From development to evaluating effectiveness in industry: Building a research model for noise control technology efforts[1)]

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The National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) hearing loss research program recognizes the importance of developing effective noise controls, as well as evaluating the technology transfer and industry usage of control technologies. As a way to focus on the direct impact of NIOSH-developed control technologies on reducing noise induced-hearing loss (NIHL), a structured research model was developed to include metrics that help to more accurately evaluate and measure the effectiveness of noise control technologies. Through the development of a process model, a more structured procedure is created to analyze the effectiveness during the development, refinement, promotion, and long term evaluation stages of noise control products. The model creates a more transparent and consistent process to evaluate control technologies with metrics identified at each stage. This paper discusses the architecture of the process model and its associated metrics to reduce occupational NIHL in the mining industry. Several noise controls developed for equipment used in underground mining serve as examples to illustrate where current research gaps exist and how they are being addressed with this new model. This research structure can serve as a model for researchers and academics to assess the development, dissemination, and evaluation of noise control technologies.

1 INTRODUCTION

In 1996, NIOSH published the National Occupational Research Agenda, which identified hearing loss as the most common job-related disease in the United States[1]. More recent studies estimate that 22 million workers are still exposed to hazardous sound levels[2]. Despite more than 30 years of noise regulation in the mining industry, the 76% prevalence rate of miners exposed to hazardous noise levels is higher than any other industry sector[2]. Although miners use hearing protection more than most other worker groups, they also have a high prevalence (24%) of reported hearing difficulty[3].

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To address the high rate of noise induced-hearing loss (NIHL) in the mining industry, the Mine Safety and Health Administration (MSHA) implemented regulations regarding noise exposure. Historically, mine operators relied on the use of personal hearing protection devices, such as plugs and muffs, to prevent hazardous noise from causing NIHL. However, this strategy did not sufficiently reduce the effects of noise overexposures among mine workers[4]. In 1999, MSHA promulgated a rule that put an emphasis on engineering and administrative controls to reduce worker overexposure to noise[5]. The rule established that use of hearing protection would not be factored into determinations of compliance with the permissible exposure level of a time-weighted average of 90 dB(A) over an eight-hour time period. However, personal hearing protection devises are required for mine workers that are overexposed to noise. Proven noise controls are incorporated into MSHA guidelines as "technologically achievable" and must be used to reduce worker exposure[6]. This approach shifted attention to the development and implementation of noise controls to reduce worker exposure.

The mining industry pursued the development and implementation of noise controls to be in compliance with federal regulations. However, mining companies and equipment manufacturers did not have the necessary resources to achieve meaningful results. Collaborations between industry organizations and government agencies were established to facilitate noise control development and implementation in the mining industry[7]. An example of this collaboration is the NIOSH Office of Mine Safety Health Research (OMSHR) hearing loss program, which provides technical expertise to aid industry partners in the development and implementation of noise controls.

The solution implementation and information transfer within the mining industry needs to be better understood so that new technologies related to reducing noise are accepted and utilized. Regulations alone will not disseminate noise control technology in the most efficient manner. On their own, neither will the research and development of effective controls. The development of a process model helps link the typical measures of control technology success (e.g. sound levels, exposure, durability, etc.) with measures of implementation and usability. The process model adds components that go further to address industry-wide exposure reduction and dissemination to bring about long-term reduction of NIHL.

2 LIMITED EVALUATION OF RESEARCH PRODUCTS

The success of the NIOSH mining hearing loss research program is linked to the integration of developed noise control technologies and research products that assist in the reduction of NIHL. Historically, the research program did not systematically evaluate the implementation of noise controls in order to link its efforts to reduction of NIHL. From an evaluation perspective, the program focused on developing noise controls that could bring noise exposure within compliance with federal regulations. It was clear that this approach was not enough to link the research program's noise control products to potential reduction of NIHL because showing the control is effective with a small sample doesn't necessarily lead to industry-wide risk reduction.

This limited evaluation also did not fully assess whether developed noise controls met industry stakeholder needs and expectations. Researcher awareness of how to best meet these expectations was identified as critical in achieving broad industry acceptance and usage of noise control products. Researchers realized there were opportunities to capture data on industry implementation and long-term effectiveness. These include metrics such as machine operation and production standards that are maintained or improved with the application of noise control technologies. Researches also recognized that understanding industry perceptions of noise controls and incorporating this information into technology transfer products could improve industry acceptance and usage of noise control.

In order to make the case for linking program efforts to potential reduction in cases of NIHL, a structured research model that linked multiple research stages was needed. While this model would include stages such as noise control development, and capturing broad industry implementation and usage, there was an awareness of other stages that could be tracked and measured in the research process. In addition to identifying distinct stages in the research and evaluation process, it was determined that corresponding metrics were critical in capturing how a control technology moved through the research process and what impact it was having in the mining industry.

3 RESEARCH PROCESS MODEL

The need for a structured research process that showed direct linkage to the reduction in the incidence rate of NIHL resulted in the development of a research process model. Figure 1 shows the process model and its associated stages. This model moves through detailed phases of research, development, and assessment of control technologies. Each stage of the model has corresponding metrics, which create a more transparent and consistent process to evaluate control technologies.

A key characteristic of the process model is the break-out of six stages of research activities that are practiced in an iterative process. Each research component shown in Fig. 1 has both input from a previous stage and output to the next stage. This creates a information feedback loop that guides research to achieve program goals. This structure creates the opportunity to build knowledge and refinement of the model metrics and evaluation efforts. Through this iterative process, best practices are developed that can be implemented during the research, development, and analysis of future control technologies.

The research process model delineates the stages with accompanying metrics built from noise control engineering, industrial hygiene and social science disciplines. The multi-disciplinary metrics associated with each stage of the process model is a key characteristic that separates this model from other research structures. The process model was developed by considering engineering, socio-cultural, and audiology factors. These varying perspectives enable researchers to think more broadly about what determines the success of a control technology. These multi-disciplinary metrics are integrated into each stage of the process model. In addition to standard engineering measures of noise control development and evaluation, awareness of the social, cultural, and behavioral work practices that will impact usage and acceptance are integrated into the research process. Also the tracking of audiometric surveillance data are conducted in partnership with the standard noise control research processes. These multi-disciplinary metrics help to improve the link between research program products and the reduction of NIHL in the mining industry.

4 PROCESS MODEL METRICS

Success at the different stages of research within the process model is measured by specific metrics. These stages were identified as distinct levels based on research activity goals that define success at a particular stage. Examples of metrics and data sources are shown in Table 1 for each research stage. There are multiple metrics at each stage, and each stage may have a different number of metrics that determine success.

The process model is a combination of six stages of the research activity. Each stage has metrics and success indicators that help determine if research products are making an impact and reaching the final goal. The following sections outline the process model stages with research activity descriptions and sample outputs.

4.1 Needs Assessment

The needs assessment phase uses evidence to identify and prioritize research goals. Where possible, the evidence is compiled from existing surveillance and stakeholder input databases. New evidence and data is collected in this phase if existing databases are insufficient to identify research gaps and priorities. Existing noise controls are evaluated in this phase to determine whether they are working or if new technologies need to be developed. The output of this phase is information used to justify and plan new development projects. The information defines the extent of the need and the type of control needed (either a purely engineering solution or a solution that entails a combined engineering and behavioral approach).

4.2 Development

The development phase involves the steps needed to develop, test, and refine noise controls to the point that they are likely to work successfully in a mining workplace. This occurs through a series of identification, quantification, design and testing steps. Noise controls are developed, evaluated, and laboratory tested to reduce sound levels generated by equipment components. Input from equipment manufactures and stakeholders are gathered to incorporate cost, manufacturing, maintenance, and durability metrics. The product is then evaluated in a working mine site environment.

In addition to their ability to reduce noise, the durability and practicality of noise controls are examined during field testing. Behavioral analysis is incorporated into the development process to examine the social, behavioral, and cultural elements that influence and impact noise control use and acceptance within a workplace. The outputs of this phase are lab-tested products that are ready for short-term effectiveness evaluations.

4.3 Short-Term Effectiveness

Final design research products are tested at a small sample of mines to determine whether they meet short-term goals. The duration of testing depends on the design objectives for the control and can vary from a few days to several months needed to determine whether it functions successfully at the sample worksites. Several factors such as noise exposure reduction, durability, and auditory response data serve as short-term goals and determine success at this stage. This information determines whether products achieve expected benefits, or whether additional refinements are needed before technology transfer.

Several acoustic quantities are used to determine if developed controls are successful. Sound pressure measurements are performed at the operators’ position to determine A-weighted levels and frequency content. These measurements are performed while trying to control as many operation and environmental variables as possible. Dosimetry is used to understand how the worker is exposed to noise over a work shift. Both of these measurements are performed before and after noise control implementation to determine success. Time-motion studies coupled with dosimeter measurements are conducted to correlate cumulative noise exposures as record with various operational tasks or procedures. This information can be used to better understand worker influence on the utilization of a control technology.

Data on auditory changes is also used to assess short-term effectiveness. A promising short-term measure of these changes involves assessing temporary shifts in otoacoustic emissions (OAEs). OAEs are low amplitude sounds emitted from the ear in response to sound. Research has shown that the emissions tend to be temporarily lower in amplitude after exposure to noise. In this evaluation, it is expected that exposure reductions related to implementation of noise controls will be confirmed by lower rates of temporary emission shifts. OAEs are measured twice a day (before and immediately after a workers full-day's use of the machine) and the two measurements are compared to see whether the emissions are reduced. The emission shifts are assessed before installation of a noise control product and again after installation. The assessment continues periodically during the life of the control to correlate auditory changes with patterns of noise exposure.

4.4 Technology Transfer

Technology transfer occurs through a two stage approach. The first stage includes securing equipment manufacturers for production and commercialization of each product. The second stage focuses on the development of technology transfer materials for targeted audiences. It includes a systematic dissemination plan that makes effective noise controls available and accessible to all potential users. Information on stakeholders identified from the needs assessment stage is used to identify potential users in "market segments" and make the controls accessible through a mix of media targeted to reach the segment effectively. These methods include a combination of marketing, educational, or training materials dependent upon the target audience. These materials are disseminated through media identified as appropriate for the particular target audience (e.g. web-based materials, industry trade publications, information circulars, refereed journals, and workshops).

4.5 Long-Term Effectiveness and Industry Usage

Long-term success can only be achieved if the effectiveness of a research product persists beyond the initial intervention effort. Success criteria will vary by the type of control, but long-term generally refers to improvements that are maintained or increased with continued use of the control. Depending on the design criteria for the control, the duration of this phase will typically be 2-3 years. This long-term effectiveness evaluation includes three concurrent assessment elements. The first is a noise exposure assessment that includes sound pressure level measurements, noise dosimetry, time-motion studies, and OAE tests. The second is an analysis of retrospective and prospective audiometric data provided by external partners that is collected over a 2-3 year period. Several years of sequential audiometric data will be examined to identify trends. The final element is a stakeholder implementation and utilization assessment. The outputs from this phase will be research data on long-term improvements in exposure levels, NIHL, dissemination, implementation, and behavior change.

The widespread dissemination and implementation of research products is also gauged by industry usage, typically in percent implementation on applicable machines and worksites. Outputs from this stage are data on the extent of usage within the identified "market segments" such as operation sizes, regions and MSHA districts. If the products are underutilized, the outputs will include an assessment of the barriers preventing utilization so that additional development work can be done to alleviate the barriers.

4.6 Reduction of NIHL

Incidence of NIHL is assessed through a longitudinal industry-wide surveillance effort. Data will be collected from audiometric service providers who support the industry's hearing conservation programs. The data will be stratified to include information about each MSHA district and other "market segmentation" variables. The occurrence of standard threshold shifts (STS) will serve as the metric to track incidence of NIHL. The STS is the conventional regulatory indicator of a change in hearing for a specific worker. Incidence of STS will be analyzed over time to determine whether changes in hearing loss patterns have occurred in conjunction with implementation of controls. Existing datasets containing reportable hearing loss from MSHA and other sources will also be tracked.

5 APPLICATION TO CURRENT RESEARCH PRODUCTS

The process model can be applied to current noise control products developed for the mining industry. Multiple variables that determine the success of research products can be correlated to reductions in NIHL through the use of the process model. The metrics that were defined in the previous section help determine the extent to which objectives of each process model stage have been accomplished.

For instance, the research program needed to evaluate whether newly developed noise controls that had met the short term goals of exposure reduction were then achieving broad industry acceptance. In order to test the process model with program products, researchers linked model stages to currently developed controls in the research portfolio. Noise control products developed for continuous mining machines and roof bolting machines serve as examples to examine how the process model works.

The noise controls developed for the continuous mining machine address noise generated by conveyor system. The first conveyor system control is a urethane coated flight bar chain. It works by absorbing impacts that occur between the chain and conveyor deck and has been shown to reduce sound levels at the operator's position by 5-7 dB(A)[8]. The second conveyor system control is a dual sprocket chain. It works by achieving smoother chain tension at the conveyor transition points and reduces sound levels at the operators position by 3 dB(A)[9]. Theses noise controls are shown in Fig. 2.

For roof bolting machines, a drill bit isolator was developed to reduce noise generated during the drilling process that is performed before inserting roof bolts. The drill bit isolator prevents vibrations that occur at the bit from transferring down the drill rod and radiating noise and reduces sound levels at the operator's position by 6 dB(A)[10]. These noise controls are shown in Fig. 3. The urethane coated flight, dual sprocket chain, and drill bit isolator are shown noise controls have shown the ability to reduce noise at the operator's position and that they are sufficiently durable to hold up in a production mining environment.

The stages in the model represent processes that need to occur for a control to result in the ultimate goal of reduced NIHL. Evidence of success toward the metrics of each stage strengthens the case that NIHL will be achieved, even though the full extent of NIHL may take a decade or more to measure. The urethane coated chain and the dual sprocket chain are currently in the long-term effectiveness evaluation stage of the process model. NIOSH researchers are partnering with mine companies and federal regulators to conduct case studies at demographically and geographically diverse underground operations. These case studies will provide data that will continue to confirm the value of the urethane coated chain and the dual sprocket chain in reducing worker noise exposure as well as capturing the industry perspective on implementation and utilization of the noise controls. These outputs will assist in moving these continuous mining machine products to the industry usage stage of the process model. This data will assist in the identification of key findings about the noise control and targeting that information to specific "market segments" through the development of a dissemination plan. The drill bit isolator is currently in the technology transfer stage of the process model. Short term effectiveness metrics were met enabling NIOSH researchers to partner with commercial vendors who can produce a widely available product. A final design commercial prototype is currently being evaluated to ensure underground durability requirements are met. To continue to move through the technology transfer stage of the process model, market segments need to be identified. These segments relate to both buyers and users of roof bolting products and machines. A business case will be created to show the operational benefits of the drill bit isolator. It will be targeted towards mine company personnel who manage procurement, production, and health and safety. A behavioral training intervention will be developed to assist in communicating to roof bolter operators why the drill bit isolator is a useful product and how they should use it during their roof bolting activities.

6 CONCLUSIONS

The development and implementation of the process model as a structure for the NIOSH mining hearing loss research program holds the promise of valuable returns. With a greater awareness of the implementation and utilization of noise controls, the research program can facilitate a more rapid diffusion of noise control solutions to the mining industry. In turn, the closer interaction with stakeholders during the development, testing and refinement of noise controls will help the research program through improved alignment and response to stakeholder needs. This will help to provide the industry faster access to new controls through technology transfer targeted to the media and messages that varied stakeholder audiences seek within the industry as a whole.

The process model can also improve the timeliness and accuracy of program evaluation. The overall goal of a reduction in the rate of NIHL has historically been a difficult metric to obtain due to the long time period over which noise exposures accumulate to result in a measurable hearing loss and the many confounding factors that influence the likelihood of NIHL. However, the evaluation metrics associated with each specific stage can usually be measured immediately or soon after the stage is implemented. By being closely tied to the specific stage, the metrics are also less prone to confounding influences. Furthermore, the multiple metrics can identify which aspects of the research program are achieving their goals and which aspects could be improved.

NIOSH is now using this model and its associated metrics to perform assessments of already-developed noise controls as they progress through the many post-development stages that need to occur. During this assessment, the research program is collecting data on attainment of each stage's metrics and/or success indicators. This assessment of developed controls will provide baseline information about the factors that affect movement from one stage to the next. Once a useful set of baseline information has been accumulated, it will be used for moving newly developed controls through the process stages more quickly. The model can also be used for staggered assessments that begin at any stage. Since independent assessments can occur for controls that are at different stages of the model, multiple simultaneous pilot studies can be conducted that build knowledge and refinement of the model metrics and evaluation efforts. This enables the research program to create best practice scenarios for each stage of the model. It is expected that these best practices will be implemented during the development and analysis of new control technologies and interventions. This revised research effort with its associated documentation of evaluations will serve to provide a more complete picture when determining the research program's impact on reduction of NIHL in the mining industry.

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Table 1 - Process model metrics and data sources.

Process	Metric example	Data source
Needs assessment	High exposure related to machine	Exposure surveillance system
Development	3 dB(A) reduction	Sound power measurements in lab
Short term effectiveness	Reduce worker exposure	Field dosimetry and OAEs
Technology transfer	Control is readily available	Manufactured and sold
Industry usage	In use in all regions	MSHA district managers
Long term effectiveness	Reduction maintained for life of product	Field dosimetry and OAEs
Reduction in NIHL	NIHL reduction in affected commodities	Audiometric surveillance

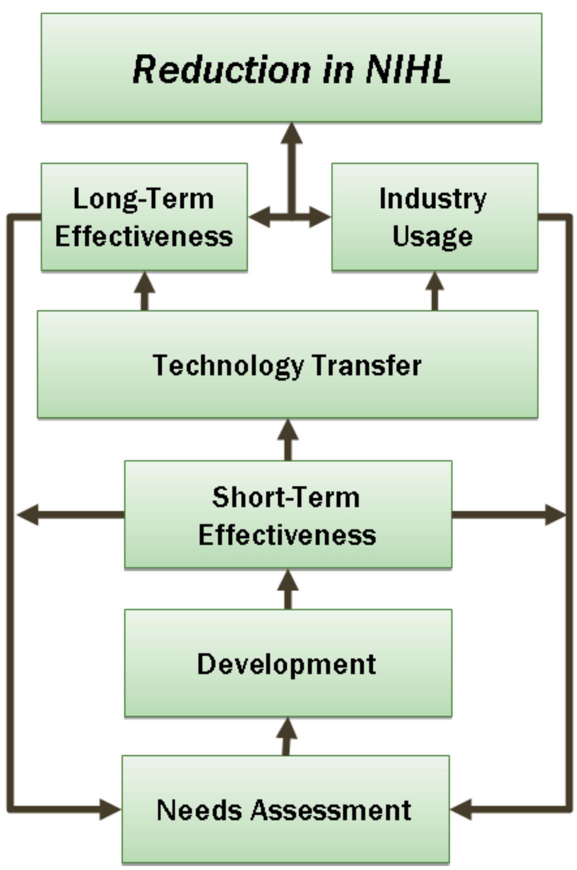

Fig. 1 - Schematic of the research process model.

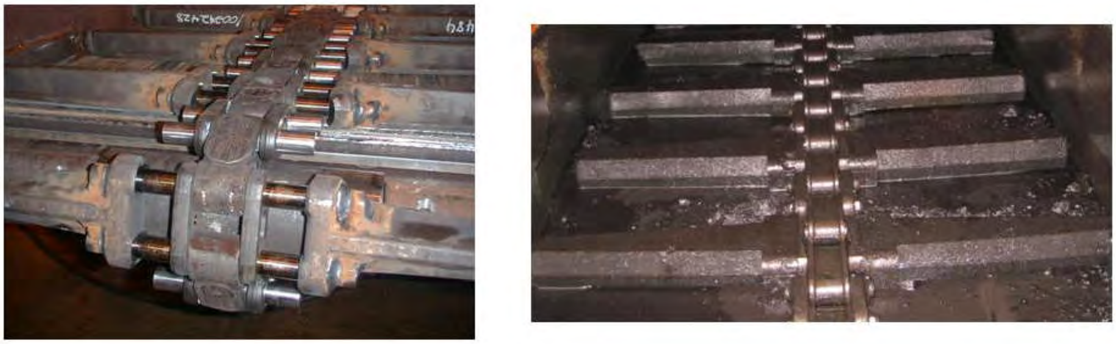

Fig. 2 - Dual sprocket chain and urethane coated chain noise controls for continuous mining machines.

Fig. 3 - 1" and 1 3/8" drill bit isolators for roof bolting machines.