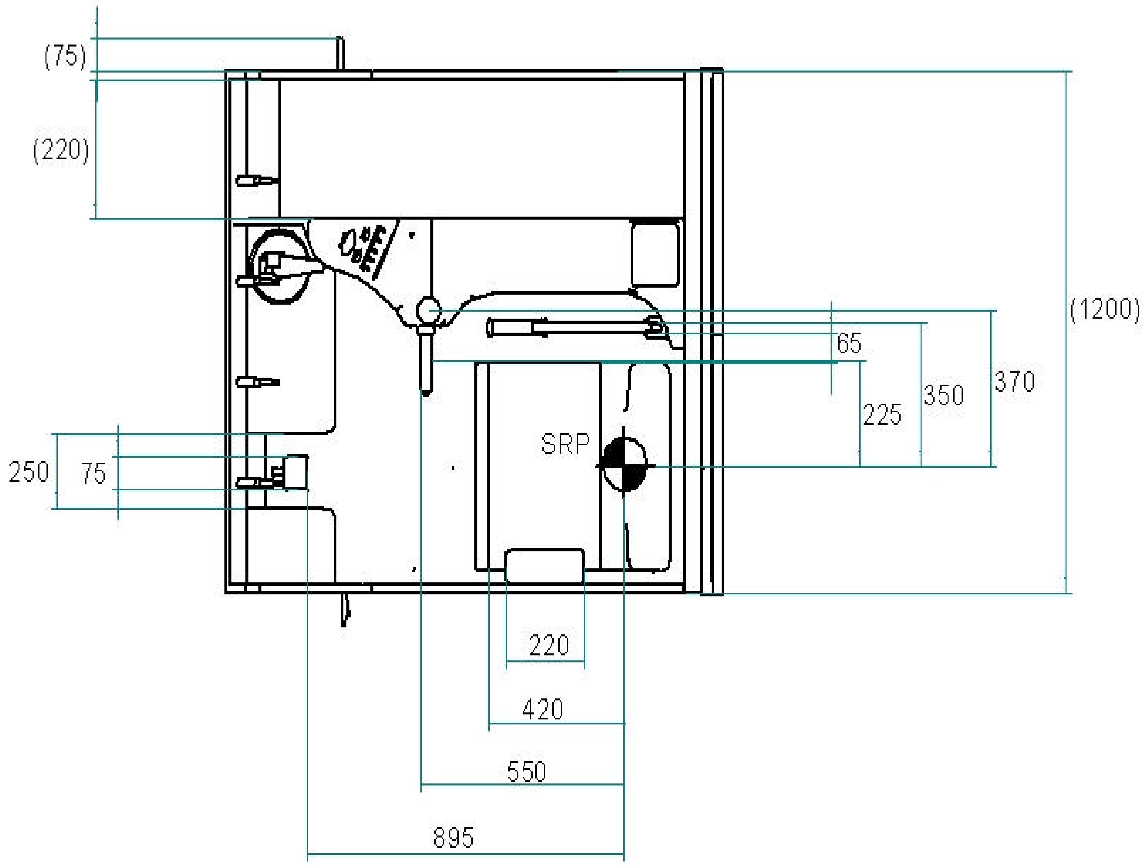


Figure 2: Dimensions – top view