The International Journal Of
Mineral Resources Engineering, Vol. 12, No.3 (2007) 179-202
© Atilim University Press

A COMPANY-PERSPECTIVE COST ANALYSIS OF THE PERSONAL DUST MONITOR (PDM)

W.R. REED[a]
J.C. VOLKWEIN[a]
G.J. JOY[a]

Abstract

The personal dust monitor (PDM) is a new coal mine respirable dust sampling instrument that has the ability to provide accurate end-of-shift and real-time respirable dust exposure data. A hypothetical cost comparison analysis of the PDM with the current MSHA-required coal mine dust personal sampling unit (CMDPSU) was conducted. Some simplifying assumptions were made to create hypothetical cases for analysis. This analysis was limited to respirable dust sampling of one designated operator (DO) and one designated area (DA) for one mechanized mining unit (MMU) which operated one shift per day. Only sampling intervals of the minimum sampling as required by federal regulations and continuous sampling were analyzed.

This cost analysis from the company perspective is only one part of an overall cost/benefit analysis that should be conducted at a later date. In this analysis, company-associated costs were examined for both sampling systems. Results show that the PDM, while it has high initial costs of approximately $12,600, may be a cost-effective sampling system for measuring coal mine respirable dust. The estimated present worth cost of conducting the minimum required dust sampling over a five-year life ranges from $5,850 to $19,000 for the CMDPSU, with the higher present worth cost including costs of potential violations incurred. For the PDM, the comparable present worth cost is $14,900 to $19,300, with the lower present worth cost representing a lower capital cost of $8,150 per unit if more than 850 units are produced per year, while the higher present worth cost reflects the result with the higher $12,600 capital cost.

1. Introduction

Coal Worker's Pneumoconiosis (CWP) is a disease which affects coal miners and is caused by the inhalation of excessive levels of respirable coal mine dust. It is exacerbated through continued exposure to high levels of respirable coal mine dust and can be fatal. There is no cure for this disease except through its prevention.[1] Progress has been ma-

[a] Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, P.O. Box 18070, Cochrans Mill Road, Pittsburgh, Pennsylvania 15236-0070, USA.

de through the use of regulations and research to reduce the number of deaths caused by CWP, from a high of over 3,000 deaths per year in 1972 to approximately 1,000 deaths per year in 1999[2]. This decrease can be attributed to the safety enforcement efforts of the Mine Safety and Health Administration (MSHA) through its dust sampling program with the coal mine dust personal sampling unit (CMDPSU). However, from 1990 to 1999 there were still approximately 15,036 deaths attributable to this disease[2].

Current research aimed at reducing CWP in miners, conducted through a partnership with government, industry, and labor, has produced a real-time respirable coal mine dust measurement system, the Personal Dust Monitor (PDM). This instrument has the potential to reduce CWP by providing real-time monitoring of coal mine dust levels, which can enable the miner and companies to prevent overexposure[3,4,5]. Ultimate documentation of its effectiveness will depend on results of its use on a continual basis in MSHA's dust sampling program in underground coal mining.

For the PDM to be implemented and accepted as a standard sampling system, its cost must be reasonable. Therefore, a hypothetical cost analysis from a company perspective is presented to analyze cost factors involved in the potential implementation of new real-time dust monitoring in coal mines. This is only one part of an overall cost/benefit analysis of the impact of this new respirable dust sampling technology to mining. A fuller analysis would examine factors such as the hiring and training costs of new workers to replace employees with CWP, the lower productivity of personnel with declining lung function, the loss of earnings for worker and family, the quality of life issues associated with CWP, and the benefits of reducing CWP, such as reduced health care costs to society, to government, to individuals, etc., along with associated costs from other perspectives.

This cost analysis was performed by comparing the PDM with the existing CMDPSU required by the Mine Safety and Health Administration (MSHA). The CMDPSU utilizes a sampling device consisting of a 10-mm nylon cyclone, 37-mm diameter 5-micron pore size membrane filter, 0.9-m length of 6.4-mm internal diameter flexible tubing, and an MSA (Mine Safety Appliance Company, Pittsburgh, PA) Escort ® ELF pump operating at a flow rate of 2.0 liters/min. The CMDPSU does not provide dust concentrations instantaneously. The 37-mm filter must be mailed to MSHA for analysis which results in a delayed response for respirable dust concentrations[6]. MSHA assumes the costs for analyzing these filters. The PDM is a new system for dust sampling which consists of a self-contained dust sampling system that displays a real-time instantaneous readout of the respirable dust concentrations to which the miner is exposed. The filters used in the PDM do not require analysis for respirable dust concentrations, therefore there is no filter analysis cost to MSHA with this system. Exposure results would be available to MSHA through electronic data files generated and protected by the PDM.

The evaluation of the PDM and CMDPSU uses present worth calculations to determine the costs. Only costs related to both sampling systems were evaluated in this analysis; no benefits which may accrue from the reduction of CWP for either sampling system were included. This analysis was conducted using the employer's perspective for the determination of the costs of both systems. The company perspective was chosen because companies, along with the government, currently take on part of the cost of sampling and will most likely continue to bear these costs in the future. Companies are concerned about using the PDM system because of its initial high cost and its perceived high operating costs.

This analysis will serve to quantify expressed concerns that the PDM is "too expensive." It will also help promote the continuing obligation of all parties involved—industry, labor, and government-to reduce respirable coal dust exposure to miners, which will be a benefit to all by providing cost information for the different sampling regimens. Other analysis perspectives, such as the economic impact of the PDM from a societal perspective, which will include the benefits accrued from the reduction of CWP, will be conducted at a later date.

The cases presented in the following evaluation are hypothetical—envisioning a wide range of potential uses of the PDM. They were not used in the promulgation of the current MSHA respirable dust sampling procedure and are not presented to propose a particular method of use for the sampling systems. Additionally, they are also not representative of all possible cases but are used for evaluation purposes only and may not necessarily be comparable to actual situations. They should not be construed to be predictive of what may occur when a PDM is put into operation nor should they be interpreted to favor one case over another.

In this evaluation, comparisons were based upon the current enforcement requirements of MSHA. Thus a brief review of the MSHA sampling procedure is required in order to understand the process of the analysis. It is assumed that the rules for dust sampling will accommodate the PDM as an acceptable substitution for the CMDPSU.

2. Regulatory Respirable Dust Sampling Procedure

Figure 1 shows a schematic of the procedure that a company must perform to complete the respirable dust sampling required to satisfy the MSHA regulatory requirements. Five respirable dust samples are required to be obtained on consecutive shifts from the designated occupation (DO), and at least one sample from the designated area (DA) of each mechanized mining unit (MMU) for each bimonthly period throughout the year.[7] These samples are then mailed to MSHA which analyzes the filters to determine the dust concentrations. If these samples do not exceed the respirable dust limit, then no more sampling is required until the next bimonthly period. If the average of the samples for the DO or the sample for the DA exceeds the respirable dust limit then a citation is generally given and an abatement process is started, which commences after the dust exposure event has occurred. This process requires resampling and possibly the submission of a ventilation plan. The ventilation plan is a document produced by the mine operator outlining the procedures that will be followed to meet the requirements for ventilation and dust control[8].

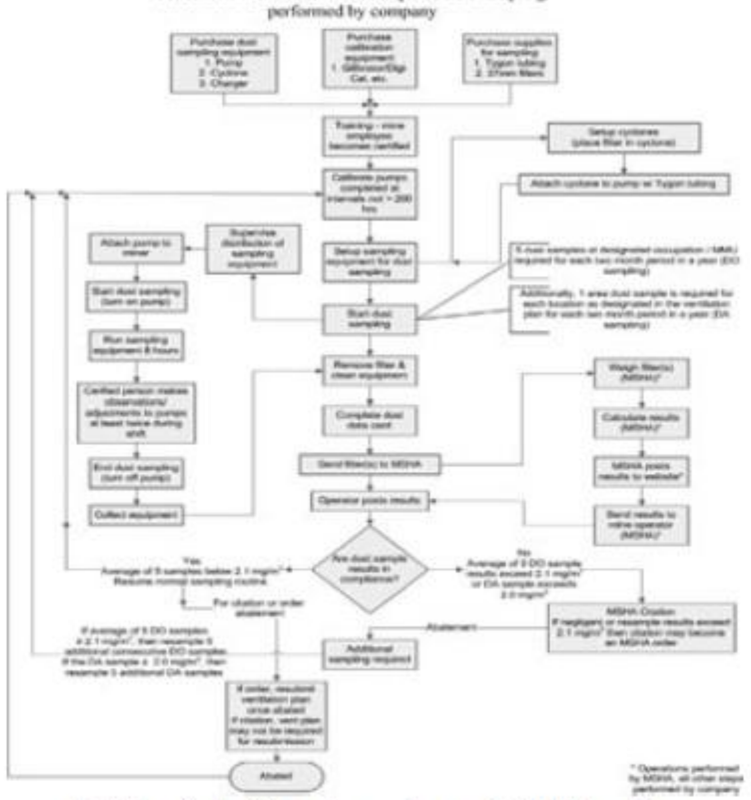

Fig. 1. Schematic of respirable sampling procedure as required by MSHA regulations.

Based upon the circumstances surrounding the exceedance, the citation may be issued as an order. Examples of circumstances causing an order to be issued include but are not limited to an exceedance of the respirable dust limit during the citation abatement process, the inspection history of the MMU, or negligence on the part of the operator. In those cases where an order is issued, all personnel are withdrawn from the MMU and no work can be completed except for work required for abatement of the order.[9] Additionally, resubmission of a ventilation plan is required.

The citation abatement process requires resampling of the DO or DA, whichever location was cited. If the average of the five DO samples is greater than the 2.0 mg/m^3 standard (if silica is present then the standard is reduced to 10 divided by the percent silica determined from the samples), then five additional samples of the DO must be taken on consecutive shifts. If the DA sample is greater than the standard, then five more samples of the DA must be taken. Once these samples are determined to be below the respirable dust standard, then the citation will be abated. Submission of an updated ventilation plan will depend upon the circumstances regarding the overexposed samples and may not be required[9].

An order abatement process also requires resampling of the DO or DA. Additionally, the ventilation plan must be updated and resubmitted showing the changes made to ensure compliance to the respirable dust standard. During an order, the MMU is not allowed to operate except during the abatement process to demonstrate that the proposed changes to operating procedures will ensure compliance to the respirable dust standard. To abate an order, the operator must propose corrective actions (operational, ventilation, etc.) to MSHA that will achieve compliance of the respirable dust standard. MSHA will then examine the proposed corrective actions to determine their viability. If MSHA deems the proposed changes as viable, then production will be allowed to proceed in order to resample the DO or DA. Re-sampling of the DO will consist of five samples taken on consecutive shifts. Re-sampling for the DA will also consist of five samples. Once these samples are determined to be below the respirable dust standard, then the order will be terminated and the operator will be required to submit a new modified ventilation plan showing the changes made[9].

3. PDM and CMDPSU Evaluation Method

The cases used to evaluate the CMDPSU and the PDM are listed as follows:

(1) The CMDPSU with minimum required sampling and no violations.

(2) The CMDPSU sampling continuously for one shift/day with no violations.

(3) The CMDPSU with minimum required sampling out of compliance every other bimonthly sampling period (three violations per year).

(4) The CMDPSU with minimum required sampling out of compliance for every other sampling period and every third violation initiating an order.

(5) The PDM with minimum required sampling and no violations using the high cost PDM.

(6) The PDM with minimum required sampling and no violations using the low-cost PDM.

(7) The PDM sampling continuously for one shift per day with no violations using the high-cost PDM.

(8) The PDM sampling continuously for one shift per day with no violations using the low-cost PDM.

The PDM cases are divided into a high-cost option and a low-cost option. The high-cost option uses $12,600 as the unit cost of the PDM. The low-cost option uses a PDM cost of $8,150 per unit. The different costs are based upon the varying market for the PDM which is difficult to predict at this time. Should sales exceed 850 PDM/year, then the low-cost option becomes viable.[b] The viability of the low-cost option is based

[b] Rupprecht, Erich, Pricing of PDM and Filters. E-mail to Ford, Thimons, & Volkwein. (East Greenbush, NY: Thermo Electron Corporation, March 10, 2006).

on the number of underground coal miners in the United States (approximately 39,000[c]), and the current draft language of the proposed S-Miner Act that specifies use of a PDM by each of these miners.[d]

There are many other different scenarios that could be conceived for this cost analysis. These cases were chosen because they represent a wide range of potential outcomes. Sampling continuously for one shift per day was selected for evaluation as it has been proposed that the PDM could be used on a continuous basis. While it is understood that the CMDPSU would never be used on a continuous basis as would the PDM, this situation has been included for comparison purposes. The cases which incur three citations per year using the CMDPSU represent a realistic scenario as seen from a review of dust-related violations from MSHA's underground coal mine statistical database. With the number of operating mines varying from 642 to 777 through the time period of 2001-2004, statistics show that, for dust-related violations, approximately 11-20% of these mines averaged three violations per year, while 47-55% incurred at least one violation per year.[e] Case 4, which receives the MSHA order after three violations, is a possible realistic worst-case situation, albeit rare. During the years 2000-2005, there were approximately 112 dust- and ventilation-related orders issued to mines.[f] This averages approximately 22 orders per year, which amounts to 3% of the mines receiving an order per year. Additionally, best-case scenarios, with no violations per year, are also reviewed to allow for comparison of a variety of possibilities.

It is recognized that proper maintenance of the ventilation plan should ideally eliminate the possibility of citations. Nevertheless, dust-related citations are still incurred throughout mining operations. It is suggested that the cause of many of these citations could be due to the inadequate informational feedback on dust concentrations of the current CMDPSU. To reduce the complexity of this evaluation, the end result of improper ventilation or dust controls leading to the citation or order was used as the metric rather than attempting to predict the cost of maintaining a proper ventilation system.

The cases that acquire citations while using the CMDPSU incur monetary charges of $387.85 per violation, which is the average amount as determined from an examination of an MSHA database for underground coal dust-related violations.[g] The MINER Act of 2006 provided MSHA the opportunity to revise the penalties assessed for violations. While this revision may increase the cost of citations, for convenience the historical data for dust-related citations will be used and these increases will not be incorporated into this analysis.

The cases using the PDM as the sampling system do not incur any MSHA violati-

---

[c] National Mining Association, "Mining Industry Employment in the United States by Sector, 1985-2005." Website: www.nma.org/statistics/pub_mining_employ.asp Last accessed August 2007.

[d] Library of Congress, H.R. "2768 S-Miner Act, Section 7." Website: http://thomas.loc.gov/cgi-bin/query/F?c110:1:./temp/~c1104YxQTn:e50516: Last accessed August 2007.

[e] Joy, J., NIOSH's Division of Respiratory Disease Studies informational analysis of MSHA's underground coal dust-related violation database, (Unpublished, 2006).

[f] Ibid.

[g] Joy, J., NIOSH's Division of Respiratory Disease Studies informational analysis of MSHA's underground coal dust-related violation database, (Unpublished, 2005).

ons. This condition of no violations for the PDM is used for comparison purposes only. It may seem an unrealistic condition, but the real-time readout of the PDM should allow the wearer to know when his or her exposure to respirable dust is approaching the respirable dust standard (2.0 mg/m^3), thereby eliminating the time delay that occurs with the CMDPSU. When exposure approaches a critical point, then adjustments can be made to prevent overexposure to respirable dust while on shift, therefore reducing the possibility of a dust violation when using the PDM. In contrast, the time delay of obtaining results for the CMDPSU always allows for the possibility of incurring an overexposure violation, because the operator may not realize that adjustments could be made to prevent the overexposure.

The adjustments being considered are those that can be completed incidentally or without excess cost during the shift e.g., minor adjustments to the ventilation system that can be made easily but may be overlooked during production operations. The oversight occurs because there is no instantaneous feedback with the CMDPSU. If these minor adjustments were to be completed, then a reduction of the respirable dust concentrations would occur, when otherwise without the repairs, the dust concentration would continue to rise. These adjustments do not include major changes to the ventilation system that are typically part of the MSHA approved ventilation plan, used in either sampling scheme, which would be noticeable when using either sampling system and would contain higher costs and be more time consuming in nature in that they may interfere with production operations. Such adjustments are treated to be equal in nature with either sampling system and are not included in this cost evaluation.

Each of the cases is analyzed using a five year life. This time frame was derived from discussions with MSHA personnel who stated that the pumps used for the CMDPSU had a five-year life.[h] Discussions with personnel at Thermo Electron Corporation produced a document which showed that Thermo Electron Corporation is willing to offer extended and expanded warranty programs for durations as long as seven years.[i] Other discussions with Thermo Electron Corporation personnel also indicated that a five-year life for the PDM was reasonable.[j] Additionally, it was presumed that the life of the pump would not be affected by the frequency of use.

Battery life was another point of consideration for both systems. The PDM contains two batteries, one for the cap lamp and the other for operating the PDM. The PDM cap lamp battery was stated to have a five-year life, while the life of the PDM operational battery was stated as having a minimum three-year life with the expectation of lasting five years depending upon usage.[k] The battery life for the CMDPSU is listed as approximately 300 charging cycles which corresponds to 300 days of continuous use.[10]

---

[h] Ford, R., Mine Safety and Health Administration, "Personal Communication." March 23, 2006.

[i] Thermo Electron Corporation, "Service Offering Overview." (East Greenbush, NY: Thermo Electron Corporation, March 24, 2006).

[j] Dunham, D., Project Engineer, Air Quality Instruments, Environmental Instruments Division, Thermo Electron Corporation, "Personal Communication." March 24, 2006.

[k] Dunham, D., Project Engineer, Air Quality Instruments, Environmental Instruments Division, Thermo Electron Corporation, "Personal Communication." March 24, 2006.

From additional discussions with NIOSH technicians and the amount of sampling required for each case, three years was considered to be a good approximation of battery life for the CMDPSU. Therefore, battery maintenance was not considered in this evaluation as the PDM cap lamp battery will last five years, equivalent to the time frame used in the evaluation, and the CMDPSU and the PDM operational battery life were considered to be three years, with replacement costs being equivalent for both systems.

The 4% annual interest rate used in the analysis was based on the interest rate of the 13-week U.S. Treasury bill for the week of 01/03/06.[11] Since there are no incomes generated from the use of either sampling system in this evaluation, the interest rate would be based upon either the opportunity cost of investing the cash used in the sampling systems, in an investment vehicle or on the prime lending rate as the cost of capital. The sampling systems were low cost compared with other high capital cost mine equipment. As a result, these costs would most likely be paid on a cash basis. Therefore, the opportunity cost of investing the cash was used instead of the prime lending rate. The interest rate of T-bills was used in this evaluation because they represent a guaranteed short-term rate of return.

The process of conducting sampling follows the schematic diagram in Figure 1. The cost of the PDM[l] and CMDPSU are shown in Table 1.[12] The purchase price of the PDM includes the charger and software required for operation.

Table 1. Cost of equipment for PDM and CMDPSU.

	PDM	CMDPSU
Sampling Equip.	$12,600.00[1]	$1351.19[2]
Filters ($/filter)	$8.00	$16.49
Factory Calibration $/year	$1,000.00	N/A

N/A –Not applicable

[1] Includes the sampler, charger, software, and an initial supply of 20 filters. Low-cost option uses $8,150 per PDM based upon production of PDM units (>850 units/year) by factory.

[2] Includes sampling pump, 10mm cyclone, Tygon tubing for connections, cap lamp, and an initial supply of 10 filters

The PDM also includes a cap lamp which is not an available feature in the CMDPSU. There is a year-end PDM calibration required, to be completed by the factory. Based upon possible service contracts to be offered by the manufacturer, a best estimate is considered to be $1,000.00/year with the unit being returned to the factory for calibration once during the year.[m] No costs associated with returning the PDM to the factory are included and in such an event a replacement PDM would be available for use from the manufacturer. The CMDPSU consists of a sampling pump, 10 mm cyclone, and Tygon" tubing (for connection of the cyclone to the sampling pump). The cost of a cap lamp and charging system that would have to be purchased for the CMDPSU are $482.19.[12] This

[l] Rupprecht, Erich, Pricing of PDM and Filters. E-mail to Ford, Thimons, & Volkwein. (East Greenbush, NY: Thermo Electron Corporation, March 10, 2006).

[m] Dunham, D., Project Engineer, Air Quality Instruments, Environmental Instruments Division, Thermo Electron Corporation, "Personal Communication." March 24, 2006.

cost is included in the CMDPSU cost. Training is required for both systems buts its cost is not considered in this analysis because it is considered equal for each. The PDM also requires the use of a personal computer to program and download information. The cost of a personal computer was not included in this analysis because it is assumed that the mining operations have access to an existing computer on-site. A cost of $100 per year is used as the cost to replace the Tygon" tubing as the sampling system is used throughout its life. Tubing costs for the PDM were not considered because the tubing is part of the cap lamp cable. Calibration equipment, required for both the CMDPSU and the PDM, is similar; therefore its cost is not included. Filters are required for each sampling system and are used once per sampling occurrence. Their costs are also shown in Table 1.

Salary and benefit costs for all personnel used throughout this evaluation are presented in Table 2. This information was obtained from a U.S. coal mine salary and benefit survey published by Western Mine Engineering, Inc.[13]

Table 2. Personnel cost base

	Annual Salary ($/year)	Benefits (% of salary)
Environmental Tech.	$39,300.00	44%
Environmental Coord.	$64,700.00	44%
Mine Foreman	$66,000.00	44%
Mine Engineer	$62,300.00	44%
Mine Supervisor	$86,000.00	44%
Mechanics (Maint.)	$41,200.00	48%
Labor	$36,840.00	48%

Personnel cost data obtained from *U.S. Coal Mine Salaries, Wages, and Benefits -2004 Survey Results* published by Western Mine Engineering, Inc.

4. CMDPSU Sampling Procedure

For CMDPSU, on-site calibration of the pumps must be completed once every 200 hrs.[9] This calibration will be completed by an environmental or safety technician. From discussions with NIOSH technicians, the calibration is expected to require 15 minutes to complete.

Setup and distribution of the sampling equipment is expected to require five minutes to complete, prior to the shift start, and will be conducted by the environmental technician.[n] All pump checks during the shift are considered incidental to normal shift work and will be completed by the mine foreman. At the end of the shift or the eight-hour sampling period, the sampling equipment must be collected and the proper paperwork must be completed. This is also conducted by the environmental technician and is expected to require five to seven minutes after the shift. Cleaning of the pump and cyclone can also be completed in five to seven minutes by the environmental technician and is performed after every sampling period.[o] Table 3 shows the summary of setup and collection times for dust sampling for both systems.

---

[n] Patts, L., Past-Assistant to Vice-President of Health and Safety of a Coal Company. "Personal Communication." (February, 2006).

[o] Ibid.

Table 3. Summary of activity for dust sampling.

Activity	Frequency	Time	Completed by	Cost per sample
CMDPSU				
Calibration	1 every 200 hours	15 minutes	Env. Tech.	$7.07
Setup & Distribution	Prior to every sampling shift	5 minutes	Env. Tech.	$2.36
Collection	After every sampling shift	7 minutes	Env. Tech	$3.30
Cleaning	After every sampling shift	7 minutes	Env. Tech.	$3.30
Total Cost (Does not include calibration cost)				$8.96
PDM				
Calibration	Once per year	Unknown	Factory	*$1,000.00
Setup & Distribution	Prior to every sampling shift	No time Required	Miner	$0.00
Collection Cleaning & Setup for Next Shift	After every sampling shift	15 minute	Env. Tech.	$7.07
Cleaning	Included in collection of PDM			
Total Cost (Does not include calibration cost)		$7.07		

* This is an annual cost

CMDPSU data estimates obtained from discussions with Patts, health & safety professional involved with dust sampling

PDM data obtained from discussions with NIOSH technicians and personnel involved with NIOSH PDM research projects

5. PDM Sampling Procedure

On-site calibration and maintenance is required for the PDM, consisting of flow checks and cleaning. This maintenance is expected to be completed within 15 minutes prior to conducting the required sampling, and will be completed by the environmental technician. Included in this maintenance time is the setup of the PDM for sampling. This setup consists of programming the PDM using a personal computer. The time to complete this setup is minimal.

Distribution of the PDM consists of the miner obtaining a PDM and placing it on his or her belt. This process is similar to obtaining a cap lamp, basically unplugging the PDM, placing it on the belt, and placing the lamp on the hard hat. Therefore distribution is considered to be incidental to the shift work. Unlike the CMDPSU, there are no checks required during the shift for the PDM, as it continuously records all data needed to verify proper sampling.

Once sampling is completed, the PDM must be collected for transfer of the sampling data. The time to collect the PDM, download the data, and clean the equipment is also included in the maintenance time. Collecting the PDM is completed by the miner by placing the PDM on charge, similar to a cap lamp, so the majority of the maintenance time consists of cleaning equipment, with minimal time required for programming and downloading data from the PDM.

6. Case Analysis

There are basically two different potential sampling schemes for both the CMDPSU and the PDM—sampling the minimum required samples and sampling continuously. All cases assume only one MMU, having one DO and one DA, being evaluated using only one sampling unit. Both the DO and DA are sampled sequentially with one sampling unit. All cases conduct sampling on a one shift per day basis.

In relation to the minimum required number of samples, as in cases 1, 3, 4, 5, and 6, the sampling process for this analysis proceeds as follows. Five samples are taken for the DO and one sample is taken for the DA, resulting in a total of six samples per bimonthly period. This is the minimum number of samples required for satisfying MSHA respirable dust sampling requirements. When sampling continuously, as in cases 2, 7, and 8, none of the sampling systems incur any violations during the year. The sampling process for this analysis occurs continuously, with one shift per day lasting 30 days per month, throughout each bimonthly period for the entire year for both sampling systems. The minimum bimonthly sampling requirements are met through this sampling regimen. Therefore, for this procedure it was not important whether the DO or DA was sampled, just that sampling occurred continuously.

Table 4 presents the information for the required respirable dust sampling for each case, showing the number of samples required per year, the number of citations/closure orders incurred per year, and the additional sampling required per year to abate the citation/ closure order.

Table 4. Respirable dust sampling information for each case.

	Dust samples required per year	Dust citations per year	Dust closure orders per year	Additional samples per year for citation/order abatement	Average citation cost ($ citation)
(1) The CMDPSU with minimum required sampling and no violations.	36	0	0	0	N/A
(2) The CMDPSU sampling continuously for one shift/day with no violations.	360	0	0	0	N/A
(3) The CMDPSU with minimum required sampling out of compliance every other bimonthly sampling period (three violations per year).	36	3	0	15	$387.85
(4) The CMDPSU with minimum required sampling out of compliance for every other sampling period and every third violation initiates an order.	36	2	1	15	$387.85
(5) The PDM with minimum required sampling and no violations using the high cost PDM.	36	0	0	0	N/A
(6) The PDM with minimum required sampling and no violations using the low cost PDM.	36	0	0	0	N/A
(7) The PDM sampling continuously for one shift per day with no violations using the high cost PDM.	360	0	0	0	N/A
(8) The PDM sampling continuously for one shift per day with no violations using the low cost PDM.	360	0	0	0	N/A

In case 3 and 4, the CMDPSU incurs one sampling violation for either the DO or DA for every other bimonthly period (three violations per year). It is not significant whether the violation was caused by the DO or the DA. This results in the abatement process having to be completed. Table 5 shows the time commitments required of the environmental or health and safety coordinator and the mine foreman to complete the paperwork and meet with MSHA personnel to abate the citation.[p] These personnel times are converted to costs using the personnel cost base in Table 2. Abatement of the citation is assumed to have a simple remedy. Further, the citation abatement sampling does not incur any violations, which results in the citation being closed. No ventilation plan is required for submission in this case and no orders are generated during this sampling process.

Table 5. Amount of time required to settle MSHA citations and orders.

Citation & order abatement	Personnel Required	Avg. Time (hours)	Cost per citation
Citation			
	H&S (Env.) Coordinator	2	$93.16
	Mine Foreman	1	$47.52
	Maintenance (2 persons)	2	$121.96
Total costs			$262.64
Order			
Investigation	H&S (Env.) Coordinator	2	$93.16
Write up corrective action	Mine Superintendent	1	$61.92
	Mine Engineer	1	$44.86
	Mine Foreman	2	$95.04
Necessary significant corrective action	Maintenance (2 persons)	2	$121.96
	Supply	1	$29.10
	Maintenance Fabrication (2 persons)	5	$304.90
	Env./Safety Technician	3	$84.90
Total cost			$835.84

Abatement times are estimates. These estimates can vary considerably depending upon the circumstances surrounding the citation or order. Data obtained from Patts, 2006

Case 4 differs from case 3 in that every third violation results in MSHA issuing a closure order. There are many different variables which could culminate in sample overexposure and result in an order. Additionally, it is unknown what activities would have to occur for order abatement. Therefore, to simplify the corrective action required to abate the order, it is assumed that this order results in a shutdown of the MMU for only eight hours. Abatement of the order requires additional time of the environmental coordinator, the mine engineer, the mine foreman, and the mine supervisor to complete the paperwork and meet with MSHA to abate the citation.[q] Additional corrective action is necessary, requiring the additional personnel listed in Table 5 to abate the order. Abatement of the order is assumed to be completed successfully, allowing the MMU to start production after the eight-hour shutdown. The order abatement sampling does not incur any

[p] Patts, L., Past-Assistant to Vice-President of Health and Safety of a Coal Company. "Personal Communication." (February, 2006).

[q] Ibid.

extra violations resulting in the order being closed. A ventilation plan is required for submission to MSHA for approval to allow the MMU to continue operating. Additionally, due to the variable nature of the causes of an order, no attempts to determine the cost of lost production were completed during this analysis and the idled section crew is assumed to be working to terminate the order during the time the MMU is shutdown. Therefore, the lost production costs and the idled crew costs are not included in each case.

7. Results of Case Analysis

The present worth cost for each of the eight cases was calculated over the five-year life. Table 6 presents the cashflow of the costs for case 4: i.e., CMDPSU with minimum sampling and three violations per year with every third violation being an order. Case 4 was chosen for illustration because it is the most intricate of all the scenario. These costs are segmented by personnel, filter, miscellaneous, and citation costs and are organized on a monthly basis as determined by the sampler use described for each case. The total cost for each month is presented and the present worth cost is calculated, compounded monthly, using the following formula:[14]

$$P_i = F_i\left[\frac{1}{\left(1+\frac{r}{m}\right)^i}\right] \text{; wher } P = \sum P_i \quad \text{and } i = 1,2,\ldots,mxn \tag{7.1}$$

where r = the annual interest rate; in this case 4.0%, m = the number of compounding periods per year, which is 12 since monthly compounding is used, n = the number of years, which is the time period of the analysis—five years; the life of the sampling instruments, F_i = the total monthly cost for the i^{th} month , and P being the total present worth cost with P_i = the present worth cost for the i^{th} month. The present worth cost is calculated for each monthly cost and then totaled to obtain the total present worth cost for the case. Present worth costs of sampling are calculated for each year, 1 through 5, the results of which are used in the creation of cumulative present worth cost graphs. Table 6 is truncated to show only a year's worth of data, but it is representative of the type of analysis completed for each case over their five-year lives as the bimonthly costs repeat. Similar analysis using this format was completed for each case. The present worth costs are summarized in Table 7 and can be compared to show differences in the costs to the company for each particular sampling case.

Table 7. Present worth costs for CMDPSU and PDM over a 5 year life.

Case 1: CMDPSU with min. sampling no violations	\$5,848.00
Case 2: CMDPSU sampling continuously no violations	\$43,773.00
Case 3: CMDPSU with min. sampling 3 violations/year	\$16,448.00
Case 4: CMDPSU with min. sampling 3 violations/year Every 3rd violation initiates an order	\$19,012.00
Case 5: PDM with min. sampling high cost PDM	\$19,302.00
Case 6: PDM with min. sampling low cost PDM	\$14,867.00
Case 7: PDM with cont. sampling high cost PDM	\$41,397.00
Case 8: PDM with cont. sampling low cost PDM	\$36,961.00

Table 6. Example present worth cost analysis of 1 year for CMDPSU case 4.

Items in red are costs associated with citations

CMDPSU -3 violation/year, 3rd violation initiates an order												
Interest rate used		0.3333% ≈4% annual interest rate										
Months	1	2	3	4	5	6	7	8	9	10	11	12
CMDPSU costs		Violation				Violation				Violation		
Personnel costs												
Calibration time	$7.07					$7.07					$7.07	
Sampling time	$33.96	$28.30	$33.96		$33.96	$28.30	$33.96		$33.96	$28.30	$33.96	
Cleaning time	$19.81	$16.51	$19.81		$19.81	$16.51	$19.81		$19.81	$16.51	$19.81	
Other cost												
Filters (pre-weighed) $16.49 ea.			$98.94		$98.94		$98.94		$98.94		$98.94	
Misc., Tygon tubing, etc.	$100.00											
Citations		$387.85				$387.85				$387.85		
Personnel time for abatement		$262.64				$262.64				$835.81		
Additional filters for out-of- compliance sampling		$16.49				$82.45				$82.45		
Total	$1,512.03	$711.78	$152.70	$0.00	$152.70	$784.82	$152.70	$0.00	$152.70	$1,350.91	$159.78	$0.00
PWC 1yrs.		$5,042.85										
PWC 2yrs.		$8,745.30										
PWC 3yrs.		$12,302.89										
PWC 4yrs.		$15,721.29										
PWC 5yrs.		$19,011.74										

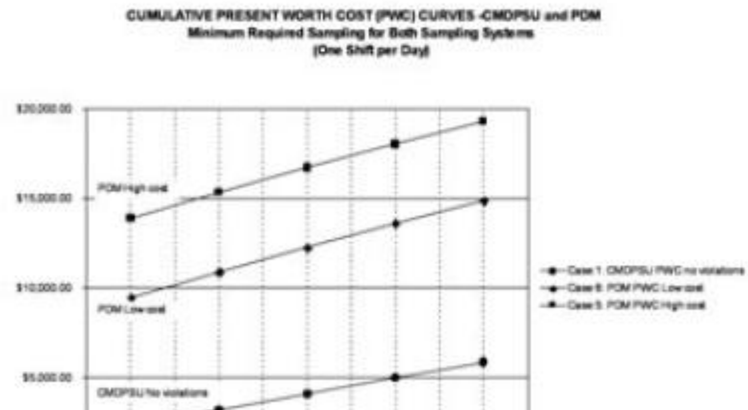

Fig. 2. Cumulative present worth costs (PWC) of minimum required sampling for PDM and CMDPSU option, with no violations incurred.

Figures 2 through 5 show the cumulative present worth cost for the PDM and the CMDPSU at various stages in the five-year life. Additionally, these figures show the breakeven point of the costs of the cases compared in graphs. This breakeven point shows an equilibrium point when the cost of one option equals the cost of another option. This equilibrium point determines when one option has a cost advantage over another.

Figure 2 shows both the PDM high- and low-cost cases in comparison with the CMDPSU. Both systems conduct the minimum sampling required by MSHA and no violations are incurred in either sampling system. This comparison shows that the PDM has a higher cost than the CMDPSU; the significant difference between these options is the initial cost of the sampling systems.

Figure 3 compares both the PDM high- and low- cost cases with two CMDPSU cases. The CMDPSU cases incur violations; with one case incurring three violations per year (case 3) while the other incurs three violations per year, with one of these violations culminating in an order (case 4) and causing the shutdown of the MMU for eight hours. All cases conduct the minimum required number of samples. This comparison shows that the low-cost PDM is less expensive than the CMDPSU at the end of the five year time period, although the CMDPSU starts the beginning of the five-year life having a lower cost than the low-cost PDM. After three years the PDM has a lower cost than the CMDPSU in case 4. For CMDPSU case 3, the PDM has the lower

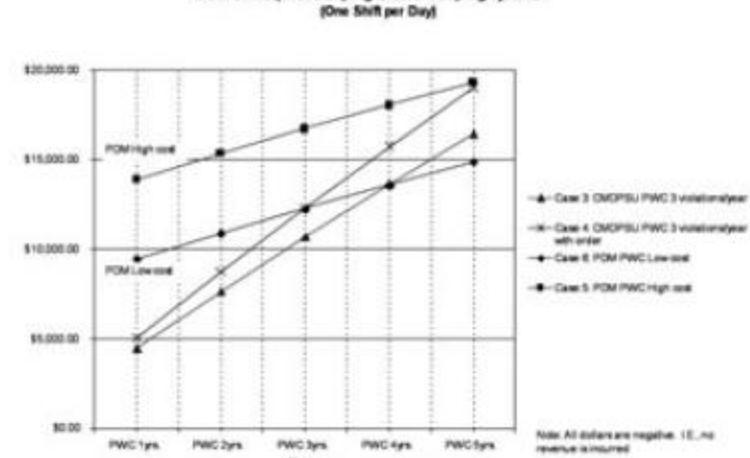

Fig. 3. Cumulative present worth costs (PWC) of minimum required sampling for PDM and CMDPSU, with the CMDPSU incurring MSHA violations and orders.

cost beginning at year four. At the end of the five-year life, the high-cost PDM is more expensive than the CMDPSU case 3, but the costs for the high-cost PDM and the CMDPSU case 4 are basically equivalent.

Figure 4 compares both high- and low-cost options of the PDM with the CMDPSU, with no violations occurring. This comparison shows the results of the PDM and CMDPSU sampling continuously for one shift per day. The PDM low-cost option has a lower cost than the CMDPSU at the end of the five-year life, with the PDM having the lower cost after approximately 2-1/2 years. The PDM high-cost option also has a lower cost than the CMDPSU at the end of the five-year life, with the PDM having the lower cost after year four.

Figure 5 compares the high- and low-cost options of the PDM, which operate on a continuous one shift per day basis, with the CMDPSU incurring violations but sampling the minimum MSHA requirements. In this comparison, both cases with the PDM are more costly than the CMDPSU. This can be explained due to the high initial cost of the PDM and the difference in usage between the PDM and the CMDPSU.

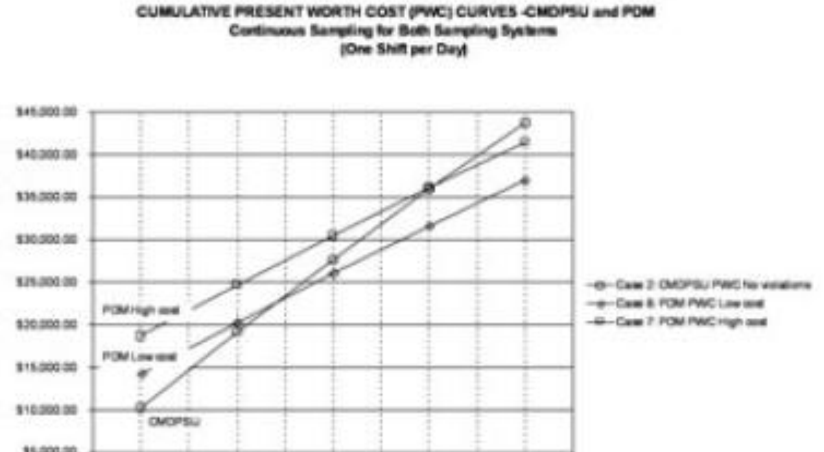

Fig. 4. Cumulative present worth cost (PWC) curves of continuous sampling for the PDM and CMDPSU, with no violations incurred.

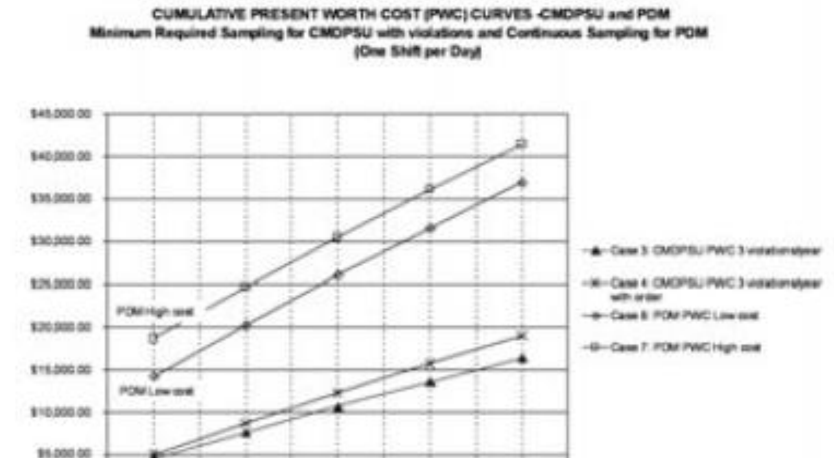

Fig. 5. Cumulative present worth cost (PWC) curves of continuous sampling of PDM and minimum required sampling for CMDPSU, which incurs MSHA violations and orders.

8. Sensitivity Analysis

Sensitivity analysis was completed for the PDM filter costs, PDM factory calibration costs, citation costs, and citation and order abatement times. These items were selected because they can vary appreciably. The flow check, sampling, and cleaning times for the CMDPSU and the PDM are not expected to vary greatly from the times used in the original analysis, and therefore they were not analyzed in a sensitivity analysis. Sensitivity analysis is presented in Tables 8 through 11 summarizing the five-year present worth costs for each case.

The PDM filter costs were varied from the initial $8.00 cost per filter by using costs of $4.00 and $2.00 per filter. The PDM filters are not sent to MSHA for analysis; therefore, filter cost may be expected to become lower because allowances may be made to allow the PDM filters to be used more than once, since these filters are not used in dust concentration calculations as they are for the CMDPSU. These changes in filter cost only affect the PDM cases. Table 8 presents the results of the sensitivity analysis for the filter costs showing the present worth costs for the initial analysis and for the $4.00 and $2.00 costs per filter for the PDM.

Table 8. Sensitivity analysis of PDM filter cost.

Filter costs	$16.49	$8.00	$4.00	$2.00
Case 1: CMDPSU with min. sampling no violations	$5,848	-	-	-
Case 2: CMDPSU sampling continuously no violations	$43,773	-	-	-
Case 3: CMDPSU with min. sampling 3 violations/year	$16,448	-	-	-
Case 4: CMDPSU with min. sampling 3 violations/year Every 3rd violation initiates an order	$19,012	-	-	-
Case 5: PDM with min. sampling high cost PDM	-	$19,302	$18,729	$18,442
Case 6: PDM with min. sampling low cost PDM	-	$14,867	$14,293	$14,007
Case 7: PDM with cont. sampling high cost PDM	-	$41,397	$34,960	$31,742
Case 8: PDM with cont. sampling low cost PDM	-	$36,961	$30,525	$27,307

Table 9. Sensitivity analysis of factory calibration cost.

Factory calibration	None	$1,500	$1,000	$500
Case 1: CMDPSU with min. sampling no violations	$5,848	-	-	-
Case 2: CMDPSU sampling continuously no violations	$43,773	-	-	-
Case 3: CMDPSU with min. sampling 3 violations/year	$16,448	-	-	-
Case 4: CMDPSU with min. sampling 3 violations/year Every 3rd violation initiates an order	$19,012	-	-	-
Case 5: PDM with min. sampling high cost PDM	-	$21,523	$19,302	$17,081
Case 6: PDM with min. sampling low cost PDM	-	$17,088	$14,867	$12,646
Case 7: PDM with cont. sampling high cost PDM	-	$43,618	$41,397	$39,175
Case 8: PDM with cont. sampling low cost PDM	-	$39,183	$36,961	$34,740

The PDM factory mass calibration costs for the PDM option were varied from the initial estimated cost of $1,000 using $500 and $1,500 for the low- and high-factory costs, respectively. These low and high costs were used to determine the effect of the factory calibration cost on each PDM option. Table 9 shows the sensitivity analysis of the factory calibration costs representing the present worth costs for the initial analysis and for the $500 and $1,500 factory calibration costs for the PDM.

Citation costs, which occurred only for those CMDPSU options that incurred MSHA violations, were varied by doubling the average citation costs to $775.70 and by lowering the citation costs to $193.93, half the average citation cost. A sensitivity analysis was completed on these costs because citation costs can vary considerably depending upon the circumstances surrounding the respirable dust violation. Table 10 presents the sensitivity analysis of the citation costs, showing the present worth costs for the initial analysis and for the $193.93 and the $775.70 citation costs for the CMDPSU.

Table 10. Sensitivity analysis of citation cost.

Citation calibration	$775.70	$387.85	$193.93	None
Case 1: CMDPSU with min. sampling no violations	-	-	-	$5,848
Case 2: CMDPSU sampling continuously no violations	-	-	-	$43,773
Case 3: CMDPSU with min. sampling 3 violations/year	$21,722	$16,448	$13,812	-
Case 4: CMDPSU with min. sampling 3 violations/year Every 3rd violation initiates an order	$24,285	$19,012	$16,375	-
Case 5: PDM with min. sampling high cost PDM	-	-	-	$19,302
Case 6: PDM with min. sampling low cost PDM	-	-	-	$14,867
Case 7: PDM with cont. sampling high cost PDM	-	-	-	$41,397
Case 8: PDM with cont. sampling low cost PDM	-	-	-	$36,961

Table 11. Sensitivity analysis of personnel time required for citation abatement.

Citation calibration	Doubled	Normal	Halved	None
Case 1: CMDPSU with min. sampling no violations	-	-	-	$5,848
Case 2: CMDPSU sampling continuously no violations	-	-	-	$43,773
Case 3: CMDPSU with min. sampling 3 violations/year	$20,020	$16,448	$14,663	-
Case 4: CMDPSU with min. sampling 3 violations/year Every 3rd violation initiates an order	$25,146	$19,012	$15,944	-
Case 5: PDM with min. sampling high cost PDM	-	-	-	$19,302
Case 6: PDM with min. sampling low cost PDM	-	-	-	$14,867
Case 7: PDM with cont. sampling high cost PDM	-	-	-	$41,397
Case 8: PDM with cont. sampling low cost PDM	-	-	-	$36,961

The last sensitivity analysis was completed on the citation and order personnel time required to abate the citation or order, because these times can vary greatly depending upon the circumstances surrounding the citation or order. This analysis only influenced the CMDPSU, in that the PDM analysis did not consider citations or orders. These times were varied by halving the personnel time and by doubling the personnel time required for citation and order abatement.

Table 11 shows the sensitivity analysis of the personnel time for abating a citation or an order, illustrating the present worth cost for the initial analysis and for the halved personnel time and the doubled personnel time for the CMDPSU.

9. Discussion

In the present worth cost results for each of the different hypothetical cases of Table 7, it can be seen that using the CMDPSU, if no violations or orders are incurred, is the least costly sampling system when conducting the minimum required sampling with the present worth cost being $5,848. When compared in relation to the same minimum sampling rate, occurrences of violations and orders while using the CMDPSU make the PDM a more cost-competitive sampling system. This can be seen in Table 7 and Figure 3, where the CMDPSU present worth cost of cases 3 and 4 approaches that of the high-cost PDM. It should be noted that the low-cost PDM is more cost-competitive than the CMDPSU when violations or orders are incurred, as defined in this analysis. Figure 3 shows that, when compared with the CMDPSU case 3, the low-cost PDM becomes more cost competitive after four years and after only three years with the CMDPSU case 4. When continuously sampling with the CMDPSU and the PDM, the PDM has a cost advantage over the CMDPSU. This is due to the savings in labor and filter costs associated with the PDM.

Further comparisons on a differing usage basis, with the CMDPSU conducting the minimum required sampling and the PDM sampling continuously, show that the CMDPSU has the cost advantage. The difference in use between the sampling systems creates the cost difference between the PDM and CMDPSU, in that they are not being compared on an equivalent usage basis. However, when the continuous use of the PDM is able to prevent citations and orders and the CMDPSU incurs citations and orders, then the difference in present worth costs between the PDM and CMDPSU, which range from $17,949 to $24,949, are small considering the difference in usage. This can be shown through a brief example that equates the excess present worth cost to production time.

Although, the cost of lost production was not accounted for in this analysis due to the varying differences among mine sites for calculating this cost, a simplistic way of considering lost production is to equate the excess present worth costs to production time. Reviewing current production information, which is shown in Table 12, for a continuous miner development section for a longwall mine, calculations can be made that show revenues would be $3,745 per hour[r].[15] The difference in present worth costs of $17,949-$24,949 can be equated to lost production time by dividing the difference in these costs by the revenue per hour. Therefore, if production stops during any of these CMDPSU cases due to citations or orders resulting from excessive dust, especially in case 4 where the order is incurred, the difference in present worth costs between the PDM and the CMDPSU can be equated to approximately 4.8[s] to 6.7[t] hours of lost production, based on coal revenues. This does not include any costs of scheduling delays due to the lost production which could render the difference in the amounts between the present worth costs for the PDM and CMDPSU options insignificant.

Table 12. Typical production information for continuous miner section.

Tons/shift	1400
Hours/shift	10
Roundtrip travel time to face	1
Tons/hour	156
Spot price/ton	$45.00

[r] Revenues per hour is calculated using tons/hour multiplied by the spot price/ton from Table 15, which is then multiplied by 57% plant recovery.[16]

[s] $17,949/($3,745/hour) = 4.8 hours

[t] $24,949/($3,745/hour) = 6.7 hours

The sensitivity analysis showed that reducing filter costs also reduced the present worth cost of the PDM options. This reduction was more pronounced for the cases which used the PDM continuously. During continuous use of the PDM, reducing filter costs to $4.00 reduced the present worth cost of the PDM by approximately 17%. Further reducing the filter costs to $2.00 reduced the present worth cost by 26% compared with the original analysis. By comparison, using the PDM on a minimum sampling basis, the present worth cost was only reduced by 4% for the $4.00 filter cost and by 6% for the $2.00 filter cost. Sensitivity analysis of the factory mass calibration costs showed that while these costs are significant, their effect on the PDM options when in continuous use was generally small (reflecting a 6% increase or decrease depending upon whether the factory mass calibration cost was increased or decreased $500, respectively). In contrast, when the PDM was used only for the minimum required sampling, increasing or decreasing the factory mass calibration costs increased or decreased the PDM present worth cost by up to 15%, respectively. Therefore, the factor that had the greatest impact on the PDM present worth cost was dependent upon the nature of the use of the PDM. Filter costs had the greater impact when the PDM was used continuously and factory mass calibration costs had the greater impact when the PDM was used only for minimum required sampling.

Changing the citation costs and personnel time required for citation abatement had a large effect on the CMDPSU cases where violations were incurred. Doubling the citation costs increased the present worth cost of the CMDPSU by 28-32%, while decreasing citation costs to half the original cost decreased the present worth cost of the CMDPSU by 14-16%. Doubling personnel time required for citation/order abatement increased the present worth cost of the CMDPSU by 22-32% while halving the personnel time from the original time decreased the present worth cost of the CMDPSU by 11-16%. There was a higher increase in present worth cost for increasing these costs than for decreasing them due to the amount of increase versus decrease in citation costs and abatement times. These percent increases or decreases show that both citation costs and personnel time for abatement are significant factors in these cost comparisons.

In reviewing the overall results of this sensitivity analysis, increasing the citation costs and personnel time have the potential to have the greatest impact on the cost competitiveness of the PDM. This is due to the fact that, depending upon the severity of the dust violations, these imposed costs can be significantly larger than the other normal operating costs. The citation cost per violation can be up to $60,000, while personnel time required to abate a citation or an order can also be large depending upon the amount of work required[17]. Conversely, filter costs and factory calibration costs are limited in the amount they can increase or decrease. Therefore, the PDM's ability to maintain compliance with the dust standard and to prevent citations or orders due to coal mine dust exposure can result in potential significant savings to the mining company.

There are additional advantages to using the PDM that have not been quantified for this analysis which also make the PDM a more desirable sampling system. The PDM provides timely instantaneous dust exposure data, allowing for the determination of causes of overexposure which can be corrected before overexposure occurs.[3] This fact, and the results of the sensitivity analysis just completed, suggests that the ability of the PDM to prevent dust overexposure can result in cost savings to the company. The main benefit of using the PDM, with its real-time instantaneous dust exposure readout, is that the health of the miner is improved in that the miner does not get overexposed to respirable coal dust. Besides resulting in fewer citation and order costs, less exposure to coal dust may improve the productivity of the worker, which has not been addressed in this study. There are also societal benefits from using the PDM through the reduction of black lung. These benefits include reduction or even elimination of the black lung fund, reduced health costs, reduction of insurance premiums, personnel satisfaction, etc. These benefits, however, have not been quantified and therefore are not included in this analysis. Future evaluations should consider these additional benefits in an overall analysis of the viability of this new technology. Another intangible benefit is that the use of the PDM may help enhance the integrity of the mine dust sampling program, because the sampling results are available to labor, management, and government.

10. Summary and Conclusions

The PDM can be used as a tool to help prevent CWP or Black Lung by providing real-time monitoring of coal mine dust. The cost analysis comparing this system with the CMDPSU shows that PDM is a viable sampling system whose costs are reasonable, in particular over five years. The analysis examined eight different sampling cases for both sampling systems which included assumptions such as: carrying out the minimum required sampling with no dust-related citations, performing continuous sampling on a one shift per day basis with no dust-related citations, conducting sampling with the CMDPSU for the minimum required samples while incurring citations and orders, and evaluating high- and low-cost PDM options with minimum and continuous sampling.

A summary of the results shows that:

(1) When examining the results of the analysis on the similar basis of continuous sampling, the PDM has the cost advantage over the CMDPSU even if the CMDPSU does not incur any dust exposure citations.

(2) If the CMDPSU does not incur any dust exposure citations or orders and the sampling rate is conducted at the minimum requirements as currently specified by MSHA, then it is the least costly sampling system.

(3) When conducting the minimum sampling required, occurrences of violations and orders while using the CMDPSU increase its cost and make the PDM a more cost-competitive sampling system.

(4) Comparing the PDM with the CMDPSU on differing sampling schedules, where the CMDPSU conducts the minimum required sampling and the PDM conducts continuous sampling, shows that the CMDPSU has a cost advantage over the PDM.

An initial examination of the cost of the two sampling systems shows that the PDM has the higher initial cost. However, upon further review, labor and material costs come into play to help alleviate the effects of the initial PDM cost, resulting in the PDM being a cost-competitive sampling system. Additionally, there are several other factors which have a great influence on the sampling system costs. The sensitivity analysis performed demonstrates that the cost of citations and the cost of personnel required to abate citations or orders are significant factors affecting the two sampling systems. Filter costs and factory mass calibrations are also significant costs, but not to the same extent as citations and personnel time. Therefore, the ability of the PDM to provide a real-time readout of dust concentrations, which may prevent dust exposure citations or orders in addition to preventing respirable dust overexposure, plays a significant role in its cost competitiveness. This can be seen especially with the cost differences of the two systems representing approximately 4.8 to 6.7 hours of lost production if the MMU is shutdown due to excessive dust, which demonstrates that preventing just one MSHA closure order for dust which causes eight hours of lost production allows the PDM to recover its cost. Moreover, there are many un-quantified health and societal advantages to the PDM which make it a desirable sampling system over the CMDPSU.

The CMDPSU has been the approved sampling device for over 35 years, since the Federal Coal Mine Health and Safety Act of 1969 was implemented (U.S. Dept. of Interior, 1970). It has been an effective factor in reducing the number of CWP deaths from a crude mortality rate of over 3,000 in 1972 to approximately 1,000 in 1999 (NIOSH, 2002). However, there are still many cases of CWP occurring. This new technology, the PDM, has the potential to further reduce or even eliminate CWP because of its real-time dust exposure readout. This analysis shows that, while the initial investment may be high, over the long term, through savings in labor and materials and the prevention of dust exposure citations and orders, the PDM is a cost-competitive sampling system.

References

1. Merck Research Laboratories, *The merck manual of medical information –second home edition, online version*, ed. M.H. Beers, (Website: www.merck.com/mmhe/index.html, Whitehouse Station, NJ, 2004-2005).

2. NIOSH, Work-related lung disease surveillance report, 2002, U.S. Dept. of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Respiratory Disease Studies, Cincinnati, OH, December 2002.

3. J.C. Volkwein, R.P. Vinson, L.J. McWilliams, D.P. Tuchman, and S.E. Mischler, Performance of a new personal respirable dust monitor for mine use, NIOSH Report of Investigations 9663 U.S. Dept. of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Pittsburgh, PA, June 2004.

4. J.C. Volkwein, E. Thimons, C. Yanak, H. Patashnick, and E. Rupprecht, Implementing a new personal dust monitor as an engineering tool, *Coal Age*, (December 2004) 26-29.

5. U.S. Dept. of Labor, Mine Safety and Health Administration, 30 CFR parts 70, 75, and 90, Verification of underground coal mine operator's dust control plans and compliance sampling for respirable dust; proposed rule, Federal Register, Vol. 68, No. 44, National Archives and Records Administration, March 6, 2003.

6. L.D. Raymond, T.F. Tomb, and P.S. Parobeck, Respirable coal mine dust sample processing, Mine Safety and Health Administration Informational Report 1156, 1987.

7. U.S. Government Printing Office, Code of federal regulations: Title 30, Volume 1, Chapter I, Part 70, Website: www.nara.gov, July 2005.

8. Mine Safety and Health Administration, Mine ventilation plan approval procedures, MSHA Handbook Series Handbook Number PH92-V-6, U.S. Department of Labor, Mine Safety and Health Administration, Coal Mine Safety and Health, May 1992.

9. Mine Safety and Health Administration, Coal mine health inspection procedures handbook, U.S. Department of Labor, Mine Safety and Health Administration, July 2003.

10. Mine Safety Appliance, Escort® ELF and escort LC sampling pumps, Bulletin #: 0810-38-MC, MSA website: http://media.msanet.com/NA/USA/PortableInstruments/PersonalSamplingPumps/EscortELFSamplingPump/0810-38-MC-ELF.pdf , Last accessed August 2007.

11. U.S. Dept. of Treasury, Bureau of the Public Debt, Treasury bill, note, bond and TIPS auction history, 1980 to present, Website: www.publicdebt.treas.gov/sec/secauc.htm, May 2006.

12. Mine Safety Appliance, Personal communication, July 2005.

13. J.B. Leinart, *U.S. coal mine salaries, wages, & benefits, 2004 survey results*, (Western Mine Engineering, Inc., Spokane, WA, 2004).

14. J.A. Sepulveda, W.E. Souder, and B.S. Gottfried, *Schaum's outline of theory and problems of engineering economics*, (McGraw-Hill, New York, 1984).

15. K. Whipkey, Productivity improvement for longwall development, *Coal Age*, (August 2005) 28-32.

16. S. Fiscor, U.S. prep plant census, -prep plant population rebounds, Coal Age, (October 2005).

17. U.S. Government Printing Office, Code of federal regulations: Title 30, Volume 1, Chapter I, Part 100 Section 3, Website: www.nara.gov May 2006.