

Ventilation control system implementation and energy consumption reduction at Totten Mine with Level 4 Tagging and future plans

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Abstract

Totten Mine has been operating a ventilation control system (VCS) with remote activation capabilities under a manual mode since 2014. The system consists of on/off and variable frequency drive fans, variable opening louvers and doors to regulate the airflow across levels, ramps and headings. Parameters that are monitored within the VCS include air volume, relative humidity, dry bulb temperature and carbon monoxide. All of the VCS components installed and commissioned in 2014 were operational during the mine production ramp-up from 2015 to 2016. The managed ventilation system demonstrated its ability to accommodate the airflow requirements of the mine in an effective and efficient manner during this time. However, changes to the mining plan generated an increase in required air volumes. It was determined these could be accomplished by further enhancements of the ventilation control system. As a result, during 2016 the automation and ventilation departments reviewed the alternatives available in the market and selected the NRG1-ECO software provided by Bestech to achieve a tag and tracking-based level of automated ventilation control.

The implementation of the software started at the end of 2016 with a single level and was then expanded to additional levels. This paper presents the state of the current VCS at Totten Mine in terms of the levels that have been commissioned, the control strategies in use and the energy reduction achieved in the range of 50 to 60%. These are compared to the baseline established before the implementation. Challenges encountered during commissioning, maintenance and the plan for future implementation and software versions are also discussed.

Keywords: *ventilation control system, mine wide implementation, measured and estimated savings*

1 Introduction

Totten Mine is located in the Sudbury Basin, Ontario, Canada. It recently resumed operations at the end of 2013 and was equipped with a ventilation control system (VCS) which was managed from a centralised surface control room that allowed for manual remote control of fans, louvers and doors. The ventilation infrastructure consists of main surface fans that are equipped with variable frequency drives (VFD), ventilation monitoring stations (VMS), louvers, doors and on/off auxiliary fans. All of the ventilation system components have the ability to be started, stopped or regulated (VFDs, louvers and doors) from the surface control room. The VMSs monitor air velocities (which are converted to a volume flow), relative humidity, dry bulb temperature and carbon monoxide. The initial VCS provided centralised remote control activated manually, which is known as Level 1 or Manual Control strategy as per Tran-Valade and Allen (2013).

Totten Mine was able to achieve significant savings with the manual control strategy in place. The savings were in the range of 25% of the annual ventilation energy consumption considering electrical power for fans and natural gas for heaters during winter months (Acuña & Allen 2017). These savings came from reducing the operational speed of the main fans through their VFDs, thus adjusting to specific mine volume requirements instead of using the main fans at full capacity. The control was achieved with the assistance of the ABB 800xA control system program (ABB Ltd 2017).

By the beginning of 2016, as the tag and tracking system was installed and commissioned, Totten Mine started the work to expand from Level 1 Manual Control strategy towards Level 4 full automated control. This involved introducing the Bestech NRG1-ECO control system program (Bestech 2017) coupled with the ABB 800xA (Acuña & Allen 2017). The hybrid approach employed considered the NRG1-ECO program acting as the 'brain' giving the control commands through the ABB 800xA program, the 'body', for all the control strategies or control levels considered from manual to fully automated (1 to 5) control. In particular, the Manual Control strategy could be operated from both programs as a failsafe.

The following sections will summarise the initial plan for implementation in terms of the areas or levels of the mine targeted, sequencing the control strategies considered and additional program features requested. The functionalities of each control strategy are described in terms of their current use at the mine site, and future potential use. A comparison is then made between previous initial saving estimates and the actual results that the mine has been able to track through the current implementation where the different control strategies have been commissioned.

2 Ventilation control system implementation plan and execution

The initial installation of NRG1-ECO considered two working fronts: control software installation, and modifications to address the mine site-specific requirements. Most of the requested changes targeted site-specific ventilation control requirements, ease of use for the control room supervisor (CRS), and ease to quickly display relevant information from multiple inputs for quicker troubleshooting. The new program was expected to provide the Totten Mine ventilation control system with these additional control strategies: Level 2 Scheduling, Level 3 Event Based, Level 4 Tagging and ultimately Level 5 Environmental. The implementation plan was developed and executed with interesting results and learnings for the mine site and Ontario operations.

2.1 Implementation plan for mine levels and software

The deployment plan at Totten Mine was based on a 15 month project schedule, from October 2016 until the end of 2017, breaking the work packages into three batches of mine levels. The first batch consisted of a single pilot implementation on 3030 Level which was currently an active production area but contributed less from its three production fronts in the mine in terms of ore generation. The 3030 Level was selected first as it had all the infrastructure required and was already managed remotely from the surface control room. It was commissioned with the control strategy Level 4 Tagging employing fresh air raise (FAR) louvers, return air raise (RAR) louvers, on/off auxiliary fans and VMS equipped with airflow, carbon monoxide, relative humidity and dry bulb temperature sensors. By commissioning only one active level, it provided the opportunity to prove and troubleshoot the system in a representative working area, while minimising potential impact to the scheduled production but demonstrate the energy savings (at Level 4) and at the same time assess the integration of systems that were previously installed but operated independently. Potentially, with tagging-based control, the mine would have additional air volume available for other areas as the control strategy Tagging was expected to result in less average air volume being demanded on 3030 Level.

The second batch of mine levels for implementation mainly included the areas that already had all the operational ventilation infrastructure in place and working (doors, louvers, on/off fans, VMSs). The third and final batch considered all other levels with only partial control of infrastructure. In total, 14 mine levels were scheduled, at approximately one level per month, for integration into the ventilation control system. In order to properly address the challenges presented by this multidisciplinary implementation effort, the resources were allocated according to the requirements from the following departments: project management, electrical, automation, information technology, ventilation and the software provider Bestech.

As part of the review process of the ventilation control system software, the Totten Mine team requested enhancements to NRG1-ECO, version 3.5, to manage the ventilation system according to specific mine site requirements. All the requested modifications were scoped and the development of two new version

upgrades of the program were included as part of the project plan. Phase 1 implementation deployed the initial software version 3.5, and the two following phases will deploy the newer versions with increased functionality, respectively versions 3.6 and 4.0. The enhancements within version 3.6 were for the control of the auxiliary fans, while version 4.0 addressed the main fan control. The two version upgrades are planned to be executed during 2017.

2.2 Implementation execution and control strategy learnings

As described by Tran-Valade and Allen (2013), the five control strategies are as follows: Level 1: User Control or Manual Control, Level 2: Time of Day Scheduling or Scheduling, Level 3: Event Based, Level 4: Tagging and Level 5: Environmental. These control strategies, their implementation and use at Totten Mine will be described in the following paragraphs.

Level 1 as applied at Totten Mine allowed for turning on and off auxiliary fans, adjusting the speed of the main fresh air and return fans (RPM), setting louvers to desired fixed openings or airflow volumes with a proportional integral derivative (PID) loop control, and positioning doors to a fixed opening. The Manual Control strategy heavily relies on the CRS who could, in theory, effectively and efficiently operate the ventilation of the mine. However, managing the ventilation control system on multiple mine levels is time-consuming and the CRS also has other responsibilities relating to pumping, crushing, material handling, and hoisting, among others. As a result, the ventilation control device settings were usually fixed at the beginning and end of the shift according to development activity and production blasts respectively. The purpose of the latter was for quickly clearing the mine of fumes to enable workers to go back underground in the shortest possible time. Changes to ventilation device settings during the shift are unusual and commonly concentrated around turning on fans that were not running when a worker entered an area later in the shift. After the auxiliary fans are turned on, they usually remained in that state. It was not the mine's common practice to call the CRS to shut down fans when leaving an area.

Currently, the Manual Control strategy savings are concentrated as being from the main surface fresh air and return fans, which are tuned by speed control seasonally due to significant mine volume changes from natural ventilation pressure. Normally in summer, the fan speeds are set higher than during cooler seasons. This is due to the temperature difference between underground and surface being smaller, and as a result, the natural ventilation pressure is less (McPherson 1993). Due to the extreme winter temperatures, the fresh air fans are equipped with mine air direct-fired heaters to provide adequate temperatures during winter months. Therefore, the measured savings reflect reductions in terms of both electrical power and natural gas usage. To date, Level 1 energy savings at Totten Mine have been estimated and confirmed through measurement as in the range of 25% (Acuña & Allen 2017).

Level 4 Tagging, considered to provide the largest energy benefits, was a major step from Level 1 Manual Control. Therefore, significant effort was concentrated in making this transition successful. Level 5 Environmental control was also coupled with the Tagging implementation, but only as a failsafe measure to prevent carbon monoxide (CO) contaminant levels going over pre-set values based on the prescribed current time weighted average (TWA) occupational exposure limits for a workshift as defined by Ontario Regulation 833 (Queen's Printer for Ontario 2016). Because Ontario Regulation 854 (Queen's Printer for Ontario 2017) prescribes 100 cfm/BHP (0.06 m³/s per kW), worker exposure to CO is already controlled well-within the limits, however, they could go over the TLV following a blast. In this situation, the activation of the Environmental strategy would assist in the quicker clearing of blast gasses.

Level 5 Environmental has been shown to potentially be the ultimate control strategy to deliver the largest savings. However, this statement assumes that the ventilation is driven by engine-specific diesel emissions and/or actual environmental exposure conditions. It is common for current diesel-powered equipment running underground to have a motor–fuel–maintenance combination that requires less than the regulated 100 cfm/BHP to adequately dilute emissions to meet an air quality standard, as per CANMET-MMSL measurements (Natural Resources Canada 2017). However, additional consideration may be required for temperature and mineral dust.

Consideration for commissioning the system in stages was to allow the various stakeholders time for training and to adjust. At Totten Mine, the CRS was required to be very knowledgeable of the system's operation, hence the need to become comfortable and competent in operating the new tool in incremental steps. Because all the CRSs were trained on Manual Control via the ABB 800xA system, it was logical to train them in the equivalent control strategy of the new program, and at the same time receive training in the Tagging and Environmental levels of control. The Tagging and Environmental control strategies became relatively easy to assimilate as the new program would automatically perform the tasks they used to manually initiate at the beginning and as requested during the shift, namely turning on and off auxiliary fans and adjusting louver opening positions or PID control loop airflow volumes. Their tasks changed from manual adjustments to visually monitoring the settings during and at the end of the shift to validate that they were correct. The CRSs felt this was a significant improvement, and it was very well received.

From the start of the project, employees were familiarised with the new functionality and behaviour of the ventilation system where fans would start in an automatic mode as soon as they received signal from a personal or vehicle tag and shut down at a set delay time after they left the area. Simultaneously, the fresh air raise and return air raise louvers would automatically adjust to accommodate the air volume required on the level specific to the activities taking place.

Level 2 Scheduling capabilities were available as part of the Phase 1 execution, but initially it was not fully implemented. The mine site felt that for auxiliary fans, Level 4 Tagging was able to provide all the savings that Scheduling could offer and significantly more. Similarly, full Level 3 Event Based control was considered for Phase 2 of the software implementation, and Phase 3 included controlling the main surface fans (FAR and RAR) to meet Totten Mine specifications.

Level 2 Scheduling was used as a backup to still ensure energy savings in the event the Tagging control function was not working. The Tagging control strategy requires several systems to be working as designed and simultaneously. It was identified early in the implementation that when a failure occurred, the tag and tracking system based control would be prevented from running properly. In these situations, the Scheduling control strategy could be effectively used to shut down or start auxiliary fans at the end or beginning of the shift, or in co-ordination with blasting schedules, as well as modulate the air volumes of the main fans during identified periods. This allowed the mine site to ensure a base level of savings with the Scheduling control strategy during the period of time Tagging may not be working. The Scheduling control strategy was also applied towards repeated actions around a certain sequence of events and being able to execute them at any desired time. For example, during blast clearance, initiating the shutting down fans once blast fumes have cleared in affected mine areas and then their re-activation for workers at the beginning of their next shift.

Level 3, by definition (Tran-Valade & Allen 2013), enables the possibility to program particular responses of the ventilation control system according to different inputs that are not already part of the pre-defined control strategies in levels 2, 4 or 5. Level 3 needs to be developed as a 'tailored suit' for each mine site. For example, the use of Level 5 Environmental coupled with Level 3 Event Based control could potentially yield significant savings. Both provide the operation with a better use of the main fan supplied air volume as a function of the time of the day and the expected in-shift or between-shift activities.

Even though the control strategies have been described as providing incremental levels of savings (Tran-Valade & Allen 2013), site-specific factors will decide which ones, their sequence, and to what extent, will provide the best energy savings (Acuña et al. 2016).

3 Achieved savings and future expected savings

Table 1 presents the initial estimated expected savings for Totten Mine from implementing the Level 4 Tagging control strategy, these were calculated in 2016 before execution of the project, and the percentages given are relative to the baseline (Acuña & Allen 2017). As summarised, Level 1 control strategy was confirmed through measurement to deliver 25% savings, and Levels 2 to 4 Tagging control strategies as implemented through NRG1-ECO (without considering main fan control) could potentially deliver an additional 18%, for the combined reduction of 43%.

Table 1 Relative energy consumption cost reduction estimate with auxiliary fan Tagging (Acuña & Allen 2017)

Ventilation energy cost	Main fans	Natural gas	Auxiliary fans	Total
Baseline (full RPM)	40%	16%	44%	100%
Level 1 operation (measured)	20%	11%	44%	75%
Bestech NRG1-ECO VCS (estimated)	13%	10%	34%	57%
Difference	27%	6%	10%	43%

It is further estimated that Level 4 Tagging and integrating main fan control could potentially deliver an additional 7% reduction for a total projected saving of 50%. As mentioned, the mine has already realised half this benefit, i.e. a 25% reduction.

With the main fan control feature, if implemented, the primary surface fresh and return air fans would modulate the mine air volume according to the underground requirements for control strategies Level 1 to 5. It is expected that a minimum fixed volume will always be required from the main fans depending on the time of the day, and that control strategies from Level 2 to 5 should be able to provide the variable component input to modulate the main fans according to requirements as long as the system is operational.

The 18% incremental savings were based on the anticipated savings from Scheduling through Tagging only. Environmental control is solely used in the background to support gas clearing, exceedances and other events. Tagging savings were expected to account for any improvements that Scheduling and Event Based could generate. It should be kept in mind that the main focus was to go from Manual Control to the Tagging control strategy, and that the initial estimate was conservative based on the knowledge and information available at that time from a small system at another Vale Ontario mine.

Table 1 also presents the relative contribution of energy cost consumed by the main and auxiliary fans as well as mine air heating. Within the additional 18% energy reduction estimated from the NRG1-ECO VCS Tagging control strategy implementation, over Level 1 operation, the largest relative contribution was from the auxiliary fans at 10%, followed by the main fans at 7% and only 1% additional reduction in heating costs. The auxiliary fan savings resulted from shutting them down 28% of the time, which was considered a conservative estimation of the average idle time.

As of February 2017, the ventilation control system at Totten Mine has been operational for three months. December 2016 and January 2017 operated only at the mine pilot level, and February 2017 at three mine levels. Of the three mine levels, two were active mining areas and the third was an old mining level with significant infrastructure mostly dedicated to maintenance and electrical shops, explosive storage, wash bay and supply storage among others.

Table 2 presents an updated summary of energy savings based on actual results that Totten Mine has achieved to date. As shown, the savings of the main fan power and the natural gas are grouped under 'Main' as both are obtained with the reduction of total air volume into the mine. 'Auxiliary' represents only the power savings achievable through the secondary distribution fans.

Table 2 Updated summary of savings per level of implementation of control strategies at Totten Mine

Ventilation energy cost	Totten Mine ventilation control system		Initial savings estimate		Updated savings estimate		Updated estimated and achieved savings	
			Main	Auxiliary	Main	Auxiliary	Main	Auxiliary
Level 1	ABB 800xA	Manual control	25%	0%	25%	0%	24.9%	0%
Level 2	Bestech NRG1-ECO version 3.5 and 3.6	Scheduling	8%	10%	8%	9%	0%	11.6%
Level 4		Tagging auxiliary fans	0%		0%	9%	8%	10.1%
		Bestech NRG1-ECO version 4.0	Tagging auxiliary and main fans	7%	0%	7%	0%	7%
	Total		50%		58%		61.6%	

Note: Bold figures are estimates.

Further analysis into the potential idle time of the auxiliary fans determined that about another 25% of the time these fans could be off, reflecting the time between shifts when no workers were in the mining areas and blast clearance was not required. This would equate to another reduction of 9% of the total ventilation expenditure, through the use of Tagging, as compared to the initial estimate for auxiliary fan savings that could be achieved mostly with the use of Scheduling. Further, the main fans could potentially provide some savings if also used under a Scheduling control strategy, but only until the integrated Main Fan Control is implemented. At that time, increased savings over Scheduling are anticipated.

By the end of the first week of February 2017, a scheduled change was required for the Tagging system-based control. This was due to changes in the mine configuration. As a result, the Tagging control strategy was disabled and the Scheduling control strategy initiated to secure continued power reduction over baseline. The value of 11.6% savings given in Table 2 for Scheduling is based on three weeks of data from the three working mine levels, which was slightly larger than the revised estimate of 9% presented in Table 2.

As indicated earlier, an initial 10% saving was estimated from Scheduling, Event Based, Tagging and Environmental for the auxiliary fans from an idle time of 28%. Through the use of the Tagging control strategy, it was observed to consistently deliver considerably larger savings for the application at Totten Mine. After separately reviewing the potential savings for Scheduling and Tagging, the new estimate for Tagging alone was an additional 9% from the auxiliary fans. The measured results indicated that Tagging could save 10.1% for auxiliary fans.

At this stage of the implementation, the potential energy reduction benefits of Event Based or Environmental control have not been estimated. However, there is potential opportunity with the controlled blast clearance feature to reduce the re-entry time and/or provide additional time for the auxiliary fans to be off and the main fans working at reduced speed compared to the current manual practice.

The updated 8% estimated savings from Scheduling through to blast Environmental control, and the updated 7% estimated from the main fan control are yet to be proven and are not scheduled to be tested until later in 2017, but have the potential to further enhance the achieved savings by 15%.

The preliminary results of the pilot level indicated that, on average, 50% of the air volume previously allocated to a mining level is not required when the Tagging control strategy is activated. This potential opportunity could not be capitalised in savings from the main fans to date. However, it is a very encouraging measure indicating that the expected 15% savings estimate could be underestimated. In order

to significantly impact the air volume delivered by the main fans and produce measurable data, it is estimated that at least five to six mining levels would need to be working with the Tagging control strategy and the integrated Main Fan Control feature.

As detailed, the overall energy reduction estimate for Totten Mine has increased from an initial 50% to a revised 58% of the original baseline due to better differentiation between Scheduling and Tagging savings. However, proper estimates for Event Based and Environmental still need to be developed, which could expand the total potential savings even further. Based on the early measured savings, which are in the range of 46.6%, and considering the estimation of an additional 15% that should come from the fully integrated Main Fan Control, the total reduction in energy could reach 61.6%, but this remains to be proven. Nevertheless, the current measured savings of 46.6% are significant and very encouraging for the rest of the ventilation control system implementation at Totten Mine and across other Vale operations.

4 Conclusion

Totten Mine is in the process of implementing all five control strategies offered by the Bestech NRG1-ECO software package, namely Level 1 Manual Control through Level 5 Environmental to manage their ventilation system. However, the primary focus is on reaching the Level 4 Tagging control strategy which was initially estimated to have the greatest potential cost benefit for the type of infrastructure already in place at the mine site. At this time, aspects of Level 5 Environmental are only used as a failsafe during non-active blast clearance periods. Legislative change would be required to allow for its full potential.

The system's deployment and implementation across 14 mine levels began in the last quarter of 2016 and is planned to continue through to the end of 2017. The results to date are encouraging, and it is forecasted that the implementation timelines will be met and that the expected savings will be achieved or surpassed within the project's initial budget.

The implementation of such a ventilation control system has been and continues to be a learning process in terms of how best to apply and develop the system features and in the estimation of the savings that can be achieved for a business case. The NRG1-ECO tool is also being further developed to meet all the needs of control at Totten Mine. Its current version has been measured as delivering 46.6% before integrating Main Fan Control, with a limited time dataset, and the final version is expected to further enhance the expected energy savings to 61.6%, or even surpass them by the end of 2017. The remaining challenge will be to adequately sustain the ventilation control system to maintain and secure the achieved savings over time.

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