CONTENT	DETAILS	NOTES FOR COMPLETING THE TABLE
Company Overview	AngloAmerican	Give us a bit of background on your organization.
Project Name	Emissions Based Maintenance (EBM) of diesel engines	Provide a short descriptive title that reflects the example and will capture the readers interest
ICSV Workstream	DPM	Indicate which ICSV workstream the project belongs too (VI, DPM, GHG)
Keywords	EBM, coal mining, DPM	Please provide 4-6 keywords to help make the case study searchable.
Background	A doctoral research student at the University of Wollongong, Australia, undertook a research project to establish the possible reduction in employee exposure to diesel emissions (Diesel Particulate Matter (DPM) and Nitrogen Dioxide (NO_2)) and potential productivity gains when an Emissions Based Maintenance (EBM) programme was introduced at an underground coal mine (intervention site). A second underground coal mine (operating similar diesel equipment as the intervention site) located in the same geographical area was used as a control site allowing a statistical comparison of results between the two operations. EBM consists of maintaining a vehicle to such a level so that the exhaust emissions are as low as can be practically achieved and that all emission control technologies are operational. An EBM programme requires regular monitoring and interpretation of the exhaust emissions for gaseous and particulate pollutants both at the manifold of the engine and after the last control technology. The study was undertaken by Mrs Jennifer Hines* and supervised by Professor Brian Davies*, Doctor Vinod Gopaldasani* and Doctor Casper Badenhorst*	Provide a short, focussed summary that considers the following: i. What was the issue or starting point? ii. What did you want to achieve? iii. How was this supported?

The Problem	Several researchers (Waytulonis 1992, Davies 2004) have established that an EBM programme can reduce exhaust emissions, and thus worker exposure to those exhaust emissions, however no scientifically designed study had quantified the reduction in worker exposures, or the productivity gains achieved as measured by using less fuel. While the available research highlighted that potential gains could be made in employee exposure reduction and fuel reduction, a lack of a comprehensive scientific study made it difficult to sell the concept of introducing EBM to maintenance engineers with high fleet availability demands and limited workshop resources. To provide evidence that the introduction of an EBM programme would in fact be beneficial in multiple ways, a rigorous study was undertaken as detailed below.	Set the scene with background information and relevant facts. Be sure to: iv. Introduce the problem. v. Explain why the problem is important and how it was identified. vi. Outline any assumptions (if any).
Steps Taken	EBM is a process by which diesel engines are maintained to not only original equipment manufacturer (OEM) requirements but also have additional maintenance as required so that raw exhaust emission levels are reduced to as low as practicable. To do this there was a need to obtain regular emissions data (usually every 250 hours) sampled in a consistent manner to make the comparison of pre and post maintenance data more informative. The sampling was carried out at the manifold (or as near the manifold as was possible) and after the last control technology, usually the disposable diesel exhaust filter (DDEF) in the tailpipe. The manifold results were used to help identify any underlying engine faults while the manifold and tailpipe results were used to evaluate the performance of the control technologies fitted to the vehicle. All sampling was done using a mixing unit to eliminate errors associated with sampling probe insertion (Davies 2013) and a water trap to reduce the exhaust moisture content specifically after exhaust water conditioning baths used for spark suppression. Analysis at both sample points was undertake for carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2) and oxygen (O_2) using a portable gas analyser and DPM as EC using a portable diesel particulate analyser. The instrumentation was selected based on level of accuracy, ease of use and workshop applicability as both instruments were to be used by the site workshop personnel, not researchers. The devices selected for this project were the ECOM EN2F gas analyser and the ERP Engineering Pty. Ltd. ChekMate™ diesel particulate analyser (Figure 1).	Summarise what was done (activities/ interventions/inputs), where, by whom, for whom?

Site personnel were trained in how to load an engine for sample collection and the use of the instrumentation including software. Shift personnel at the intervention site had hands on training until the researchers were confident that they could accomplish the sampling and analysis tasks. From this point all engine exhaust data was collected by site personnel (Figure 2).

	 Exhaust samples were collected by the researcher at the control site so as not to influence the outcome of the exercise (i.e. no change in normal practice). Following the introduction of the sampling and analysis instrumentation specific “target values” for each contaminant were developed for each engine type and used to assist in the identification of atypical engines. Any vehicle with an atypical exhaust analysis was investigated to establish the cause and remedial action undertaken at the intervention site. No such action was taken at the control site. Personal exposure samples were also collected on designated underground workers using accepted occupational hygiene monitoring techniques, and these were analysed for EC and NO_2 by external laboratories. Samples were collected at both the intervention and control sites at the beginning of the project, mid-point and at the end. All personal exposure data was reported to management and workers and the extensive data package statistically evaluated. Fuel usage at the intervention site was manually monitored as it was a manual fill and recording system. Data collection was undertaken on 40 diesel vehicles (23 PTVs and 17 LHDs) over a 15-month continuous period at the intervention site to embrace normal weather and operation conditions during an operational year.	
Results	The implementation of an EBM programme resulted in a significant reduction (47%) in worker exposure to DPM (measured as the percentage change in the median EC concentration from the baseline starting point to the end of the data collection period) at the intervention site whereas the DPM worker exposure levels increased (58%) at the control site (Figures 3a and 3b). The reduction in DPM exposures at the control site between the mid-point and final data	What were the results of the intervention, focusing particularly the significant or unique results?

collection points can be attributed to the control site initiating their own intervention strategy independent of the research team.

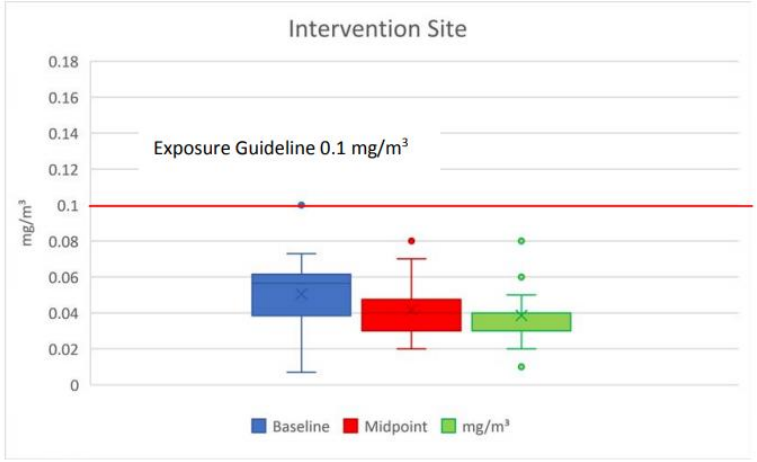

Figure 3a – Workplace DPM (EC mg/m^3) exposures at intervention site

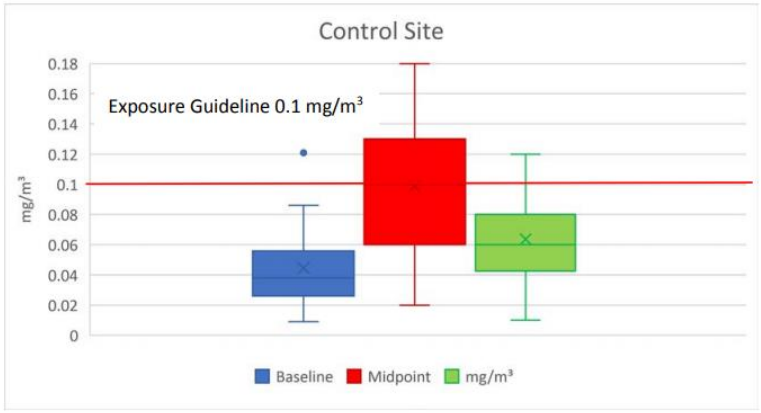

Figure 3b – Workplace DPM (EC mg/m^3) exposures at control site

Workplace exposures for NO_2 at the intervention and control sites are shown in figures 4a and 4b. The increase in NO_2 exposures at the intervention site can be attributed to the site retuning engines to meet their statutory requirements however the increased exposure is within the current Australian and ACGIH exposure standards.

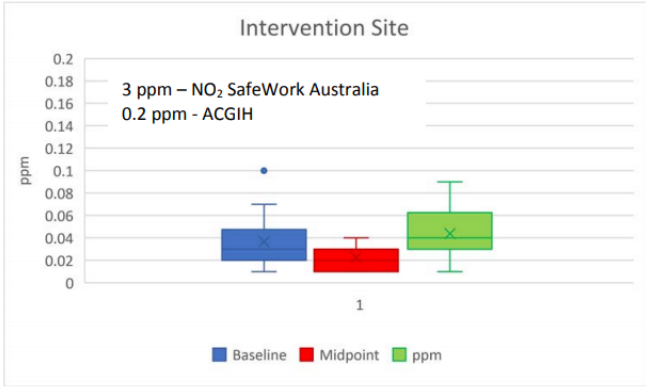

Figure 4a – Workplace NO_2 (ppm) exposures at intervention site

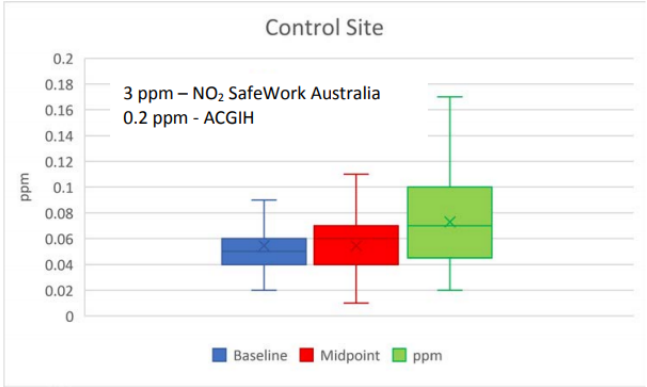

Figure 4b – Workplace NO_2 (ppm) exposures at control site

	In addition to the improvement in worker exposures a significant productivity gain in reduced fuel usage for PTV's and LHDs was attained by the intervention site Table 1– Productivity gain from EBM programme at intervention site	
Challenges & How they were met.	While the research project confirmed previous beliefs there were several aspects when implementing the EBM programme that could be improved. These include: 1. Review and interpretation of exhaust emission data more frequently. The amount of data generated from a site EBM programme is significant and for maximum benefit this needs to be reviewed and interpreted regularly. This was not always possible in the research project which meant some maintenance issues may have gone unattended for a short period of time. A major project is planned to computerise the interpretation and management of data which should overcome this issue. 2. The tracking of exhaust emission results and the subsequent maintenance actions needs to be more rigorous. The proposed computerised system should improve this important aspect of an EBM programme. 3. The monitoring of fuel usage is critical if a true assessment of productivity gain is to be established at the site level. Given this, it is essential that an appropriate fuel management system be in place so that the daily consumption of fuel by each vehicle can be monitored accurately.	Focus on what challenges or difficulties were encountered and what you did to overcome them.

Percentage Fuel Savings			
Vehicle Type	Running cost per annum	Cost savings per annum	% savings
Personnel Transporter	$287,511	$20,748	**7**
Load Haul Dump	$431,374	$86,275	**20**
TOTAL	**$718,885**	**$107,023**	**15**

Beyond Results	This project has proven that when an EBM programme is embraced by mine management and workshop mechanics it is an effective tool in reducing employee workplace exposures to DPM and provides a 8 ©2019 University of Wollongong substantial productivity gain. The project has also highlighted several issues that impact on the sustainability of such a project and thus the next step is to develop appropriate measures to make the introduction of EBM programmes into mining operations simpler and sustainable. To this end the University of Wollongong and its mining industry research partners are working on a research project to develop a global EBM computerised management system. The proposed system will input engine emissions data from sites at any location in the world with Wi-Fi access, which will then be interpreted at a central server location with an instant response to the site as to compliance re target values and possible maintenance issues. The system will also enable scheduling of exhaust monitoring, profiling of the same type of engines (or individual engines) and include an alert mode if no action is recorded showing that issues have been addressed. With appropriate access, such a system could enable the tracking of exhaust emissions from any diesel fleet in the world without being present onsite	Are the results mentioned above sustainable? Why or why not?
Lessons Learned	1) A reduction in worker exposure to DPM (measured as the percentage change in the median Elemental Carbon (EC) concentration from the baseline starting point to the end of the data collection period) of approximately 47% against an increase of 58% at the control site over the same period. 2) A reduction in diesel fuel usage of 7% for light duty personnel transportation vehicles (PTVs) and 20% for load haul dump (LHDs) vehicles. At the control site, workplace exposures to both DPM and NO_2 increased.	What lessons were learned: programmatic, technical, financial, process, etc?
Further Information	Mrs. Jennifer Hines, University of Wollongong, Email: jenhines@uow.edu.au or +61 408 168 410 - References: Davies B, 2004; The control of diesel particulates in underground coal mines, PhD Thesis Victoria University, 2004 - Davies B, 2013; Calibration of Portable Raw Exhaust Diesel Particulate Analysers, Coal Services Health and Safety Trust project 20621, 2 August 2013 - Waytulonis R.,1992; An overview of the effects of diesel engine maintenance on emissions and performance, United States Bureau of Mines Publication IC 9324, September 1992	Please provide us with details of any useful weblinks, links to video, references in CSR reports, news articles or research papers. .

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