ARRB PRO-ACTIVE FATIGUE MANAGEMENT SYSTEM

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The ARRB Pro-Active Fatigue Management System utilises fatigue education with ongoing performance management supported by the ARRB Fatigue Monitoring Device. The fatigue monitoring device is a stimulus-reaction device that measures reaction times to stimuli. It establishes a baseline performance measure for each operator and tests against this measure throughout the working shift. Data is produced and can be utilised to establish a performance profile of each individual operator. The fatigue management aspect couples fatigue research, education and training into a system of pro-actively managing operator performance. It commences with training that highlights the most pertinent performance issues in a short session directed at what is relevant to the mining environment. The training provides personnel with materials to take home to conduct their own sleep research for inclusion into their personal fatigue management profile. The information collected from this exercise is added to the first (approx.) 6-weeks of data collected from the fatigue monitoring device that has been installed into haul trucks or other mobile plant. Each operator has his/her data analysed and a performance profile is generated to assist in the management of performance. Countermeasures are discussed where appropriate with each individual. At regular intervals, the data for each personnel is revisited and an updated performance profile developed. This unique system offers a very practical combination of fatigue education, training and feedback support from technology. It takes a risk management approach to fatigue by addressing the issues at a grass roots level.

1 BACKGROUND

Operator fatigue has attracted a great deal of attention over the past two decades. Within this time, numerous technological and managerial solutions have been offered to various industries. The constant highlighting of the issues must surely be having some impact on the workforce, however, positive outcomes are rarely shown. Similarly, although technology abounds, the system that appears to get most usage – the 'dead man's handle' in trains – is said to be far from minimising the risk associated with becoming tired on the job.

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 report (Mabbott, Lydon, Hartley & Arnold, 1999) described several devices that were examined for their implementation into open cut coal mines. Similar research was later conducted for the long distance heavy transport industry for the National Road Transport Commission (Hartley, Horberry, Mabbott & Krueger, 2000). Both reports noted the lack of practical devices available for implementation into environments utilising heavy vehicles in rugged terrain.

2 FITNESS FOR THE ENTIRE SHIFT

Fitness for duty testing is unfortunately limited to the number of times an employee is tested for fitness levels. The usual practice is to test at the start of the shift only. Although some supporters of fitness for duty testing are advocating more tests (eg. at lunch and some other down times), this will often require a trip back to the buildings where the fitness for duty tests are housed. It is hard to argue the cost/benefit of such an action without the necessary validation data to substantiate the action.

Research has shown that the human can (in times of drowsiness) pull together a certain amount of resources to achieve an endpoint if thought necessary. For example, even sleep deprived subjects can perform tasks for up to 15 minutes in duration (Arnold & Hartley, 1998). If people can reflect on periods whereby they felt very tired, they may also recall having smaller periods of feeling reasonably alert. Therefore, when we find ourselves nodding off at the conference, we also find we can 'pull ourselves back together' for short bursts. Electroencephalograms (EEGs) have shown this to be caused by shifts in brain waves. For example, Khardi and Vallet (1995) noticed alpha and beta activity through normal operating conditions, then shifting to alpha and theta activity. The shift coincided with impaired driving. What this means is that when drivers are feeling tired, they might become alert after a while, become drowsy again, become alert again, and so on.

The amount off additional resources that an individual can muster when feeling drowsy will depend upon many variables (eg. time of day, time since last sleep, etc). The basic fact is that if an operator of machinery is feeling tired, he/she is a liability to the company. Research has shown that a simple break will not restore alertness. Lisper, Laurell and van Loon (1976) showed that drivers falling asleep, being woken and given a five-minute break, were asleep again in an average of 24 minutes. A brief nap may be all that is needed to restore alertness for an individual.

3 THE ARRB FATIGUE MONITOR

ARRB Transport Research Ltd. have developed a device that can measure operator alertness levels through the operator's reaction to a visual and audible stimulus. It does this in real-time (while the operator is working) and throughout the whole working shift. It has the capability to acknowledge reductions in alertness levels and allows an intervention strategy to counter the effects of driving fatigued. This is made possible by alerting significant others to the fact that the operator is becoming drowsy.

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. Decisions are a much harder task than simple responses for individuals during periods of tiredness. Therefore, a slower response would suggest a fatigued state.

The stimulus box is approximately 3 cm high and 10 cm wide, located to the left of the steering wheel on top of the dashboard. It contains two stimuli arrows that point left and right. One at a time, an arrow will illuminate (green) and the operator must determine which direction the arrow is pointing. The reaction box houses the main processing unit and two large green heavy duty response buttons. The operator responds to a stimulus by pressing one of the buttons (left or right). The box is approximately 20 cm wide and 4 cm high and is located to the right of the steering wheel on top of the dashboard.

The concept and specifications for the operation of the Fatigue Monitor were relayed to the builder of the device – Romteck Pty Ltd. Romteck engineers worked closely with the ARRB Project Leader to develop the device to make it applicable to the mining industry. It was trialed in three mines, whereby many glitches were taken out of the system and improvements to the devices were born.

Electronically, the Fatigue Monitoring System consists of the following components: 1.) A PC with Romteck communications module, 2.) A talk through repeater (if required) and 3.) A Fatigue Monitoring Unit. These three main components work in unison to make up the complete monitoring system. The Fatigue Monitoring Unit consists of a 'Stimulus' enclosure and a control module. The control module (the heart of the vehicle system) houses a Romteck Delta IV series microcontroller board incorporating a Motorola 32 bit microprocessor. This board controls and monitors all the functions of the vehicle monitoring system. Attached to it are a Dallas Touchkey reader, inputs from vehicle park brake and reversing signal as well as heavy duty response buttons from the front of the unit. It also controls the two stimulus lights (mounted in a separate module) as well as a piezo buzzer. A separate connection to a FSK data radio, which allows data to be routed between the vehicle and the base PC, makes up the last of the in-vehicle system.

The radio unit is generally connected to a 4.5dB UHF whip antenna. The entire system runs on 12V DC. All components are housed in a rugged tamper-resistant enclosure. The stimulus lights are mounted in a separate module that connects to the main module via an umbilical cable.

The in-vehicle system communicates to the base PC via a talk through repeater site. One trial site comprised a Romteck RM1000RR talk through repeater unit. This unit is a 2U rack enclosure and consists of all equipment required for a complete talk through repeater unit including 2 data radio's, a Romteck data switch unit and duplexor. The install is usually complemented with a dipole or co-linear antenna mounted on an adjacent mast.

At the PC end, a Romteck communications module is connected for the purpose of communicating with the PC on a RS232 connection and formatting this information in a suitable manner to send through a data radio unit via the repeater to the remote vehicle units. The communications module consists of a FSK data radio, PC interface and power supply.

3.1 Baseline and Normal Operation

The stimulus-reaction device collects baseline reaction time over 20 tests and analyses the mean and standard deviation of the reaction times. It is also designed to not add reactions slower than three seconds to the baseline. This avoids operators setting up slow baseline times.

The device operates in four defined stages. Under normal circumstances (and the operator is alert) the device will present a light and audio stimulus every 7 to 10 minutes apart. If the operator reacts within one standard deviation (SD) of the baseline mean, nothing else will happen and another stimulus presentation will occur within the next 7 to 10 minutes. Stimulus presentations are random in time and for left and right stimulus light.

3.2 Slow or Wrong Responses

If the reaction to the light stimulus is between one SD and two SD slower than the mean, or if the wrong reaction button is pressed (eg. left stimulus light – right reaction button), the device will automatically reduce the period of time between stimulus presentations. The next presentation will occur within 4 to 7 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 between two SD and three SD slower than the mean, the device will again reduce the time between tests. However, on this occasion the next stimulus presentation will occur within the next 2 to 4 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

Responses to stimulus presentations slower than three SD or completely missed, 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 his/her attention on something within the visual field, thus not seeing the stimulus light immediately. In this case, the next stimulus presentation will be sooner than 7 to 10 minutes apart dependent on the reaction time. If the operator then responds quicker, the stimulus presentations will slowly move back out to the normal 7 to 10 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

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

Operators that will be utilising the fatigue monitor will be issued with a personal 'touch key'. Each time the operator uses the vehicle, he/she must touch the key onto the receptacle on top of the reaction box. When this is done, the device will emit a beep indicating a successful log-on. It will also identify the operator and enable the system to use his/her personal reaction time data. When finished operating the vehicle, the operator 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 testing 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 within the fatigue system 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 truck is turned off, the operator will automatically be logged off.

3.10 Supervisor Warning Messages

In the event that an operator responds in a slow manner, the device will emit a warning message via a radio link to a control/dispatch room. The warning will be shown on a computer monitor that will highlight the warning. In the case of successive warnings, it will rank the warnings in priority. The supervisor (or assigned personnel) should contact the tired operator and discuss possible countermeasures. It may simply be changing crib breaks with other personnel or moving onto a less risky task.

4 THE PRO-ACTIVE FATIGUE MANAGEMENT SYSTEM

The Pro-Active System comprises the Fatigue Monitoring Device together with fatigue education and ongoing management. The fatigue management aspect couples fatigue research, education and training into a system of pro-actively managing operator performance. It commences with a 2-hour training session that does not bombard personnel with information that they will feel they do not need and will not retain. Rather it highlights the most pertinent issues in a short session that will be directed at what is particularly relevant to the mining environment.

The training session leaves personnel with materials to take home to conduct their own sleep investigations for inclusion into their personal fatigue management program. The information collected from this exercise is added to the first (approx) 6-weeks of data collected from the fatigue monitoring device that has been installed into the haul trucks. Each person has his/her data analysed and a performance profile is plotted. A report is generated to assist the personnel to manage their performance. The report will contain advice on practical countermeasures to help manage performance.

Personnel are monitored continuously to ensure the fatigue management is supporting good performance in the vehicles. Once this is achieved, a decision is made whether or not the operator remains using the fatigue monitoring device. At six, nine and twelve months, the data for each operator is revisited and feedback reports will be forwarded to them. Countermeasures will be discussed is required. At 12 months, a report to the mine will be made on the overall performance of the employees and the system as a whole.

The Pro-Active Fatigue Management System saves the mine paying the full cost of using the devices as a leasing arrangement is offered. A cost is charged per system and all maintenance will be carried out by ARRB staff or their contractors. A spare device will be provided so that a quick change in and out can be made and the unit sent to ARRB/Romteck for maintenance. A remote access system allows ARRB/Romteck employees to run diagnostics through the base computer connection. This allows investigation of the working system from the Perth offices.

5 BENEFITS TO MINING

The most immediate benefit will be a reduction in the number and severity of fatigue-related crashes and incidents (fatigue-related crashes are generally more severe as avoidance manoeuvres are not used). The workforce should become healthier if they utilise what they have learnt and performance should increase. Other savings may be realised through operators taking more care of their vehicles (past research has shown that tired operators do not always treat company vehicles as well as they would if they were not tired). Having the ARRB Pro-Active Fatigue Management System in place also supports the legislative requirements of providing a program to enhance ‘fitness for duty’ of employees.

6 SUMMARY

6.1 Originality and ingenuity of the solution

The origins of the project were to determine what practical fatigue management devices were available for use in real-time driving operations in open cut mines. Many practical additions were made to a simple stimulus-reaction device that would present a stimulus and cause a buzzer to sound if it was not reacted to. The ingenuity came from closely working with industry and determining what was necessary to both monitor operator performance and work practically in the mining environment. Several additions were made through responses gained within the three trials.

6.2 Original program

In the initial program, two trials at open cut mines were planned. There were problems with gaining the adequate support at one mine and as luck would have it, some of the equipment was crushed in an accident whereby a dozer reversed over a small vehicle containing a data collection unit. For these reasons, a third trial was initiated to collect additional data. This was very successful in finalising the validation of the device. The Industry Monitor for the Australian Coal Association Research Program (the funding body) responded with:

> *I have reviewed the final report draft and I am pleased to advise, in my capacity as industry monitor, that I am satisfied Stage 3 of this project has been successfully concluded and reported. The project has delivered its stated objective - that being the trial of the fatigue monitor at selected mine sites and determination of its capability to monitor operator fatigue. It was evident that the technology developed by the ARRB, and its application using the device, will monitor fatigue and detect a tired operator.*
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> *I am confident that the experience gained throughout the trial will enable the ARRB Transport Research group to develop a commercial version of the device suitable for the open cut mining industry. I believe the only outstanding issue of any consequence is the possible exposure of alert operators to constant monitoring which if not addressed during commercialisation or implementation, may see a gradual reduced acceptance by operators. The device has demonstrated that it is capable of detecting a tired operator and in this respect offers industry with a means to reduce fatigue related incidents, thereby promoting safe (controlled) operation of mobile mining equipment at all times. This device coupled with the proposed Fatigue Management Program developed by the ARRB potentially offers industry the means to pro-actively monitor operator fatigue and successfully manage this issue.*
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> *I wish to note the enthusiasm and perseverance of Mr Nick Mabbott in leading Stage 3 of this project, often in trying circumstances. Operating mines are not always the most ideal environment to conduct trials of this nature, but the experience gained by both researcher and ACARP representatives has been invaluable in the development, operation and testing of the device. Given the ongoing and committed efforts of the ARRB Transport Research group throughout Stage 3, I have every confidence that they will be successful in their endeavours to commercialise the device.*
>
> ***Robert Spencer*** - *(Industry Monitor for ACARP Project C9032)*

6.3 Occupational health and safety record.

The complete Pro-Active Fatigue Management System has only recently been completed, the most recent development being the fatigue management training package. As such, the occupational health and safety record is somewhat short. During the trials, operators that were detected as becoming tired changed crib breaks with others or changed onto less hazardous work tasks. Performance profiling also allowed one operator to be counselled in his diet and eating regime. It appeared that the operator was getting tired between 8 PM and 9 PM after eating a large three-course meal with his family prior to shift commencement at 6 PM. He has since changed this regime and is performing better. It is expected that a huge safety benefit will be noted by any mine or rail organisation that utilises the Pro-Active Fatigue Management System.

6.4 Benefit to the community

Benefits to the community will be manyfold. The immediate benefit is the early detection of lowered performance of operators of dump trucks in open cut mines. Over the long term, the fatigue management education, together with feedback from the devices, will create a better performance level of operators and bring about healthier lifestyles. This will also impact on the families of the workers. Another major benefit will be an increase in safety on roads whilst operators drive home at the end of considerably long day and night shift operations. This will be due to the operators managing their fatigue and performance more effectively at both work and home. Significant savings to the community will eventually be recognised from reduced accidents and incidents normally attributed to fatigue.

6.5 Cooperation with other disciplines and professions and effective use of industry consultation

The ARRB Pro-Active Fatigue Management System was developed utilising information and experience from psychology, ergonomics and engineering. The ARRB Project Leader for the project is a psychologist with expertise in fatigue management. The device and system concept were developed by him and relayed to Romteck engineers for building. A reasonable amount of ergonomics of the design was necessary as the devices had to be user-friendly in the cabs of dump trucks. Considerable consultation with the mining industry was gained through the trials at three distinctly different mining operations and from the ACARP Industry Monitor. Many other individuals from mining organisations were also consulted regarding the operation of the devices.

6.6 Attention given to the needs of users

Considerable attention was given to the needs of operators that may involved in the Pro-Active Fatigue Management System. The design of the device is such that it is safe, effective and practical to use from an operator's perspective. The management component is conducted by ARRB staff, reducing the need for mining personnel to investigate data and arrive at solutions. This then frees their time to combat other potential sources of injury within the work environment. It also assists to provide the organisation's 'duty of care' for providing safe systems of work.

6.7 Summary

The Fatigue Management Device is one component in the ARRB risk management system, and its main use is to provide feedback as an aid to operator assessment and training, and to allow ongoing monitoring of system performance. It is NOT a stand alone device intended to be used as a "dead man's handle"; that is in a similar manner to the systems used in the rail industry to stop the locomotive if the event that the operator becomes incapable for any reason. The goal of the ARRB system is to prevent situations in which operators experience fatigue related incidents – not to reduce the effect of incidents which occur.

In summary, the package takes a risk management approach which traces back from the immediate causes of fatigue incidents to examine the basic causes and to identify controls which can operate at the level of those basic causes. The resulting system educates supervisors and operators about fatigue, provides base-line data on individual operator's diurnal rhythms, designs strategies for individuals to minimise the risk of fatigue incidents, and provides an ongoing high level monitoring of the performance of the risk management process.

References

ARNOLD, P. K. & HARTLEY, L. R. (1998). It's not just hours of work: Ask the drivers. In HARTLEY, L. R. (Ed.). *Managing Fatigue in Transportation.* Elsevier Science Ltd., Oxford, UK.

FOLKARD, S. (1997). Black times: Temporal determinants of transport safety. *Accident Analysis and Prevention,* Vol 29 (4), pp. 417-430.

KHARDI, S. & VALLET, M. (1995). Drowsiness of the driver: EEG and vehicle parameters interaction. *Proceedings of the Fourteenth International Technical Conference on Enhanced Safety of Vehicles.* Munich, Germany.

LISPER, H. O., LAURELL, H. & VAN LOON, J. (1986). Relation between time to falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway. *Ergonomics,* Vol 29 (3), pp. 445-453.

MABBOTT, N. A., LYDON, M., HARTLEY, L. R. & ARNOLD, P. K. (1999). Procedures and Devices to Monitor Operator Alertness Whilst operating Machinery in Open Cut Coal Mines. Report RC7433 ARRB Transport Research Ltd. Perth, Western Australia.