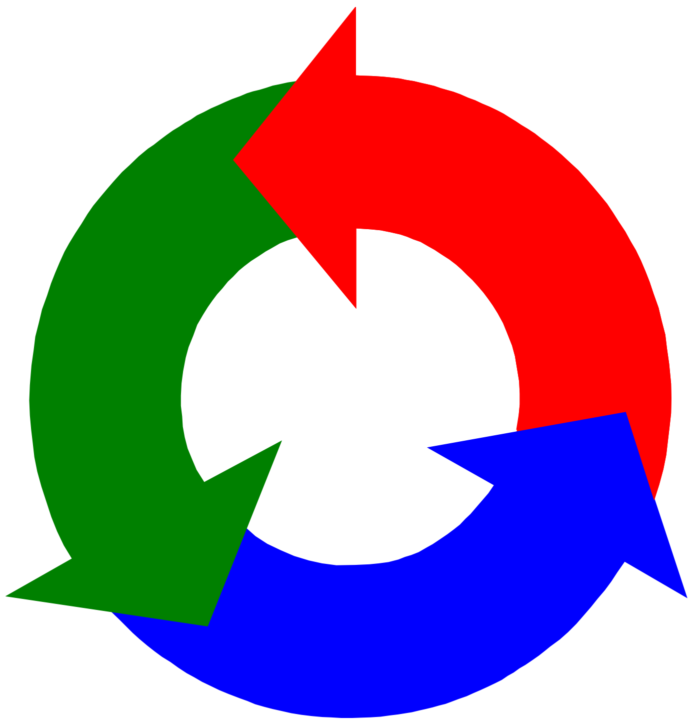

Maintenance and Diesel Exhaust Emissions

Submitted by Sean McGinn and Philippe Gaultier to the DEEP Technical Committee

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Maintenance and Diesel Exhaust Emissions

Overview

This is a project that targets the area of underground maintenance and how it affects diesel exhaust emissions. It is designed to investigate and improve maintenance on underground diesel equipment and evaluate the impact of improved maintenance on diesel exhaust emissions. It impacts personnel from the production and maintenance departments of the mine operator.

The principal technology around which this project will be based is the Undiluted Gas Analysis System (UGAS) developed at Noranda Technology Center. In addition to the UGAS technology an undiluted DPM measurement tool developed by CANMET will also be employed and integrated with the UGAS software database.

The test apparatus will be used to acquire emissions data based on implementation of a revised maintenance process targeted at reduction of diesel emissions. Data will be acquired initially on existing practices to establish a baseline and then on a revised maintenance process and activities. Resources from the test mine site maintenance and production departments will be involved in all stages of the project. Individuals will be trained in the operation of test equipment as well as in improved maintenance activities for emission reduction. This will provide a mechanism that ensures technology transfer over the course of the project to personnel at the mine site and continued effort at the mine beyond the completion of the project.

Stage 1 – Define Maintenance Practices and Resources Necessary For Diesel Emissions Reduction

- Consult with a group of authorities from the industry to establish guidelines for maintenance procedures and practices targeted at diesel emissions and DPM reduction
- Identify resources and practices required to carry out these procedures on an ongoing basis
- Establish a site maintenance review process for evaluating performance of a mine mobile maintenance department

Stage 2 – Site Review and Selection Process

- Identify potential mine sites to conduct the research project
- Utilise the maintenance review process to evaluate current practices at the selected potential sites
- Identify the candidate site for the research project

Stage 3 – Evaluating Emissions From Existing Maintenance Practices

- Set up test apparatus at site for monitoring and acquiring emissions and DPM data
- Conduct training with on site maintenance personnel on use of test apparatus
- Over a one month period acquire emissions and DPM data based on current maintenance practices

Stage 4 – Implementing and Measuring an Improved Maintenance Process

- Make necessary improvements and adjustments to take the guidelines and practices established in Stage 1 and put them in place at the site
- Train maintenance personnel in adopting the new maintenance process
- With the new guidelines and practices in place measure the emissions and DPM with the same apparatus and protocol consistent with the previous stage

- Over a three month period acquire emissions and DPM data based on the adoption of the new maintenance process

Stage 5 – Analysis of Impact

- Assess the extent to which the new maintenance practices have been successfully adopted and problems encountered in achieving them
- Analyse the changes in emissions related to specific maintenance practices and combination of procedures and practices
- Using a modified Exhaust Quality Index value estimate changes in overall emissions based on the adoption of new maintenance procedures and practices

Stage 6 – Recommendations Based on Results

- A final report will be produced explaining in detail the effects of the new maintenance procedures and practices on reductions to exhaust emissions and DPM

Resources from Noranda Technology Centre, CANMET, diesel engine manufacturers, and an as yet unidentified Canadian underground mining operation will undertake this research.

Purpose and Objectives

The purpose of this project is to identify key maintenance activities that can reduce engine emissions. This will be accomplished by a scientifically proven relationship between maintenance practices on diesel engines and a reduction in exhaust emissions. Once established this relationship will form the basis on which changes and improvements to the maintenance process with respect to diesel engines can be recommended.

The primary objectives are:

1. **Drawing on previous research and in consultation with industry authorities, identify the principal engine maintenance procedures and practices which reduce diesel emissions**

2. **Establish a maintenance review process to determine the current status of a maintenance operation and recommendations for improvements to reduce engine emissions**

3. **Test and evaluate this process in an underground mine(s)**

4. **Develop a model of good maintenance practice with an emphasis on reduced emissions**

5. **Perform before and after implementation sampling of exhaust gases and DPM to establish relationship between improved maintenance and reduced emissions and DPM**

6. **Educate and train maintenance personnel on the importance of effective maintenance on diesel engines and exhaust emissions**

Background

The maintenance of diesel engines on underground mobile equipment generates concerns and criticism from all branches of the mining community. Excessive exhaust emissions from diesel engines are directly related to how well the engines are maintained. It has always been understood that the better an underground diesel engine is maintained the cleaner and ultimately longer it will run. The conflict with this basic fact lie in finding a better balance between cost effective production and utilisation of effective maintenance tools, procedures, people and attitudes. This requires total teamwork involving maintenance, production and management commitment. As these groups combine to adopt proactive maintenance strategies the closer we get to cleaner and more cost effective engines in the underground production environment.

The effect of maintenance on diesel engine emissions has been clearly identified in work by the Southwest Research Institute [1] and Waytulonis [5,6]. This work employed the use of a combination of in-mine and laboratory tests with induced faults on Deutz and Caterpillar engines to establish recommendations for engine maintenance practices. From this work a list of ten recommendations for safe use of diesel equipment in underground mines was established.

1. *Use indirect injection (IDI) combustion chamber engines*
2. *Read operation and maintenance manuals*
3. *No ventilation, no operation*
4. *Use low sulphur fuel*
5. *Keep it clean*
6. *Keep it cool*
7. *No extended idling*
8. *No lugging*
9. *No overpowering*
10. *Beware of black smoke*

Pertaining to maintenance Waytulonis identified six major systems and how changes to parameters under each of the systems affected emissions levels. For example, he indicates that under the Fuel Injection System the most critical adjustments affecting exhaust pollutants are fuel flow rate and fuel injection timing. The six major systems are:

1. *Air Intake System*
2. *Cooling System*
3. *Diesel Fuel Handling and Quality*
4. *Fuel Injection System*
5. *Lubrication System*
6. *Exhaust System*

A study and report by Matthew Spears [9] of the University of Minnesota – Centre for

Diesel Research describes an emissions-assisted maintenance program (EAMP). What distinguishes this study from previous studies by the U.S.B.M. and others similar is that EAMP is designed to be a weekly test procedure performed by mine maintenance personnel. It incorporates the use of an ECOM-AC gas analyser communicating with a computer database. The test protocol utilised torque converter stall engine loading method for consistent engine loading across various pieces of equipment. EAMP studies were performed in a laboratory, at a mine equipment manufacturer facility, and on site at an underground mine.

From the tests performed in the laboratory and based on emissions data gathered the field pass/warn/fail criteria were established for each engine tested. EAMP proved to be an effective tool for identifying engines in need of maintenance.

The one common idea that comes out in all research studies on this subject is the importance of the total maintenance process with respect to diesel emissions.

The Mechanic's Stethoscope [7, 8] developed by Noranda Technology Centre was a breakthrough in maintenance technology. It identified five levels in the maintenance process and dealt with all of them equally on one common platform. It has been described as the *The Maintenance Cycle*

1. Problem Identification
2. Scheduling
3. Repair
4. Recording
5. Monitoring

The UGAS technology, which will be outlined for use in this proposal, was developed as a module within the Mechanic's Stethoscope. It fits into the maintenance cycle under problem identification as a diagnostic tool as well as monitoring and an emissions history analysis. The UGAS system utilises the same measurement apparatus as used by the EAMP system of the University of Minnesota. The advantage of UGAS is that the software is developed with the end user in mind. A clear process for measuring and recording engine emission conditions is available to the mechanic.

In a typical underground operation the cost of maintaining equipment is considerable. At Noranda – Brunswick Mining Division [10], the total cost of maintenance is in the order of $61 M/yr. Of this, 35% is directly associated to underground mobile equipment. Maintenance on the equipment breaks down into several major components (engine, hydraulic, electrical,…). The portion related to engine maintenance is approximately 12% of the total. In the report presented, effects of low sulphur fuel, the use of diesel particulate filters (DPF), and the use of tools like the Mechanics Stethoscope all aided the reduction of cost of maintenance as well as facilitating the reduction of engine emissions.

The underground working environment poses distinct challenges to maintaining mobile equipment effectively, particularly to intricate and sensitive systems such as diesel engines. The variables in the environment such as dust and humidity are uncontrollable and make in-frame overhauls and major engine repairs ineffective at best. The most effective way to work around these obstacles is to improve the routine maintenance practices and utilise more effective tools for accurate diagnostics. In short – it means learning to do the basics BETTER.

To reach this goal we must first identify new practices and procedures and then measure how they affect engine performance, emissions, and ultimately engine life in the underground environment. Utilising a tool for measuring undiluted exhaust emissions we can quantify each practice and procedure to fully understand its impact on changes in emission levels and overall performance.

REFERENCES

[1] Branstetter, R., R. Burrahm, and H. Dietzman. 1983. *Relationship of Underground Diesel Engine Maintenance to Emissions*. Volume I (Contract H0292009, SwRI), Bu Mines OFR 110(1).

[2] Fiscor, S., *Off-Highway Diesel Engine Trends – Environmental Concerns, Fuel Efficiency, and Extending Operating Life Challenge Designers*. Article – E&Mj Magazine. August, 1994. Pp 38 – 40.

[3] Sauerteig, J. E., G. Perkuhn. *Influence Of Maintenance On The Exhaust Emission Quality Of Diesel Engines*. Diesel Use Seminar – American Mining Congress and U.S.B.M.. 1988. Pp. 118 – 144.

[4] U.S Department of Labor – Mine Safety and Health Administration. 1997. Practical Ways To Reduce Exposure To Diesel Exhaust – A Toolbox, Draft. pp. 29 – 35.

[5] Waytulonis, R. W., *An Overview Of The Effects Of Diesel Engine Maintenance On Emissions And Performance. Diesels In Underground Mines: Measurement And Control of Particulate Emissions.* Proceedings: Bureau of Mines Information and Technology Transfer Seminar, Minneapolis, MN, September 29-30, 1992. Pp. 113 – 120.

[6] Waytulonis, R. W., *The Effects Of Maintenance And Time – In – Service On Diesel Engine Exhaust Emissions. Diesels In Underground Mines: Measurement And Control of Particulate Emissions*. Proceedings: Bureau of Mines Information and Technology Transfer Seminar, Minneapolis, MN, September 29-30, 1992. Pp. 103 – 111.

[7] L. Fauteux, A. Dasys, P. Gaultier, R. Johnson, *Mechanic's Stethoscope: A Technology Transfer Model*, CIM Bulletin, Vol 72, No. 1001, November 1995.

[8] P. Gaultier, A. Dasys, and R. Johnson, *The Maintenance Cycle and The Mechanic's Stethoscope*, CIM Maintenance Operators Conference, Sept. Isle, Quebec, November 1994.

[9] Spears, M. W., "An Emissions-Assisted Maintenance Procedure for Diesel Powered Equipment"**,** Graduate Thesis, University of Minnesota-Center for Diesel Research.

[10] Gavel, K., *Engine/Machine Maintenance Consideration*, The Canadian AdHoc Diesel Committee Proceedings of the November 6&7, 1996, Plenary Conference, Toronto, pp. 12.1-12.8.

Description of Work

The project will be spread across six separate stages. Total duration of the project will be 9 months. In the event of delays between stages due to equipment or site availability for example, the total duration will be extended. Delays of this nature will not affect the total budget however. The work will be divided across the six stages as follows:

Stage	Duration
Define Maintenance Practices and Resources Necessary For Diesel Emissions Reduction	4 Weeks
Site Review and Selection	5 Weeks
Evaluating Emissions From Existing Maintenance Practices	6 Weeks
Implementing and Measuring an Improved Maintenance Process	15 Weeks
Analysis of Impact	3 Weeks
Recommendations and Report	5 Weeks

Stage I – Define Maintenance Practices and Resources Necessary For Diesel Emissions Reduction

The first task for this project will involve consultation between the management team and a number of recognized authorities in the field of mobile equipment maintenance. This would include individuals from the mining industry as well as diesel engine manufacturers and researchers. The final selection of individuals for this group will require the approval of the DEEP Technical Committee before proceeding. The result of this consultation process will be a set of recommended guidelines for maintenance procedures and practices targeted at the reduction of diesel emissions and DPM. As a starting point in this process the project team will begin with the findings and recommendations from previous work as outlined in the background section of this proposal. At the same time the authorities will also be requested to identify a list of realistic resources and practices required to implement the guidelines on an on going basis. This will ensure that the work of this project becomes a transferable technology that will continue after the research project has been completed.

The next task in this preliminary stage is to establish a site maintenance review process for evaluating the performance of a mine mobile maintenance department. Once again this will involve consultation with authorities in this field. The group will be comprised of individuals from maintenance, management, manufacturers, and audit process backgrounds. The intent of this review process is to have an effective way of evaluating a site in less than a week without having to adopt a formal audit process. As an example the management team could go to a site and complete the review process including a summary in three days. An example of department areas that would be reviewed in the process:

1. ***Responsibilities & Roles***
2. ***Work Order System***
3. ***Scheduled Maintenance System***
4. ***Preventive Maintenance Detail***
5. ***Engine Specific***
6. ***Parts & Service Manuals***
7. ***Housekeeping & Organization***

Each area would be broken down into a tree structure of sub categories and specific detail. The process could be automated so those notes taken through the review would assist in producing the summary directly upon completion.

Stage II – Site Review and Selection Process

A short list of potential sites for conducting the project will be drawn up with assistance from the DEEP Technical Committee. Basic qualifications for potential sites will remain consistent in consideration of all potential candidates. Each potential site that is approached will be given a detailed description of the scope of the project and the commitment involved. As well the sites will be reminded of the benefits to mine environment and health, maintenance, production, and overall bottom line profit that come with this approach to diesel emissions and maintenance.

Mine Site – The test site should be equipped with U/G mobile equipment using hydraulic power trains and hydraulic implement systems (i.e. boom/bucket) for consistent engine loading during testing. The site must be prepared to have a commitment to improved maintenance. Additional factors specific to the site are the availability of personnel, consistent quality fuel, vehicles, and engine types.

Personnel – The mine must be prepared to make maintenance personnel available for the duration of the project. One individual at the site will be chosen as project champion. This individual should possess a combination of mechanical, organisational, and computer skills. The site for this project will have to commit to making this individual available for the length of the study.

Consistent Quality Fuel – The mine must be prepared to supply a consistent high grade low sulphur fuel for the duration of the study. Fuel will be sampled at pre, mid, and post phases and sent to CANMET for analysis to ensure consistency.

Vehicles – To establish a good cross section of mobile equipment eight vehicles should be employed for the study. These vehicles should be a combination of scooptrams and haulage trucks all equipped with torque converters and hydraulic systems.

Engine Models – The cross section of eight vehicles will be equally divided across two major engine manufacturers. The two will be a combination of Detroit Diesel - DDEC, Deutz, or Caterpillar engines.

Each potential candidate site will be visited and reviewed using the process established in Stage I. It is anticipated that each review will involve three days of on site inspection followed by a short analysis and summary. Once all sites have been reviewed and summary reports are complete for each the project management team will meet with the technical committee to identify the candidate site for this research project.

Confounding Variables

Once the site has been chosen the next step will be to address the confounding variables. Each variable will need to be addressed between project staff and mine site personnel.

- Consistent high quality fuel supply
- Consistent on site testing
- Vehicle availability
- Test apparatus reliability
- Engine wear – replacement
- Ambient conditions
- Filter selection consistency and availability of parts

At this stage of the project the DEEP Technical Committee will meet to review the progress to date. Based on this progress the committee will make a decision as to whether the project has a good chance for success and should continue from this point forward or regroup.

Stage III – Evaluating Emissions Based On Existing Maintenance Practices

All test apparatus will be moved to the selected site and set up in the maintenance shop. The hardware and software in the system will be set up and configured prior to transport to the site to facilitate quick setup and verification. Prior to training and testing all equipment will be verified for proper operation. An initial week of training will involve two members of the project management team and the site project champion. This will include the use of the ECOM analyser and UGAS software combination as well as the DPM sampling device. Extensive use will be made of the multimedia tutorial for training. It is anticipated that the site champion will be able to conduct tests on his own after two days of training with project team support and supervision. During this first week we will also attempt to include at least one other on site maintenance individual in the training. It is important to note that the only training done at this point involves the actual testing of exhaust emissions. Training individuals on the new maintenance process will not take place until the baseline stage has been completed.

Test Apparatus

The test apparatus will be comprised of several individual components contained in a common enclosure, which will be situated on the underground shop floor.

An ECOM –AC four gas analyser will be used to perform exhaust emission measurements. The analyser measures O2, CO, NO, NO2, gas and ambient temperatures, and exhaust back pressure. With these measured parameters the analyser also calculates additional parameters such as combustion efficiency, excess air, and CO2. An RS232 communication port allows all parameters to be communicated to an external computer.

An apparatus for measurement of undiluted DPM will also be integrated into the system. CANMET has developed a simple portable system for sampling of undiluted particulate matter from vehicles in production. In this system DPM sample is collected on a pre-weighted filter. After the sample collection, the filter is weighed again to get the total weight of the sample collected during a typical cycle or a number of cycles. The sample is drawn using a constant flow pump for the duration of a cycle(s). The volume of exhaust gas passed through the filter is obtained by the pump flow rate and sampling duration. The DPM concentration is obtained by dividing particulate mass by the volume of exhaust gas passed through the filter. For mine vehicles, a sampling duration of 10 to 20 minutes has been found suitable at a flow rate of 2.5 LPM. However, sampling duration can be reduced by using a higher pump flow rate. The higher flow rate sampling for a shorter duration has not yet been tested.

The system uses a stainless steel sampling probe which is inserted in the exhaust pipe. The sample probe is connected to a heated line and to a filter cassette. The sampling line is heated continuously using power from the vehicle battery. A proper heated line is essential to make sure that there is no condensation in the sampling line. The sample on the filter is drawn using a calibrated constant flow pump. The system includes sampling probe, heated lines, filter cassette, moisture drier, constant flow pump, temperature sensor and a datalogging device. The temperature of the

exhaust gas at the pump location is recorded by the datalogger. During the sampling period atmospheric barometric pressure is also recorded. This information is useful in expressing DPM concentrations to standard conditions. In this system no attempt was made for isokinetic sampling as bulk of the DPM is in submicron size and, therefore, errors introduced due to partial inertia are considered small and non-isokinetic sampling significantly simplifies the sampling system.

Measurement is based on gravimetric analysis using glass fibre filters and 37 mm cassettes. A heated sampling probe is temperature adjustable to ensure that no condensation enters the cassette. The flow rate of the instrument is also adjustable although isokinetic sampling is not as critical as would be the case for mineral dust sampling and coarser particulate. Data collected from the DPM measurements will be integrated with the database in the UGAS software application.

The computer is a standard Pentium processor with 16 Meg RAM and a 1.6 GB hard drive running Windows '95 operating system. The UGAS software tool developed by NTC will be installed on the PC to communicate with the ECOM analyser. The software permits all parameters from the analyser to be communicated to the software and time weighted samples saved to a database indicated by user, time, date, vehicle, and description. As a companion to the UGAS application a multimedia tutorial outlining analyser operation, software operation, and test protocol steps has been developed by NTC and will be included in the software package. This provides an invaluable training tool as well as ongoing reference for the mechanics while testing. For remote support of the test apparatus the PC Anywhere software package will be installed to permit modem access to the computer by the project management team.

New tools that have been identified in the new maintenance practices and procedures that are computer based will also be integrated into the package after the baselining stage has been completed. This would include such possibilities as the Detroit Diesel Diagnostic Link that replaces the current ProLink with a computer interface and software application for diagnosing all DDEC engines. Additional possibilities could include a new or existing CMMS package and computerised parts manuals.

The entire package will be housed in an Ice Station industrial enclosure. The Ice Station is a sealed, filtered and locked enclosure containing all sensitive computer and electronic equipment. The computer keyboard and mouse remain external on a tray
with a window for viewing the monitor inside. The computer runs continuously allowing access with different security levels for mechanics to use 24 hours a day.

When a vehicle enters the shop to be tested the mechanic will bring the vehicle to the test station and initialise the analyser and software to begin the test sequence. Before any testing takes place the vehicle must be brought to full operating temperature.
With the gas probe inserted into the exhaust system the mechanic logs into the software application by user, vehicle number, and test location identifier. The sampling sequence incorporates a 60 second full load state on the engine. The load state is a full converter and hydraulic stall condition. During the 60 second sample the software acquires values for each parameter at the rate of 1sample/second. Upon completion the software then averages the 60 samples and saves one value for each parameter to the database.

Acquiring Baseline Data

Testing will be consistent over a one-month period on the profile of selected vehicles. The project leader will remain on site for the first week to assist and ensure that testing is being done accurately and the test apparatus is functioning properly. Remote support will be provided for the remaining three weeks of testing. Testing of vehicles during this stage will take place at 50-hour intervals. This frequency is much higher than the industry average of 150 but will be necessary for gathering of data for this study. An attempt will be made to baseline maintenance practices at the same time as the baseline sampling using an existing tracking system or one put in place for this project. It will be imperative that the mechanics involved with the testing understand that no additional maintenance or repairs beyond current practices are to be done while the vehicles are tested during the baseline stage. To help ensure this does not occur, the test sampling during the baseline stage will be done at the completion of the maintenance cycle on the vehicle in the shop. The last activity before the vehicle is released to production will be the gas and DPM sampling for acquiring baseline data.

The logging of test data will be automated into the testing process and saved to a database. DPM and gas sampling will run parallel in that both tests will be performed during each sampling session. Included in the database will be the following tables: Vehicle, Test Data, User, and Measurement Location. The Vehicle table will contain the following information: vehicle model, vehicle #, location, engine type, number of cylinders, number of exhausts, converter model, and transmission model. A user database will contain the user names, passwords and security rights. Measurement locations will contain all potential positions that data can be acquired on the exhaust system. The maintenance data will be acquired using a CMMS system or if one does not exist a paper or spreadsheet log will be kept. The data recorded will include engine system, engine sub system, maintenance activity, users, and vehicle number. The test matrix or data acquired for the engines will remain consistent for baseline and implementation stages. The parameters measured are as described in Table 1. The Vehicle Number, User, and Measurement location fields will point to lookup tables to link the static data associated with it.

Veh #	UserID	Name	Parameter	Parameter Values	RPM	Measurement Location	Time	Date
VL197	6624	Sean McGinn	Smoke, O2, CO, CO2, NO, NO2, DPM, Efficiency Lambda, Gas and Ambient Temps	xxxx	2300	Exhaust After Treatment Device	10:02	01/01/97

Table 1 - Parameter Test Matrix

The acquisition of baseline data will continue for a period of one month in total. This includes one week with the project team on site providing support followed by three weeks of testing by site personnel with remote support and supervision from the project team. Once the gathering of baseline data is complete a review meeting between the project management team and the site team will take place. An analysis of the baseline test results along with feedback from the on site maintenance team will determine whether the baseline data set is conclusive enough to proceed to implementation testing. There is a contingency that if the baseline data proves inconclusive this stage may have to be redone. Strengths and weaknesses encountered during the testing will be discussed at the meeting in order to assist in the remaining stages of the project.

Stage IV – Implementing and Measuring an Improved Maintenance Process

To begin the implementation of the new maintenance process we will first take the guidelines and practices outlined earlier in the project along with recommendations from the site review process and put them into place at the site. This would involve the addition of new tools for the mechanics to use in the maintenance of diesel engines. As mentioned earlier, this could include items such as the Detroit Diesel Diagnostic Link, Bosch Timing tools, Electronic Parts Manuals, and any combination of new tools and technology currently available. The UGAS technology employed for sampling and acquisition of data also serves as an excellent diagnostic tool. If a vehicle is tested and shows high emissions levels the mechanic will be able to use this as a trigger to employ further diagnostics. For example, if the CO levels are unusually high the mechanic could suspect a problem with either restricted air intake or excess unburned fuel. Using one of the other tools put into place for the project such as the Detroit Diesel Diagnostic Link, he could perform more refined troubleshooting on the engine in the case of a DDEC, and isolate the problem quickly. This would be two quick steps in detecting and isolating a problem that would have otherwise likely gone unnoticed.

In addition, there will be possible changes to existing maintenance practices such as frequency of Preventative Maintenance routines and filter replacement. The project team will spend one week on site with mechanics and maintenance personnel training and testing with these new practices and tools before beginning testing of emissions based on the new process. Who, what type of training and how much time will be required will be assessed prior to this stage.

The actual testing procedure and protocol will remain consistent with Stage III.
The schedule of every 50 operating hours will remain the same with an overall test period of 3 months. As with the baseline testing, we will be on site for the first week to
ensure accurate test results and assist the mechanics with any problems and questions. It is anticipated that the project team will make a field trip at the 6 week
interval to provide assistance and support. We will also be able to get an evaluation of the success and or failure of the testing to that point and make appropriate adjustments. In between the on site work the project team will maintain remote

support via phone, Internet and direct modem. As with the previous stage a review meeting between the project management team and the site team will take place upon
the completion of the 3 months of testing. Based on a review of the test data and discussion of any problems encountered during testing a summary report will be drafted. Once again, there is a contingency that if the summary report and the data collected during this stage proves inconclusive the testing may have to be extended.

Stage V - Analysis Of Impact

The initial analysis will be a measurement of the extent to which the new maintenance practices and procedures have been successfully adopted. It is to be expected that the practices and procedures as implemented will be less than 100% adopted. The level of success and factors affecting it will be analysed before attempting to analyse the actual test data.

Utilising the test data gathered from both the baseline and implementation stages a correlation of maintenance activity vs measured parameter values will be drawn. Each activity in the new maintenance process will be quantified and compared against baseline values. From this we will establish a criteria for success for each parameter. A modified exhaust quality index formula will interpret data from three of the most critical measured parameters. This index will allow a comparison of a single value measurement against maintenance activity performed for each test to determine quick evaluation of emission reduction.

Depending on the test site and the current systems in place, there may be a possibility to incorporate more advanced analysis. If there is an advanced CMMS system in place it may be possible to correlate individual maintenance practices to specific sized reductions in emissions. If the site tracks fuel consumption it may be possible to correlate changes in fuel consumption to changes in engine maintenance practices. These are possible scenarios only and will be looked at only if the systems are currently in place and data can be easily incorporated. It is beyond the scope of this project to look at incorporating such systems where they do not currently exist.

Data Analysis Variables

- Engine Type
- Engine System
- Engine Sub System
- Gas Test Values
- DPM Test Values
- Repair Types
- Engine Hours

Stage VI - Recommendations Based On Results

Based on the analysis of the collected data a list of recommendations and final report will be produced on the affect of maintenance activities on reduction of diesel emissions and DPM.

With quantified results from the data analysis recommendations will be written as to how specific maintenance activities affect exhaust emissions, DPM, and to what degree. The recommendations will be specific and mine operators will be able to use them to make changes to their maintenance program in order to improve exhaust emissions. The analysis criteria will be applied throughout mine maintenance departments who utilise this emissions measurement technology.

Costs and Timeline

Direct Costs

Hardware and Software (1 Unit)	$20,000.00
Use of UGAS technology	$0.00
Engine Diagnostic Tools (DDDL, Timing Tools, etc.)	$10,000.00
TOTAL	**$30,000.00**

Resource and Travel Costs By Stage *

Stage	Trips @ $ 1,500 per	Labour Costs	Total Stage Cost
Define Maintenance Practices and Resources		$16,800	$16,800
Site Review and Selection	$6,000	$21,840	$27,840.00
Evaluating Emissions Based on Current Practices **	$6,000	$13,160	$19,160.00
Implementing and Monitoring	$6,000	$19,920	$25,920.00
Analysis of Impact		$15,600	$15,600.00
Recommendations & Final Report		$21,000	$21,000.00
		TOTAL	**$126,320**

In Kind Contribution

Existing Development (Noranda)		$150,000.00
Mine Maintenance Department	$80/hr x 728 hrs	$58,240.00
Mine Usage – 4 months X 8 vehicles @ 1 day/week		$40,000.00

TOTAL PROJECT COST (Excluding In Kind)	**$156,320**

***** Travel costs have been allocated at $1,500 per trip until a test mine site has been selected. The resources required for fieldwork in this project will be drawn from Noranda Technology Centre, and CANMET. Travel will be from Ottawa, Ontario and Montreal, Quebec.

****** There is a contingency that the baseline stage will be repeated if the data set proves to be insufficient. This will double the baseline resource and travel costs.

Personnel

This project will utilise resources and collaboration from several organisations. The list of organisations includes:

- Noranda Technology Centre – Sean McGinn, Philippe Gaultier, Donald Thibault
- Mine Site (yet to be chosen) – 1 project champion and 2 mechanics *****
- Diesel Engine Manufacturers (yet to be chosen) – x2
- CANMET – Dr. Mahe Gangal

***** Although mine production personnel will be encouraged to participate in the project with questions and feedback, they will not be involved in actual testing and maintenance practices.

Technology Transfer

Technology transfer will take place over the entire course of the project. The exchange of information will take place through meetings, training, reporting, and analysis of the testing in conjunction with the mine operators and maintenance personnel. Union Health and Safety representatives will be included in pre and post project meetings to expand the transfer of technology beyond one test site.

Environmental Health and Safety

There are no environmental health and safety concerns anticipated in the work of this project. All tasks should fall within the normal working practices of the mine operator.

Benefits

The perceived benefits of this project can be weighed against the costs to undertake it. Costs can be divided into three categories, resources, capital, and in kind contribution. Total cost for the project will be in the area of $156,000. The largest portion of this total will be allocated to labour resources followed by capital expenses. In kind contributions are not included in this total.

The principal benefit of this work will be improved air quality in the underground work environment and better health. Improved maintenance on diesel engines is an area of work that directly targets the source of DPM and underground air pollution. Secondary to this but no less significant is the improved performance that will result from better maintenance. Improved performance results in increased production with direct implications on the bottom line. Improved availability is generally offset by utilization so that actual operating hours remain constant. An increase in vehicle availability and improved performance in the muckpile on top of cleaner engines adds up to a healthier and more cost efficient mine.

Deliverables

Milestone	Deliverable Date
Define maintenance guidelines, practices, and resources	
Established maintenance review process	
Conduct review process and site selection	
Emission evaluation data based on current practices	
Emission evaluation data based on new implementation	

Analysis and correlation of baseline and implementation data	
Recommendations and final report	

Implementation Issues

Due to the nature of this project and the mine environment where it will be undertaken there may be unforeseen issues which could change the scheduled progress.

- Control of outside issues would likely be the largest variable to contend with. This would include such things as inconsistencies in fuel and lubrication, vehicle abuse, and loss of vehicle to mine environment (buried in stope).

- Although the project management team will do everything in its power to ensure accurate data collection, consistency while not on site can cause problems. We will attempt to be on site as much as possible to ensure thorough training and understanding of the project.

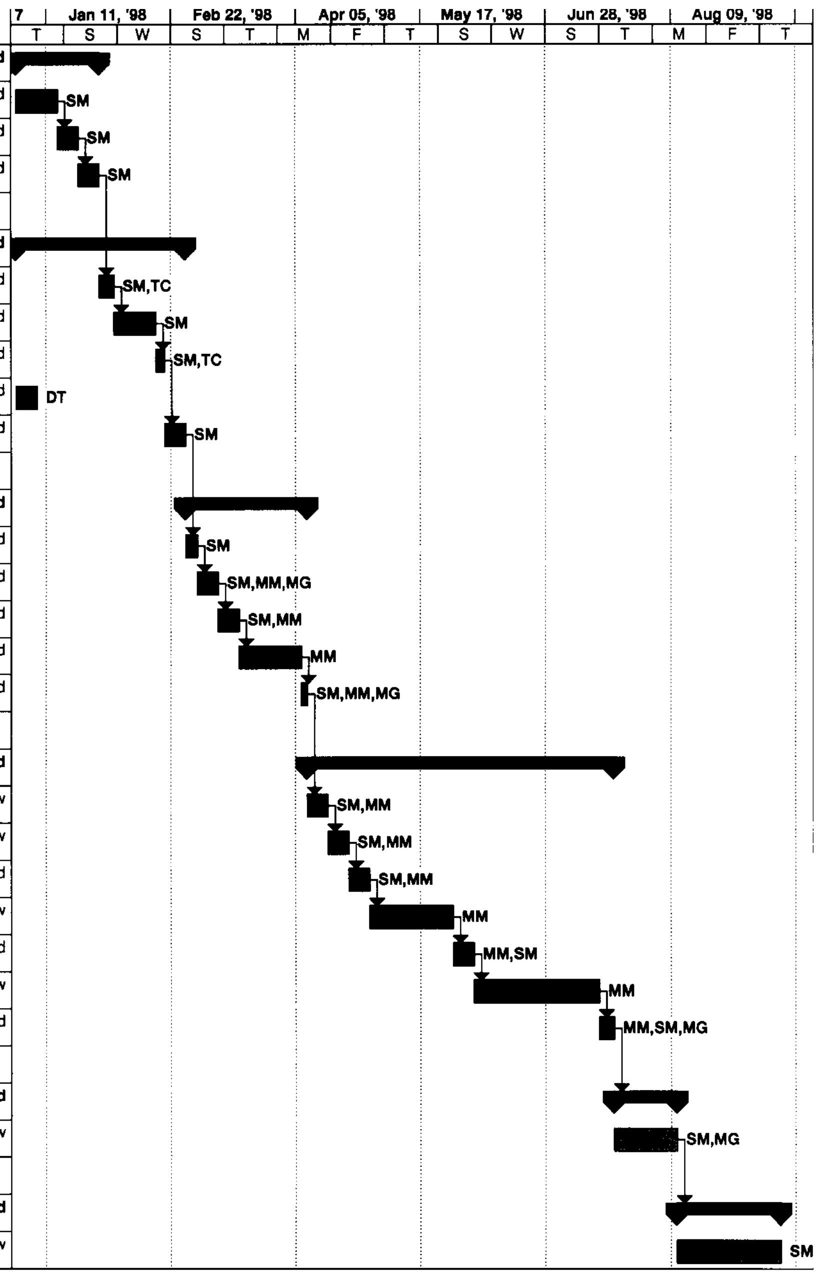
- Mine production dictates over maintenance concerns in every underground operation. Regardless of how well we plan and communicate this project to all affected departments we will still be at the mercy of the mine production department. This will affect such things as the availability of equipment and mechanics.

- All test equipment will be thoroughly tested before being transferred to the mine site. Due to the length of the project and exposure to mine environment and new personnel there will be a risk factor to the test equipment. We will attempt to minimise this through training and availability of spare parts.

- During the baselining stage the mechanics will be inclined to make repairs to the vehicle during the emissions testing instead of making the emissions test only. This is a natural reflex for a mechanic and will need to be over emphasised during training.

Timeline Gantt Chart

ID	Task Name	Duration
1	**Define Maintenance Practic**	**20d**
2	Consult with authorities t	10d
3	Identify resources and pr	5d
4	Establish site mtce reviev	5d
5		
6	**Site Review and Selection**	**41d**
7	Identify potential sites	3d
8	Conduct review process	10d
9	Identify candidate site	3d
10	Modify software for test	5d
11	Assemble MS & UGAS u	5d
12		
13	**Evaluating Emissions Base**	**29d**
14	Set up test apparatus on	2d
15	Training on test apparatu	5d
16	1st week on site testing	5d
17	3 weeks testing with rem	15d
18	Post baseline meeting &	2d
19		
20	**Implementing and Measurin**	**73d**
21	Put guidelines and practi	1w
22	Train mechanics on new	1w
23	1st week testing on site	5d
24	4 weeks testing with rem	4w
25	1 week mid term support	5d
26	6 weeks testing with rem	6w
27	Post test meeting & revie	3d
28		
29	**Analysis of Impact**	**15d**
30	Correlation of measurem	3w
31		
32	**Recommendations**	**25d**
33	Report and recommendat	5w



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Task		Rolled Up Task	
Progress		Rolled Up Milestone	◇
Milestone	◆	Rolled Up Progress	
Summary			

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Resource	Identification
SM	Sean McGinn, Noranda Technology Centre
MG	Dr. Mahe Gangal, CANMET
MM	Minesite Maintenance Dept.
DT	Donald Thibault, Noranda Technology Centre
TC	DEEP Technical Committee