

DEVICE FOR MONITORING HAUL TRUCK OPERATOR ALERTNESS

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1 BACKGROUND

Operators of heavy mining machinery sometimes find themselves in situations where they struggle to remain awake whilst driving. This problem is one that appears to be shared with other occupations, as people these days tend to put sleep last on the day's agenda. The main issue for operators of haul trucks is the likely consequences of either falling asleep at the wheel or suffering from diminished motor, cognitive and perceptual skills. These diminished skills are often passed off as "lack of attention" but are commonly found in lowered states of arousal long before sleep onset occurs.

Considerable research has focussed on fatigue management, leading to many changes in shift and rostering patterns, education and training on sleep hygiene, maintaining healthy lifestyles, and the recognition of factors that contribute to fatigue. Although this has probably had an influence on reducing fatigue in some workplaces, there are operators that, for one reason or another, do not place enough emphasis on their personal fatigue management. Therefore, technology may offer the potential for a more reliable and earlier warning of performance impairment, before operator drowsiness leads to an adverse outcome. Research has shown that fatigue onset develops slowly enough to be capable of intervention long before a subject gets to a dangerous level.

2 THE CHALLENGE

In 1999, ARRB Transport Research Ltd. were commissioned by the Australian Coal Association Research Program (ACARP) to conduct a review of local and international technology that would be useful for monitoring heavy vehicle operator fatigue in open cut coal mines. The research team consisted of the following members:

Alex Campbell	Research Coordinator	Australian Research Administration Pty Ltd
Robert Spencer	Industry Monitor	Bayswater Coal Co
Nick Mabbott	Project Leader	ARRB Transport Research Ltd.
Mary Lydon	Quality Manager	ARRB Transport Research Ltd.
Laurence Hartley	Project Consultant	Institute for Research in Safety and Transport, Murdoch University
Pauline Arnold	Project Consultant	Institute for Research in Safety and Transport, Murdoch University

2.1 Commercially Available Devices

Review of the literature has identified six different basic means of measuring an operator's level of arousal¹. They are summarised in Table 1. The first two; fitness for duty testing and mathematical models of alertness, are methods of predicting whether or not an operator is capable of maintaining high alertness levels throughout the task period. The latter four take

¹ For a comprehensive review of the technological devices, see Mabbott, Lydon, Hartley and Arnold (1999) *Procedures and Devices to Monitor Operator Alertness Whilst Operating Machinery in Open-Cut Coal Mines*. ARR 344, ARRB Transport Research Ltd., Vermont South, Victoria.

one or more measurements of reaction time, physiological changes, vehicle parameters, or a hybrid of different forms of measurement.

Table 1: Six basic forms of fatigue monitoring devices.

MONITOR	TYPE OF MEASURE
Fitness for duty tests	Behavioural or biological estimate of an operator's functional capability for work yet to be performed. Generally involve a mixture of pupilometric & ocular tests, and performance based tests.
Ambulatory devices & mathematical models of alertness	Mathematical models that predict operator alertness/performance at different times based on interactions of sleep, circadian rhythms and related antecedents of fatigue.
Stimulus – response reaction tasks	A simple technology where a stimulus is presented to the operator, to which he/she must respond. Failure to respond elicits a warning signal or shut-down of the operation.
In-vehicle, on-line, operator status monitoring	Seeks to record some biobehavioural dimension/s of an operator, such as features of the eyes, face, head, heart, brain electrical activity, skin potential, etc, on-line (during driving). More than 20 different technologies in this area are in various stages of development (Dinges <i>et al.</i> 1998).
Vehicle parameters	Measures the behaviour of the transportation hardware systems under the control of the operator, such as lane deviation, or steering or speed variability, which are hypothesised to reflect changes when a driver is fatigued.
Hybrid measures	Some technologies utilise a combination of both in-vehicle, on-line operator status plus some form/s of vehicle parameter measurements.

After reviewing a considerable number of devices from around the world and liaising with several fatigue experts, it was decided that no single device either seemed appropriate for the environment that is particular to open cut mining, or was not scientifically supported in reputable published material. The challenge was to develop a fatigue monitoring device that would be intelligent enough to monitor declines in operator performance, whilst being suitable for the rugged environment of open cut mines. The device would have to overcome all the deficiencies of the technology that performed less than adequately in the past.

The report for ACARP was presented at the seminar held in Emerald 1999. Thiess Contracting pledged their support for the device and offered their Burton and Mount Owen mines as venues for which to trial the devices. ACARP once again provided funding for the continuation of the project, commencing in January 2000.

3 THE SOLUTION - STIMULUS-REACTION DEVICE

Stimulus-reaction tasks have been used in research studies to measure several functions of humans. One such function is human performance decrements such as that displayed during periods of operator fatigue. Research has shown that simple stimulus-reaction tasks can become automated to the extent that an operator can still respond rapidly even when in a decreased state of alertness. By using two stimuli lamps instead of one, the simple reaction task becomes a forced decision task. Forced decision tasks have been utilised by cognitive psychologists for decades to accurately measure (in milliseconds) higher cognitive processes in humans. Decisions are a much harder task than simple responses for individuals during periods of tiredness. Therefore, a slower response would suggest a fatigued state.

3.1 Normal operation

The stimulus-reaction device operates in four defined stages. Under normal circumstances (and the operator is wide awake) the device will present a light stimulus every 11 to 15

minutes apart. If the operator reacts within a short time, nothing else will happen and another stimulus light presentation will occur within the next 11 to 15 minutes.

3.2 Slow or wrong responses

If the reaction to the light stimulus is slightly slower than normal, or if the wrong reaction button is pressed (eg. left stimulus light – right reaction button), the device will automatically speed up the period of time between stimulus presentations. The next presentation will occur within 6 to 10 minutes apart, based upon the notion that more testing should be carried out if the operator is getting tired.

3.3 Slower responses

If a reaction to the stimulus light is considerably slower, the device will again speed up the time between tests. However, on this occasion the next stimulus presentation will occur within the next 1 to 5 minutes and an alert will be sent to the supervisor. At this stage, the device has determined that the operator is at risk of becoming sleepy enough to possibly cause an accident. The supervisor should contact the operator on the radio to discuss possible countermeasures to the current state of lowered alertness.

3.4 Extremely slow responses

Extremely slow responses to stimulus presentations will cause the device to emit a warning buzzer sound in the vehicle cabin. This is not designed to increase alertness levels but to advise that the operator has responded extremely slow or missed the stimulus altogether. The supervisor will also receive a warning message that will prompt immediate action. It is at this stage that the operator should no longer drive the vehicle without first having a rest/nap/sleep. Until the supervisor acts on the warning message the fatigue monitor will test reactions every minute.

3.5 Faster responses

There are likely to be occasions whereby the reactions to the stimulus presentations were slow for reasons other than fatigue. For example, an operator may have been focussing all of their attention on something within their visual field, thus not seeing the stimulus light immediately. In this case, the next stimulus presentation will be sooner than 11 to 15 minutes apart dependent on the reaction time. If the operator then responds quicker, the stimulus presentations will slowly move back out to the normal 11 to 15 minutes apart. Therefore, the quicker operators react to the stimulus presentations, the fewer tests will have to be conducted on that shift.

3.6 Disabled When Reversing and With Park Brake Applied

In either a reverse movement or when the vehicle is not in motion (stopped, loading or tipping), the fatigue monitoring device will be disabled so that operators are not tested as they may be looking elsewhere. The device's internal clock will continue to run during the period of disablement, however, no stimulus presentations will be made.

3.7 Safety

Operator safety has been given highest priority within all parameters of the trial. The research team has given priority to safety in every step of the development of the fatigue monitoring device, through their skills in ergonomics and human factors. The device is non-invasive and will neither distract nor cause high mental workload for the operators.

3.8 Touch key pad

On top of the reaction box is a receptacle for the 'touch keys' that will be used to identify the operator using the fatigue monitoring device. The use of this will be explained in the next section (Logging onto the device).

3.9 Logging onto the device

Each of the sixteen operators at each site will have their own personal 'touch key'. They will be numbered from 1 – 20 for Burton personnel and 21 – 40 for Mt Owen personnel. Each of the two sites will have four spare keys in case any are lost and will be held by the supervisors. In the event that a spare key must be used, the supervisor will reprogram the system to allow that key to be used.

Each time the operator uses the test vehicle during baseline or test times, they must touch their key onto the receptacle on top of the reaction box. When they do this, it will emit a beep indicating that they have logged on. It will also identify the operator and enable the system to use their personal reaction time data. When they have finished operating the vehicle, they will need to log off by touching the key onto the receptacle again. When logging off, the device will emit three short pip sounds to indicate the trial has finished.

If the operator forgets to log off at the end of operating the vehicle, one of two things will happen. If the next operator is part of the trial and he/she touches their key onto the receptacle, the device will automatically switch to their data. Nothing more will need to be done. If the next operator is not included in the trials (and does not have a touch key – does not log on), the system will continue to work based on the previous operator's data. If this happens, the operator should press the subjective response buttons '1' followed by '5' to disable the device.

4 TESTING THE DEVICE'S CAPABILITIES

4.1 Baseline testing

Baseline data will be determined for each individual who will be operating the haul truck throughout the trial period (total of 32 personnel) in the following manner: Baseline data will be established through periods that are not low in the human circadian cycle (ie. not between midnight & 6 AM, and 1 PM & 5 PM). It will be measured at the start of shifts when the operators are likely to be freshest (eg. 6.30 – 11.30 AM, and 6.30 – 11.30 PM). During the baseline testing, the device will merely record the reaction time information and tests will only be performed every 11 to 15 minutes apart.

4.2 Validation testing

The fatigue monitoring devices will automatically switch to validation testing at a predetermined time (approximately two weeks after installation). At this stage, all testing will be conducted at the full potential of the device. In other words, slow reactions to stimuli will speed up the time between tests and alert the supervisor of likely fatigue.

The fatigue monitoring device will be programmed to function only at specified times throughout the 24 hour day. This was at the request of Thiess Contracting and for the trial period only. During the testing phase, the device will only become active when an operator touches their identification key and operates the test truck between the hours of 12.30 AM to 6.30 AM, and 12.30 PM to 4.30 PM.

4.3 Video monitoring of facial images

Video monitors will be utilised in all haul trucks which have the stimulus-reaction device installed. Video images will be encrypted with the time to allow accurate correlation with reaction measures. The video will record facial images 15 seconds before and 15 seconds after the presentation of the visual stimuli. Each thirty seconds of video evidence can then be monitored to detect periods of long eye closure. Correlational analysis between video evidence and recorded reaction times can determine whether the device is accurately detecting slow reaction responses when the operator is in fact drowsy. Table 2 below shows how the scientific measurements of the device's capabilities will be analysed.

Table 2: Scientific measurements of the device.

Validity	Does the device measure what it purports to measure?	Correlational analyses of video evidence of eye closures at times of slow reactions. Subjective measures of fatigue levels may be useful.
Reliability	Does it measure the same thing consistently?	Correlational analyses of reaction times and warnings for the same subject over repeated periods.
Generalisability	Does it measure the same events in everyone?	Between subjects analyses of reaction times and warning signals.
Sensitivity	How often will the device miss detecting a fatigue event or operator?	Correlational analyses of reaction times and warnings, with video frames of eye closure and subjective sleep states.
Specificity	How often will the device give an alarm that is false?	Correlational analyses of reaction times and warnings, with video frames of eye closure and subjective sleep states.

4.4 Amount of Data to be Collected

The collection of data for the validation of the fatigue monitor will come from 32 operators over a three-month period. This will supply around 3,200 hours of real-time data that places the project close to one of the largest of its type around the world. The largest is said to be the joint US/Canadian 'Driver Fatigue and Alertness Study' where data from around 4,000 hours of truck driving was analysed.

5 BENEFITS TO OPERATORS AND MINING IN GENERAL

When it comes to fatigue, humans are their own worst enemy. The lack of respect for rest and restorative sleep places many people at risk of death or injury when their internal drive for sleep overcomes attempts to continue working. Even those with the best intentions will sometimes suffer from a sleep debt after a late night or a poor quality sleep. This particular technology has the capability to detect low alertness levels early enough to warn both the operator and the immediate supervisor long before personnel are placed at risk of an incident. Used as an adjunct to fatigue education and management, the device will considerably reduce the risk of accidents attributable to fatigue.

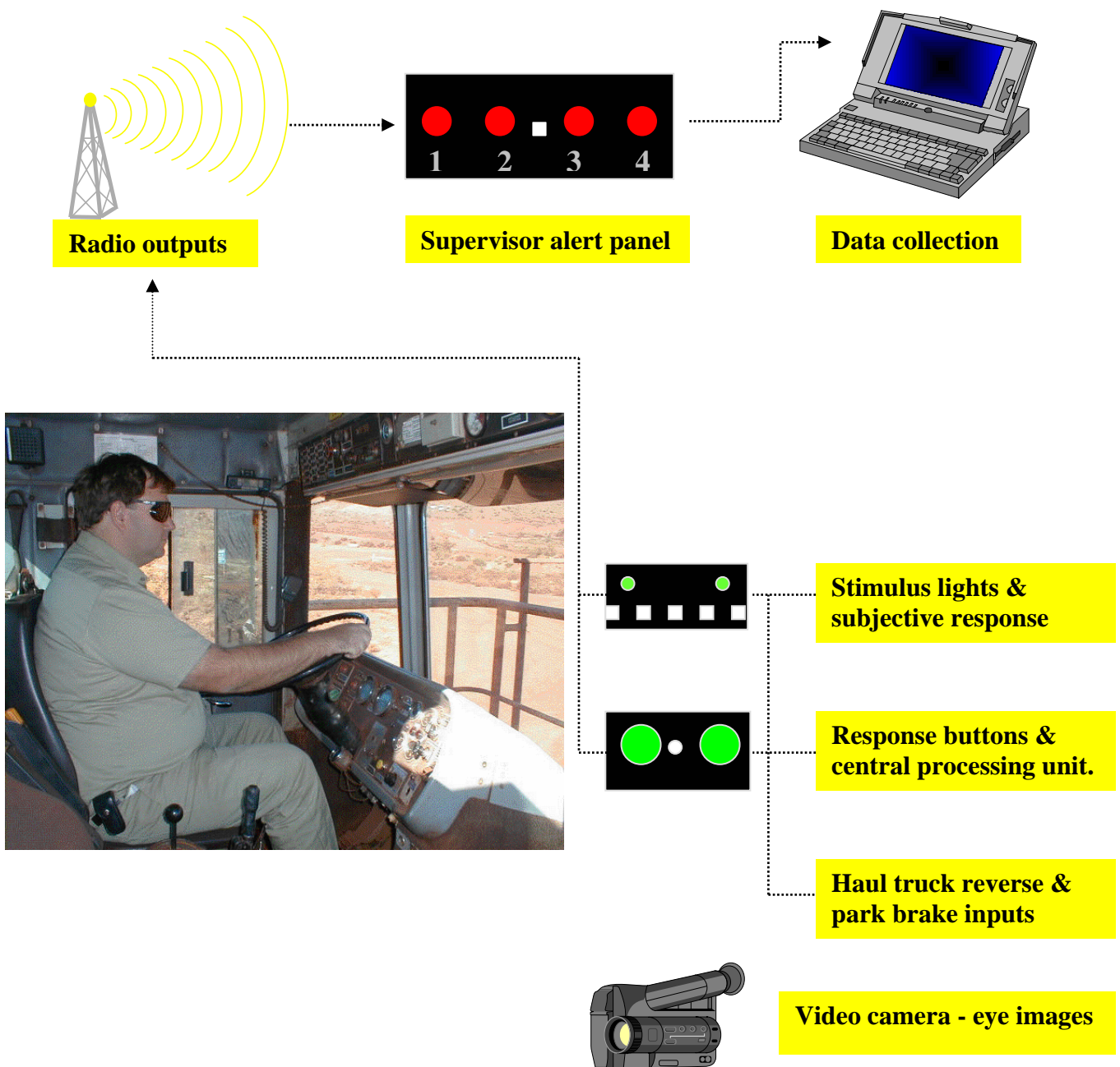
The cost of installing the system into a fleet of haul trucks is likely to be considerably less than the costs (for example) of repairing a haul truck with minor damaged. The cost would also pale in significance against the human costs of injury or death. Further, there would be no ongoing costs associated with the system and the data outputs would be useful for those wishing to analyse data pertaining to high risk work times of the day, rosters and lengths of shifts.

Estimations of costs relating to fatigue related incidents have been shown to be considerable and research into the effectiveness of current fatigue monitoring devices has demonstrated that there is potential to reduce fatigue related incidents. The potential for savings to the industry justifies the continued effort to develop and test new devices. At present, very few fatigue monitoring or fitness for duty testing devices have been scientifically tested. The outcome of this project will be the evaluation of a fatigue monitoring device that is the most appropriate device for reducing fatigue related incidents and accidents for operators of machinery in open-cut mines anywhere in Australia.

6 THE FUTURE OF THE DEVICE

It is envisaged that the scientific testing of the device’s capabilities will highlight the benefits of installing such a system into haul truck fleets. The device can also be adapted to suit other vehicles such as water carts and other mobile plant. Once commercially available, the fatigue monitoring device will be one of very few that will be sold with the support of comprehensive scientific testing. At present most fatigue detection technologies are sold on a promise that they will work and experience has shown that this is not always the case. Data will continue to be collected and the results published as widely as possible. A full report will be presented to ACARP at the end of this year.

Figure 1 below is a sketch of how the fatigue monitoring device will be assembled and implemented in the vehicle in real time. The video camera will only be used during the testing phase of the device. It will not be included in a commercial unit.



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