DEVELOPMENT OF A NON FLAMEPROOF DIESEL POWERED TRANSPORT VEHICLE FOR UNDERGROUND COAL MINES

Mel Bell
D. Chrzanowski
ACIRL

INTRODUCTION

An ACARP Study No C3063 into the use of diesel powered vehicles concluded that non-flameproof vehicles could be used safely in an underground coalmine. A program was undertaken to develop such a vehicle. This paper covers the development process and describes the additional controls necessary to meet the needs of the underground coal mine environment. It also summarises the operational risk assessments conducted prior to use underground. A trial of the prototype was conducted underground at Oakleigh Colliery and at Collinsville No2 Colliery. The vehicle performed safely and to specification. Preliminary results indicated that it offered advantages over the current personnel transport vehicles, particularly in passenger comfort and manoeuvering ability. Subsequently two further vehicles have been developed and these are intended for a long-term trial at Moranbah North.

DEVELOPMENT PROGRAM

Scope

A consortium of coalmines, Moranbah North, Crinum, and Gordonstone contracted ACIRL to develop a prototype non-flameproof vehicle and conduct a trial to assess its feasibility.

The development program covered a period of 18 months and had two main objectives.

- To identify the risks to personal safety associated with using a non-flameproof diesel vehicle in an underground coal mine.
- To identify and develop controls necessary to manage the risks to an acceptable level.

Following research into the operations of this class of vehicle in other mining areas the risk of fire was identified as being the one major risk for which additional controls would be necessary for satisfactory uses in underground coal mines.

The risk of the vehicle operating in hazardous areas was also identified as requiring additional control.

Vehicle Selection

The specifications for a number of possible vehicles were obtained and evaluated against a specific set of criteria considered essential for satisfactory performance as shown in Appendix 1
A scoring mechanism was devised to allow comparison of the vehicles.
The Toyota Landcruiser Troop Carrier received the highest score and was deemed the most suitable for the purpose.

Development Trials

Initial trials were conducted to gather base information on how the vehicle performed against a range of criteria. These were conducted using a wheeled dynamometer over different power outputs.
Following these tests, development targets were set for various components.
As development work continued, further trials were conducted by load simulation on public highways. This method was used to gain confidence that the changes were meeting expectations and to emulate the vehicle operations in the field. Final testing was conducted on a wheeled dynamometer. The information gained from this testing was used to support the application for approval by the Chief Inspector of Coal Mines

Fire Control

The methods used in currently approved vehicles are considered to provide satisfactory control for engine fires. These were adopted for the project. In essence they require all engine and exhaust surfaces to be below 150° C. In addition to surface temperature requirements, the temperature of the exhaust gas is to be maintained below 150°C. The maximum temperatures at 2500RPM with the engine fully loaded are shown below.

Table 1: Temperature Fully Loaded at 2500 rpm

Maximum Power:	49.5kW
Maximum Exhaust Gas Temperature at outlet:	113°C
Surface Temperatures of Water Jacketed Manifold	109°C
Surface Temperature after muffler	82°C
Surface temperature at first bend in double insulated pipe	85°C

Note: There was an increase of approximately 5 °C when the engine was turned off after testing. This was due to the absence of circulating cooling water.

Tests were conducted to determine the surface temperature of the brake discs. This was done by using the brakes to control the descent on a 7° slope for distances of 1km and 2 kms. The results of these tests are as follows:

Table 2: Brake Temperature (oc)

Trial	Stage of Trial	Distance = 1km				Distance = 2km			
		Wheel				Wheel			
		RF	LF	RR	LR	RF	LF	RR	LR
1	Before	65	111	64	61	72	124	57	64
	After	160	200	113	120	184	133	147	137
2	Before	60	107	67	68	82	116	68	68
	After	130	179	124	124	130	220	129	129
3	Before	74	98	84	67	74	96	74	70
	After	99	174	106	113	130	127	126	115
Maximum Temperatures		160	200	124	124	184	220	147	137
Average Temperatures		98	144.8	93	92.2	112	136	100.2	97.2

Ambient Temperature = 19°C
Note the higher temperatures from the Left-hand front wheel, caused by a sticking piston in the calliper.

It was decided to provide totally enclosed wet disc brakes, despite the reasonable performance of the standard brakes. It is anticipated that these will reduce maintenance requirements.

Emissions

Results of exhaust emission monitoring from the first series of dynamometer tests indicated that the risk of exceeding underground mine environmental limits was extremely low. The levels of CO, NO, and NO_2 emitted through the range of power outputs from the engine are all well below the requirements of legislation and are in some cases lower than the emissions from currently approved engines. The results recorded under full dynamometer load were: -

Table 3: Raw Exhaust Emissions (ppm)

Undiluted Exhaust Emission Component	Toyota Landcruiser	AS 3584 (Maximum)	Perkins Typical Series 1006
NO	376	750	750
CO	154	1500	400
NO_2	8	-	-

THE VEHICLE

General Description

The vehicle is a standard Toyota Troop Carrier that can transport ten people. The vehicle has the potential to be used by any coalmine with a minimum roadway height of 2.2. metres.

Whilst the vehicle retains its standard features the safety levels have been increased to allow use in an underground coalmine, including a location control system that restricts the vehicle from entering areas requiring flameproof equipment.
The major advantages of employing such a vehicle relate to occupational health and safety. The occupant's exposure to noise is one quarter of that

experienced with current underground personnel transporters. The occupants are exposed to lower vibration through the use of sprung seats and reduced suspension stiffness. This gives the vehicle a greater level of comfort than a conventional underground personnel carrier.

The vehicle is easier to operate. It has a reduced turning circle which is on an average three metres less than that of existing underground coal mine personnel transport. It also has a better power to weight ratio than current personnel transporters.

Safety Features of the Vehicle

Fire Prevention

The engine system is designed to operate at temperatures of less than 150^{0}C. This is achieved by a four-stage exhaust system.

- Water-cooled exhaust manifold.
- Water-cooled exhaust header pipe.
- Double insulated exhaust tail pipe.
- Air-mixing chamber into which cool air is injected.

See figure one for schematic layout

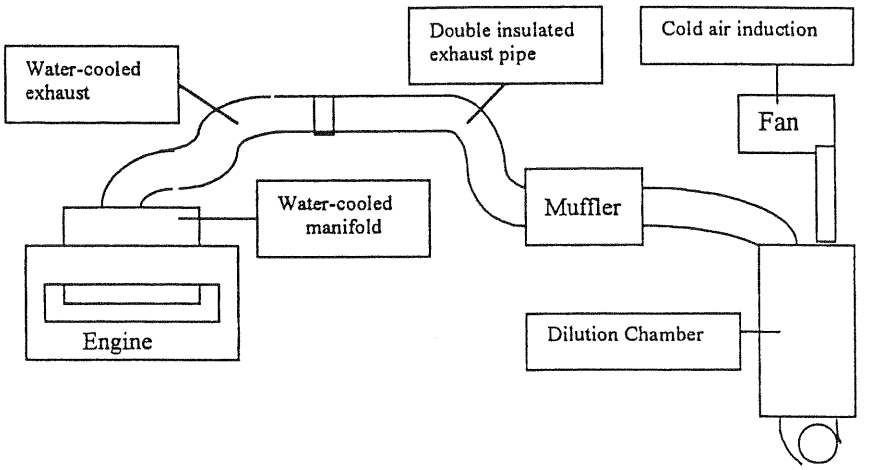

Figure 1 *Schematic Layout of Exhaust System*

Engine Management System

The vehicle is provided with an engine management system that includes the following sensors:-

- Low Engine Cooling Water Level
- Low Engine Oil Pressure
- High Engine Cooling Water Temperature
- Exhaust Temperature
- Starter Motor temperature

Activation of any of these sensors will cause the engine to shut down. The condition causing activation must be rectified before the engine can be re-started.

Engine Overspeed

The engine speed has been limited on the prototype to control the temperature of the exhaust gas. If the operator attempts to accelerate the engine past the pre-set value, the system drops the speed to a lower level. Once the engine speed has been reduced, the operator is than able to accelerate as normal. This has additional benefits in that it also controls maximum road speed. The vehicle is restricted to the first three gears through mechanical means Maximum road speeds at 2500 RPM are shown below.

Table 4: Speed Ranges (kms/hr)

Low Range		High Range	
Gear	Speed	Gear	Speed
1	10	1	19
2	18	2	35
3	31	3	61

Location Control System

This system has been designed to prevent the vehicle from being driven into restricted areas of an underground coal mine. It has a radio-receiving device on the vehicle and a series of three intrinsically safe transmitters located at the approaches to the restricted areas.

If the vehicle enters the first transmitter zone, called the RESET zone, an alarm and light sequence is activated to indicate that the vehicle is approaching a prohibited area.

If the vehicle enters the second transmitter zone, called the WARNING zone, a secondary alarm and light sequence is activated. A timer is initiated and if the vehicle does not retreat from within the WARNING zone before the pre-set time has elapsed, the engine will shutdown.

If the vehicle enters the third transmitter zone, called the SHUTDOWN zone, it will cause instantaneous engine shut down as well as automatic battery isolation.

Following shutdown the system prevents re-starting until the vehicle is moved back to the RESET ZONE

A regulated key can be used to override the system and allow the vehicle to be driven out of the transmitter zones. The use of this must be controlled through the development of safety protocols.

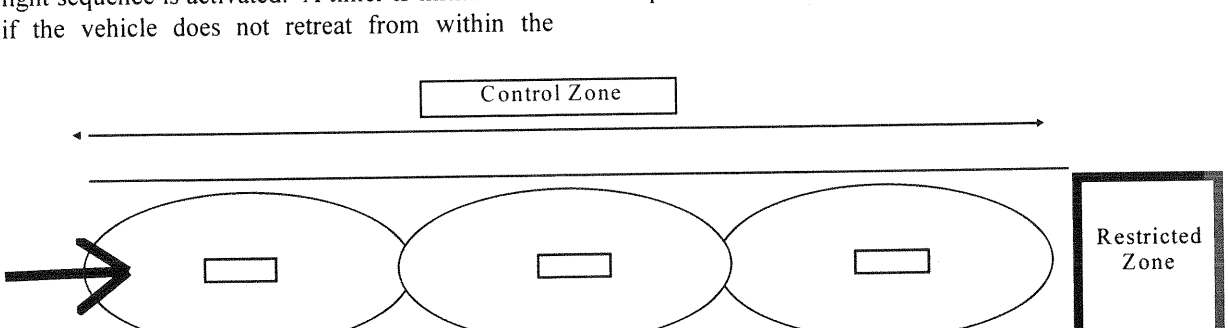

Figure 2 *Layout of Location Control System*

Enclosed Wet Disc Brakes

The machine is provided with enclosed wet disc brakes which replace the standard brakes. The operation of these is consistent with the normal requirements. All the brake safety features of the standard Toyota Troop Carrier have been retained, including load proportioning valve and split hydraulic system. The hand brake is operated in the normal way.

The wet disc brakes reduce the influence of contamination from the mine environment and will minimise maintenance requirements.

Automatic / Manually operated Fire Suppression System

The pressurised system automatically detects a fire in the engine bay through the use of a pyro tube. The system, upon activation, expels an AFFF (foam) solution from nozzles in the engine bay for approximately 80 seconds. The system pressure is monitored and the engine is automatically shut down when a drop in pressure occurs from any cause. Engine shutdown includes isolation of the fuel by a fail safe cut-off solenoid and battery power isolation.

There are two points from which the operator can activate the system manually. One is inside the vehicle cabin and the other on the front of the vehicle.

The operator is notified of system activation by a visual and audio alarm.

Fire Extinguisher

There is a secondary fire extinguisher fitted to the vehicle for use as deemed necessary.

Reversing Lights and Alarm

Two reversing lights and an audible alarm are fitted to the rear of the vehicle. These are activated whenever reverse gear is engaged.

Emissions

The vehicle exhaust emissions during final testing fully loaded and at 2500 RPM on the dynamometer complied with the requirements of the Queensland Coal Mining Act and AS 3584. The results of undiluted exhaust gas test are shown below.

Table 5: Raw Exhaust Emission at Final Testing (ppm)

NO_2	NO	CO
8	376	154

When these figures are considered in conjunction with the ventilation practices in modern coalmines

where typical quantities of ventilating air are 60 m^3/sec for longwall panels, and 35m^3/sec for development panels, the risk of exceeding acceptable limits is extremely low.

Standard Vehicle Safety Features
As well as the above mentioned safety devices, the standard Toyota features are still included. These are: -

- Seatbelts for all occupants
- Side intrusion beams fitted to side doors
- Temperature Gauge
- Alternator Charge Light
- Oil Pressure Gauge
- Battery Voltage Gauge
- Internal Roll Cage
- Bull Bar

OPERATIONAL RISK ASSESSMENTS

Operational risk assessments on the use of this vehicle have been conducted. The results are briefly discussed.

General Summary of Operational Risk Assessments
The assessments identified uncontrolled movement of the vehicle that could lead to personal injury as being the highest risk. The controls identified were in three groups. Those associated with the vehicle, those associated with the operating pavement, and those associated with the operation.
The controls used are the same as those for the on-road and off-road environment in which these vehicles normally operate.
The vehicle controls comply with Australian Design Rules. In addition to these there are extra controls relevant to the specific mine environment. The brake system is totally enclosed to minimise deterioration in brake performance due to contamination. The vehicle speed has been limited.
The roadway pavement will be installed to a pre-set standard, which includes a concrete floor in the main drifts and blue metal aggregate in the development roads.
Medium risks included arc and spark associated with electrical wiring. Modifications to the wiring ensure that it meets the requirements of (AS 4242).
The outbreak of fire due to combustible materials contacting hot surfaces fell into the medium risk class. The controls used for this hazard are the same as those required for an approved flameproof vehicle.

Operation of the vehicle in a hazardous area was evaluated and considered to be a low risk. However the vehicle is provided with a location control system which will prevent operation in restricted areas. This system which relies on triple redundancy will also disconnect the vehicle battery.
The distribution of control intents generally showed that the emphasis is placed upon prevention. The distribution of controls being: -

Table6: Distribution of Control Intents (%)

Prevention	Monitoring	Contingency
54	23	23

CONCLUSION

The Toyota troop carrier as developed is suitable for use in non-flameproof areas of coalmines. Its use has several advantages over current personnel transport vehicles.

- Operator and passenger exposure to noise is considerably lower and is well within the requirements of recognised standards.
- Operator and passenger exposure to skeletal injury from vehicle vibrations is considerably lower
- The potential for operational accidents and vehicle damage is reduced through better manoeuvering ability from a lesser turning circle and an improvement in vehicle lighting
- The vehicle is considerably less expensive
- The vehicle has an automatic AFFF fire suppression system.

The disadvantage is that its use is restricted to non-flameproof areas.

APPENDIX 1

Specifications of Vehicle

Specification	Hummer	Canter	L/Cruiser	Defender	Patrol	Rodeo	Hilux	Triton	Courier	Navara	Best
Turn Circle	16.2	12.8	13.8	15	13.8	12.2	13.2	13.6	13.6	11.8	11.8
Power/Weight	0.0267	0.0185	0.0307	0.0265	0.026	0.0262	0.0213	0.022	0.0226	0.0205	0.0307
Support	1	3	3	3	3	2	2	2	2	2	3
Ride	3	1	3	3	3	2	2	2	2	2	3
Brakes	1	1	1	1	1	1	1	1	1	1	1
Seating Number	10	10	10	8	8	8	8	8	8	8	10
Corrosion	3	2	2	3	2	1	1	1	1	1	3
Price ($)	80000	72000	47000	43000	48000	37000	47000	47000	47000	47000	3700

Score

Specification	W	Hummer	Canter	L/Cruiser	Defender	Patrol	Rodeo	Hilux	Triton	Courier	Triton
Turn Circle	5	3.64	4.61	4.28	3.93	4.28	4.84	4.47	4.34	4.34	5.00
Power/Weight	8	6.96	4.82	8.00	6.91	6.85	6.83	5.55	5.73	5.89	5.34
Support	3	1.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00
Ride	3	3.00	1.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00
Brakes	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Seating Number	10	10.00	10.00	10.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Corrosion	3	3.00	2.00	2.00	3.00	2.00	1.00	1.00	1.00	1.00	1.00
Price	8	3.70	4.11	6.30	6.88	6.17	8.00	6.30	6.30	6.30	6.30
Score		**31.30**	**29.54**	**36.57**	**34.72**	**33.29**	**32.66**	**29.32**	**29.37**	**29.53**	**29.64**