

EVALUATION OF FATIGUE MANAGEMENT TECHNOLOGIES USING WEIGHTED FEATURE MATRIX METHOD

David J. Edwards,¹ Bill Sirois,² Todd Dawson,²
Acacia Aguirre,² Bill Davis,² Udo Trutschel²

¹Caterpillar Inc.

Peoria, Illinois USA

E-mail: Edwards_david_j@cat.com

²Circadian Technologies Inc.

Stoneham, Massachusetts USA

E-mail: bsirois@circadian.com

Summary: Operator fatigue is one of the most prevalent root causes of accidents, both on the highway and in workplaces where heavy equipment is used and 12-hour shifts are employed, such as in the mining industry. In response to this concern, a growing number of Fatigue Management Technologies (FMT) are becoming available to help maintain operator alertness and performance levels by detecting operator fatigue and interfacing with the operator and/or supervisor to prevent accidents and incidents (Williamson et al., 2005, Barr et al., 2005). In light of the numerous competing technologies, the research community, as well as industry, could benefit from the flexible evaluation tool proposed here. It will assist industries as a whole, and corporations more specifically, in identifying the best FMT solutions for different work and/or driving situations. This project was specifically focused on the needs of operators of heavy equipment in the mining industry, but could also be of value to other like industries where shift work is necessary and maintaining high levels of alertness are crucial for ensuring workplace safety and productivity.

INTRODUCTION

Operator fatigue is one of the most prevalent root causes of earth-moving equipment accidents in the mining industry. While fatigue and alertness is predominantly a people-management issue, there is available technology that can be adapted to assist in the detection of the onset of fatigue, interface with the operator to prevent an incident, and subsequently, allow remedial actions to be taken.

The mining industry has become extremely safety conscious, particularly with regards to fatigue, with companies establishing extensive corporate-wide fatigue management strategies. It is not uncommon for mining companies to provide their employees elaborate living facilities with environmentally controlled sleeping quarters in mandatory noise-free areas for both day and night shift workers, dining facilities with nutritionally balanced meals and recreational facilities including televisions, basketball courts, exercise equipment and swimming pools. Even with the implementation of such employee health policies, mining employees still struggle with the same fatigue-related issues found in other 24/7 shift-working industries.

In light of growing public awareness of the impact of fatigue on both employee health and on public safety in general, shift-work industries including mining, utility providers, medical services, transportation, on-highway transport, rail, aviation, etc. are looking to technology to provide a solution to the fatigue problem. In response, the marketplace is becoming inundated with products claiming to provide the solution to every industry’s fatigue problem. The research literature and scientific community as a whole is not geared towards providing the corporate world with particularly useful guidance when it comes to identifying which technologies are likely to provide any substantive help to industries’ fatigue problems due to the fact that many researchers are becoming themselves purveyors of technologies. It is with this concern in mind that a weighted-feature matrix was developed so that organizations, industries and/or companies could objectively compare fatigue detection technologies with a method that can be adapted to different industry and/or driving situations.

METHODS

Identifying commercially available and emerging technologies

Commercially available products and emerging technologies were identified primarily through web searches, literature reviews, interviews with subject matter experts and a patent search on alertness/fatigue technologies. This process resulted in identifying 35 technologies. Each product or technology was then evaluated based on its current availability, history of experience in the mining industry (past, present or future trials), feasibility of implementation within a heavy mining equipment operator station and the technology’s current stage of development if it was not commercially available. This process narrowed the original 35 technologies down to a much smaller list of 22 products and technologies (Table 1).

Table 1. Final Technology List

Company	Product	Technology
AcuMine	HaulCheck	Lane Deviation
Advanced Safety Concepts	PASS	Head Nodding Detection
ARRB Transport Research	NA	Mental Reaction Time
AssistWare Technologies	SafeTrac	Lane Deviation
Atlas Research Ltd	NOV Alert	Muscle Tone Analysis
Attention Technologies	Driver Fatigue Monitor	Eye Blink Detection
Delphi Corporation	Driver State Monitor	Eye Blink Detection
International Mining Technologies	Voice Commander System	Mental Reaction Time
Iteris Inc	Lane Departure Warning Systems	Lane Deviation
MCJ	EyeCheck	Fitness for Duty System
Mobileye NV	Vision/Radar Sensor	Lane Deviation
Neurocom	EDVTCS	Skin Conductance
Ospat Pty	OSPAT	Fitness for Duty System
Pernix	ASTID	Steering/Machine Movement
Precision Control Design Inc	SleepWatch	Activity Monitor
Muirhead/Remote Control Tech.	Fatigue Warning System	Mental Reaction Time
Security Electronic Systems	Sleep Control Helmet System	Head Nodding Detection
Seeing Machines	Facelab	Eye Feature Monitoring
Sleep Diagnostics	Optalert	Eye Feature Monitoring
Smart Eye	NA	Eye and Head Monitoring
SMI	InSight	Eye and Head Monitoring
Welkin	Nap Zapper	Head Nodding Detection

Gather information on most promising technologies

Once the final 22 technologies were identified, a more thorough investigation was conducted to ensure the evaluators had as much technical information as was publicly available for each of the technologies. Users of these technologies in the mining industry were contacted for input regarding the technology and any outcomes from technology trials if data was available. Additional information was gathered from, but not limited to, the following sources: public domain reports and interviews with users and vendors.

Development of matrix/feature criteria

Through interviews with mining customers and fatigue experts, a list of technology features was created including descriptive, technical and functional criteria. A total of 93 features were selected across 16 categories (Figure 1). Features and feature categories were finalized using input from both the fatigue and mining industry.

1. Focus of technology
2. System capabilities
3. Primary sensor technology
4. Primary measures (eye)
5. Primary measures (behavior/physiology)
6. Primary measures (operator performance)
7. Primary system characteristics
8. System integration requirements
9. Fatigue countermeasure
10. Environmental requirements for technology
11. Data evaluation, recording, reporting methods
12. Validation and system accuracy
13. Technologies integration ability
14. Operator acceptance
15. System data integration, calibration, maintenance and infrastructure costs
16. Technology readiness

Figure 1. Feature categories

Development of weighting and scoring system

A weighting system was developed to allow users of the matrix to rate each feature and a feature category on a 0-10 level of importance of that feature or category. Each category's weightings were then normalized across all categories to ensure categories were equally represented regardless of the number of features in each category. Scoring was based on a 6-point scale (none, potential, possible, low, medium, high) to allow a score of each technology feature based on the degree to which that feature was applicable to the technology or the likelihood that a feature could be incorporated into the technology through additional development. Numerical values were assigned to each score (0.00, 0.10, 0.20, 0.25, 0.75, 1.00, respectively) for purposes of calculating the overall scores for each technology.

Scoring and weighting of each fatigue/alertness technology

To ensure that the scores generated for these technologies were as objective as possible, ratings for technologies were conducted both by the authors as well as by several experts from throughout the fatigue research community from disciplines including optics, occupational medicine, human factors, mining, and transportation research. Experts had no known conflicts of interest with any of the technologies included in the matrix. In addition to providing actual product ratings, the experts were given the opportunity to provide their weightings to the features and feature categories as they deemed appropriate. In addition to the weightings provided by the fatigue experts, input from a major global mining company was provided to produce a set of weightings for the features and feature categories based on mining-specific applications. Following the objective scoring, each expert was given the opportunity to rate each technology subjectively on a simple 1-10 scale, with 10 being the highest rating.

RESULTS

Objective and subjective scores from all experts were combined into a final composite pair of scores (Figures 2 and 3). Products composite scores were influenced by the differing weights applied to them between the general fatigue versus mining-specific weights. Looking at the objective scores for the general fatigue weightings, there appears to be three tiers of product scores. The top tiered products consist of FaceLab, ASTiD, Optalert, HaulCheck, Delphi's Driver State Monitor and SmartEye. Of the top six scoring products, four are eye feature detection systems and two (ASTiD and Haulcheck) are vehicle-monitoring systems. The second tier consists of 12 products. Of these 12, two are eye feature detection systems, four are physiology/behavioral devices (DVTCS, SleepWatch, NovAlert, and PASS), three are mental reaction time tests (Voice Commander, ARRD, Muirhead/RCT) and three are vehicle-monitoring systems (SafeTrac, MobileEye, and AutoVue). The bottom tier of products consists of two pre-shift fitness-for-duty tests (Ospat and Eyecheck) and two head worn, head nod sensors (Sleep Helmet and NapZapper).

When mining industry specific weights are applied, the same top six technologies remain, however, their positions switch slightly. If we used the same tiers of products, then membership of the first tier of six products remains unchanged. The second tier sees significantly more shifting of technologies and finds 2 technologies dropping into the third tier (both lane deviation systems), while two tier three technologies climb into tier 2 (both fitness-for-duty tests). These findings are consistent with the difficulty one would expect to find trying to implement technologies that rely heavily on image recognition of painted roadway markings into an off-road environment where few to no roadway markings exist. Further support for the technology shifts is apparent in that fitness-for-duty tests increased in value with respect to the mining industry, and having closed work sites allows for more controlled pre-shift testing than one might find in more general applications. Of particular importance is the fact that head-worn, head-nod sensors were consistently ranked low by the panel of experts. If the objective is to provide users with valuable fatigue monitoring/assessment regardless of industry or application, this particular technology is not recommended.

Subjective scoring of the technologies demonstrates a clear trend for the expert reviewers towards eye feature detection systems for both the general and mining industry weights. Due to the popularity and preponderance of research funding on methods for automatically tracking percent eye closure (PERCLOS), these subjective scores are not surprising. Further evaluation of the general fatigue subjective scores show that the next most highly rated technologies were those that monitored lane deviation utilizing image recognition. The lowest general fatigue subjective scores were for the mental reaction time and head nod-sensing technologies. In contrast, when considering mining industry requirements, following the automatic PERCLOS detection systems, the same expert reviewers subjectively scored the two lane deviation/steering deviation devices that do not depend on image recognition and then mental reaction time technologies and head nod sensors. Image recognition lane deviation technologies, based on mining industry requirements, were subjectively scored the lowest.

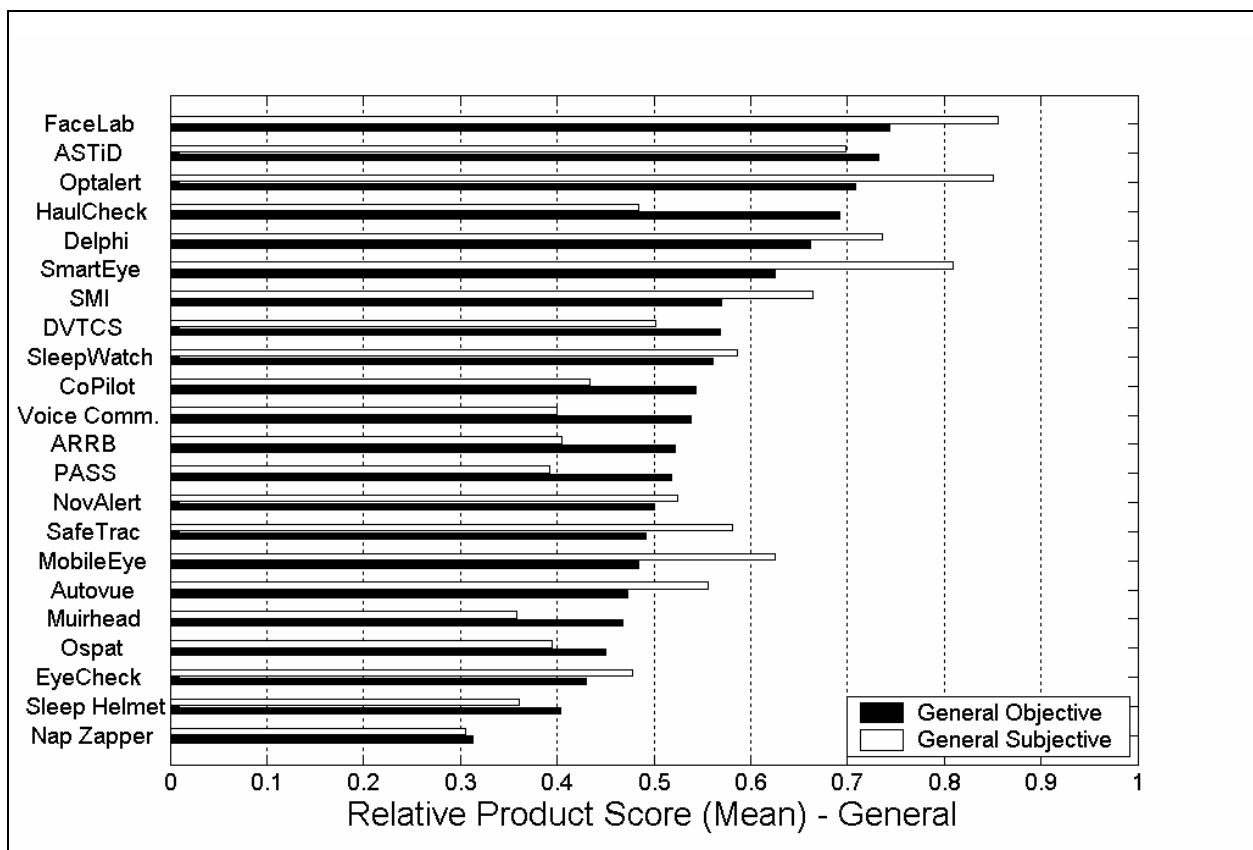


Figure 2. Product and technology ratings with general weights

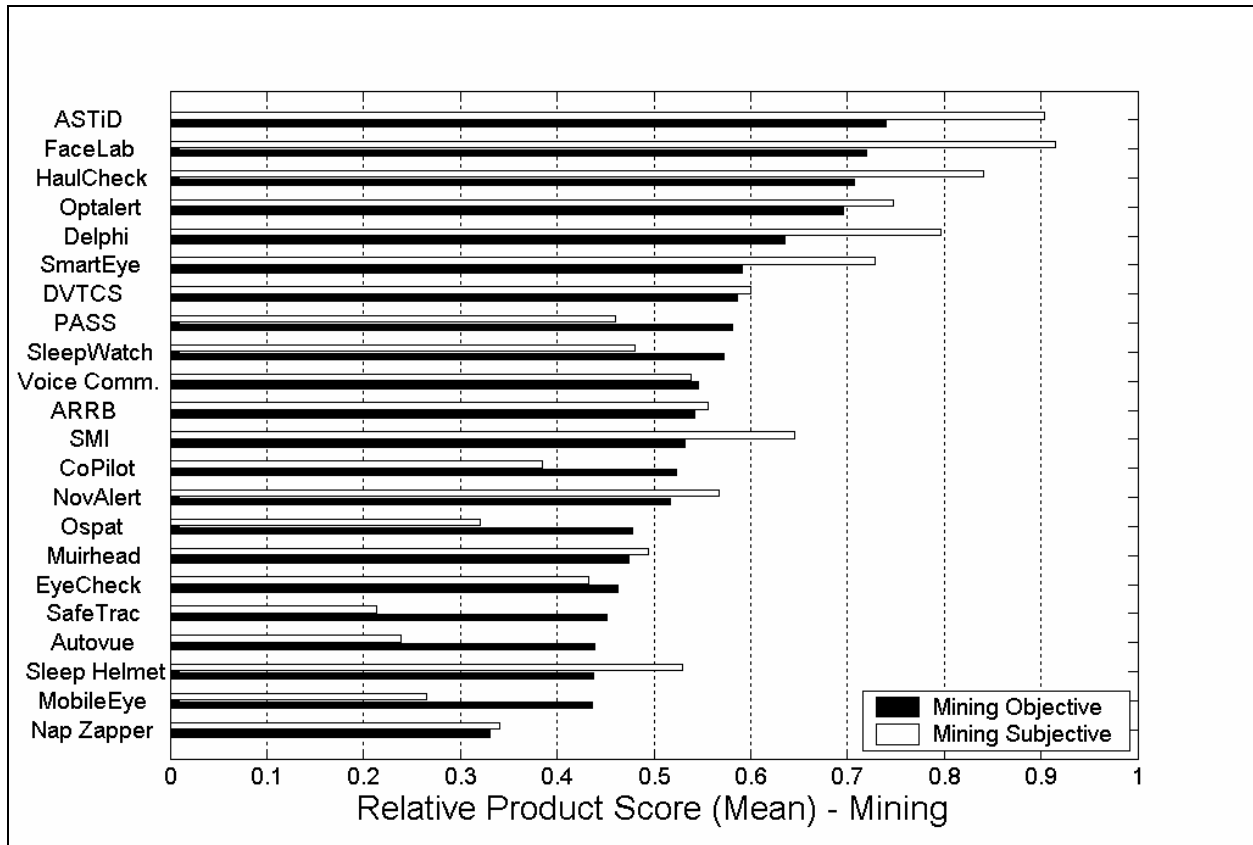


Figure 3. Product and technology ratings with mining industry weights

CONCLUSIONS

The highest ranking products displayed the following characteristics: (1) multiple sensors or ability to process multiple features; (2) multiple means of alerting the operator of impending fatigue, and signaling the supervisors and/or dispatchers; (3) previous validation tests in the field, particularly in rough environments; (4) the capability to be customized to the individual; and (5) required little or no operator input. With regard to the features of user/operator acceptance, devices that focused primarily on the vehicle tended to score higher. Some of the products that focused on the drivers and did not score in the upper rankings were nonetheless promising for the long term. It is important to note that none of the systems could account for all outcomes. As a result, the best solution for managing fatigue might be comprised of a system merging several different technologies.

Comparing the subjective and objective scores using the two weighting systems emphasizes the importance of such a matrix. Were these experts to merely provide their professional opinion on which technologies they were to recommend, their response could be largely biased on the knowledge of their own particular industry and field of technological study. However, when industries outside of the on-highway transportation industry look to fatigue experts or to the scientific literature for advice, not having a way of adjusting the experts' opinion to their industry's particular needs could lead to drastically different and potentially inappropriate

recommendations. This matrix provides each industry a way to leverage the knowledge of the fatigue research community by tailoring it to each industry's specific needs.

This project is significant in that it brought together a wide range of experts from various backgrounds and used the same methodology to objectively and subjectively assess several commercially available and emerging fatigue management technologies. The end result of this collaboration and methodology was not only an objective assessment of the currently available technologies, but it also assessed the merits of emerging technologies that may become available in the near future.

ACKNOWLEDGMENTS

The authors would like to extend their appreciation to the following individuals for providing their expertise in the rating process: Dr. Larry Barr, Dr. Martin Golz, Dr. Richard Hanowski, Todd Ruff, and Dr. Mario Sandoval.

REFERENCES

- Barr, L. et al. (2005). A review and evaluation of emerging driver fatigue detection measures and technologies; *Proceedings from the International Conference on Fatigue Management in Transportation*, Seattle, USA
- Williamson, A., & Chamberlain, T. (2005). Review of on-road driver fatigue monitoring devices. Technical Report, NSW Injury Risk Management Research Centre, University of New South Wales, April (2005).