



Reducing Employee Noise Exposure in Manufacturing: A Review of the 2014 workshop

William J. Murphy¹

National Institute for Occupational Safety and Health

1090 Tusculum Ave. Mailstop C-27, Cincinnati OH 45226-1998

ABSTRACT

In 2014, the INCE Foundation, the Noise Control Foundation and the National Institute for Occupational Safety and Health (NIOSH) organized a meeting of industry, government, and academic experts to discuss “Reducing Noise Exposures in Manufacturing: Best Practices, Innovative Techniques, and the Workplace of the Future.” This presentation will review the content of the recommendations for hearing loss prevention programs, successful implementations for noise control engineering, and new techniques to predict noise exposures in the workplace. Efforts to develop Buy Quiet programs and to promote the Safe-in-Sound Excellence in Hearing Loss Prevention Awards™ will be reviewed.

1. REDUCING EMPLOYEE NOISE EXPOSURE IN MANUFACTURING

On February 19-20, 2014, the National Academy of Engineering (NAE) hosted a workshop entitled “Reducing Employee Noise Exposure in Manufacturing: Best Practices, Innovative Techniques, and the Workplace of the Future.” A report [1] was generated by the Institute for Noise Control Engineering (INCE) and the National Institute for Occupational Safety and Health (NIOSH) that addressed these five themes:

1. Hearing Conservation Programs in Manufacturing Industries,
2. Best Practices: Noise Control in Manufacturing Industries,
3. Engineering for Noise Control in Manufacturing,
4. Innovative Techniques for Engineering Noise Control,
5. The Manufacturing Workplace of the Future.

The fundamental tenet of engineering noise control is to reduce noise exposures in the workplace through a combination of eliminating noise hazards, replacing noisy processes with quieter processes, or isolation of noise sources and/or nearby workers. Noise surveys need to be accurate and comprehensive to avoid over-exposing workers due to underestimates of exposure or to prevent the noise control measures from being overly restrictive. Although administrative controls and personal protective equipment (PPE) in the form of hearing protection devices (HPDs) are relied upon, they are potentially ineffective solutions to reduce noise exposures and the risk of hearing loss. People are reluctant to follow basic instructions and requirements for using PPE if it is perceived as interfering with their ability to communicate or conduct normal activities.

¹wjm4@cdc.gov

This paper will summarize the INCE report available from the INCE-USA website: <https://www.inceusa.org/publications/technology-for-a-quieter-america/#reducing-exposure> [1].

1.1. Hearing Conservation Programs in Manufacturing Industries

Reducing noise exposures is described by the hierarchy of controls shown in Figure 1. The four presentations in this section highlighted the efforts of NIOSH to publicize and translate successful solutions in the workplace to at other plants within the larger corporations. Gregory Lotz provided an overview of the Safe-in-Sound Excellence in Hearing Loss Prevention Award™. The Safe-in-Sound award program was developed by Dr. Thais Morata (NIOSH) and has recognized more than 25 companies and individuals who have demonstrated excellence in hearing loss prevention. The award program is managed by the National Hearing Conservation Association (NHCA), the Council for Accreditation in Occupational Hearing Conservation (CAOHC), and NIOSH.

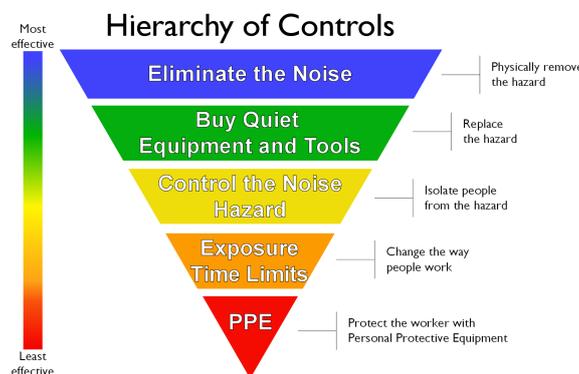


Figure 1: The hierarchy of controls for Hearing Loss Prevention. Engineering noise control involves eliminating the hazardous noise, substituting quiet tools for noisy tools, and isolation of people from the noise (or the noise from the people). Administrative restriction on exposure duration and personal protective equipment tend to be less effective when employees ignore the time limits or choose not to wear hearing protection in an effective manner. Image credit: NIOSH

One of the notable successes has been the 2015 award to United Technologies Corporation (now Raytheon Technologies), the parent company of Pratt & Whitney. After receiving the award in 2009, Pratt & Whitney’s approach to reducing workplace noise exposures was replicated throughout United Technologies’ global operations. In Figure 2, the number of employees exposed to noise above 85 dBA for an 8-hr time-weighted average (TWA) was more than 10,000 in 2010. United Technologies implemented Buy Quiet methods and applied noise control solutions to reduce the number of employees enrolled in the hearing loss prevention programs in 2015 to about 2,000 - an 80% reduction. These reductions translate into an improved working environment for the employees and lower operating costs for the company. Reducing noise in the workplace doesn’t always require complex, expensive projects. Simple solutions such as isolating a noise source or tightening bolts can yield significant reductions in workplace noise.

John Downey described the efforts of Colgate-Palmolive Company towards adopting a company-wide standard of 85-dBA recommended exposure limit (REL) and 3-dB exchange rate and an action level of 82 dBA from the 1998 NIOSH Criteria Document for a Recommended Standard for Occupational Noise. [2, 3] According to Themann et al. [4], “the European Union has established an average exposure level of 80 dBA as its ‘lower exposure action level’ at which employers must make hearing protection available to workers.” [5] As a global corporation, Colgate-Palmolive is subject to the noise exposure regulations in each country where manufacturing takes place. Rather than

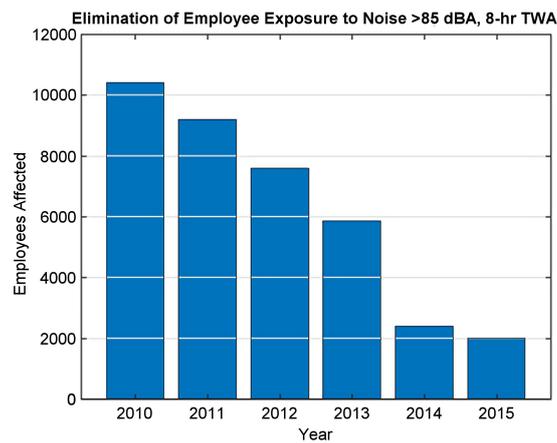


Figure 2: The number of United Technologies’ employees enrolled in the hearing loss prevention programs in from 2010 to 2015. Through the use of Buy Quiet methods and noise control solutions, an 80% reduction of employees exposed to noise above 85 dBA for an 8-hour TWA was achieved. Image credit: United Technologies

applying country-specific requirements, they adopted occupational safety and health standards that are more protective than the United States (U.S.) Occupational Safety and Health Administration’s (OSHA) 90 dBA permissible exposure limit (PEL) and 5-dB exchange rate. Globally, Colgate-Palmolive implemented more than 70 noise reduction projects at 60 facilities based around the principles of designing quiet equipment, reducing noise at the source, developing capabilities in the health, safety and engineering staff, and committing to operating quietly. As a result, noise exposures for about 2,000 workers were reduced substantially. As well, some facilities no longer require hearing protection because noise levels were reduced to below Colgate-Palmolive’s 82 dBA action level.

John Mulhausen presented a multipronged approach that 3M Company has implemented to manage noise exposures in manufacturing. Reduced noise exposures were achieved through high-quality noise surveys, the use of sustainable noise exposure controls, and implementation of efficient and effective hearing conservation programs. 3M applies statistical analysis of the exposures to understand the uncertainties associated with these measurements of both noise exposure and the amount of attenuation provided by hearing protection. Quantitative hearing protector fit testing estimates the attenuation of workers’ protectors and accounts for the variability across noise spectra, repeated fitting and the measurement process. The target exposure level was less than 85 dBA for 95% of the workshift. 3M has empowered managers to control noisy operations within the factories. Training for workers and managers was provided and award incentives were developed to encourage innovations in quieter equipment and processes.

Dan Westrum presented 3M’s efforts at the plant in Hutchinson Minnesota to implement a holistic hearing loss prevention program. Integral to the plan were efforts to monitor noise exposure in the plant, plan to accommodate lower noise exposure limits (75 dBA) needed for extended workshifts, quantitative hearing protector fit-testing for noise-exposed workers, and creating a holistic program to promote the use of hearing protection for activities outside of the workplace. Through the hearing protector fit-testing program, the selection of protectors was tailored to the needs of the employees. As well, the hearing conservation program could provide hearing protectors for workers to use in their recreational activities such as hunting. Helping workers to understand that hearing hazards include recreational exposures may help to reduce the incidence of occupational hearing loss.

The holistic nature of hearing loss prevention has been a theme for these featured Safe-in-Sound award recipients as well as many of the awardees since the 2014 INCE workshop. Awardees such as

Sensaphonics Hearing Conservation Inc. (2009), Etymōtic Research Inc. (2010), Kris Chesky (2010), Dangerous Decibels® project (2013), Benjamin Kanters (2014), John Casali (2016), Kurt Yankaskas (2019) and National Aeronautics and Space Administration's Hearing Loss Prevention and Acoustics program for the International Space Station (2020) illustrate that hearing loss prevention applies to our enjoyment of music, concerts, education of children and adults, and noise controls for dive helmets, aircraft, and even the exposures of astronauts and cosmonauts. Hearing is integral to communication. NIOSH has developed an integrated Total Hearing Health program to consider risk factors intended to protect workers from work-related injury, on and off the job [6].

1.2. Best Practices: Noise Control in Manufacturing Industries

Five papers were presented that dealt with the design of quieter equipment and implementation of Buy Quiet and Quiet-by-Design techniques to control noise in the workplace. Wolfgang Probst presented a comprehensive noise modeling tool, CadnaR® [7], and how it can be adapted to predicting occupational noise exposure. CadnaR® has traditionally been used to describe architectural acoustic problems, modeling the sources within an auditorium or room, capturing the absorptivity and geometry of the space and then creating realistic auralizations of the space and accurate prediction of sound propagation in the space. Simplistic prediction methods such as the Sabine or Eyring equations developed almost a century ago do not capture the reflections within a room, the transmission of sounds through materials within the space, nor the effects of manufacturing floors that tend to be more flat than uniform in their dimensions. His presentation demonstrated both sound ray mirror image and sound propagation particle methods to developing a virtual model. Accuracy of these methods require a detailed understanding of the noise generation and an accurate sound power measurement of equipment inserted into the space.

David Herrin's presentation discussed the Source-Path-Receiver approach to designing low-noise equipment and machinery. To implement the model, each of these parts must be characterized. Sources may be air-borne, structure-borne, or liquid-borne. Air-borne sources may have turbulence or shock components (e.g. pneumatic exhaust). Structure-borne sources may have impact components, rolling noise, or inertial noises that require different control approaches. Liquid-borne sources may have flow or cavitation noise sources. Limiting or controlling the path can involve acoustic isolation (enclosures), barriers (screens), silencers, vibration isolation, and damping approaches. As the noise at the source and the transmission pathways are limited, the receiver will experience lower noise immisions.

James Thompson provided examples of noise controls developed by the NIOSH Pittsburgh Mining Research Division (PMRD). PMRD has applied short- and long-term approaches to evaluating noise controls developed for mining. The process of reducing noise in the continuous mining machine was conducted in collaboration with Joy Komatsu Mining Corporation. Coal is removed at the seam from the cutter head and transported along a conveyor bed with flight-bars attached to a chain and sprocket assembly. Flight-bars were coated with a polyurethane material and noise reductions were measured for iterations of the flight bar coatings in the laboratory. Short-term durability was assessed in actual mining operations. Modifications of the chain and tail sprocket were developed and further reduced operating noise. As of 2014, the dual sprocket chain had been installed on 35% of continuous mining machines. NIOSH's partnership with Joy Komatsu Corp. reflects an approach to development that successfully reduced noise in mining equipment.

William Murphy described the American National Standards Institute (ANSI) processes for developing standards for noise emissions measurements that is administered by the Acoustical Society of America's (ASA) Committee on Standards. Sound power is an inherent property of a noise source that can be used for developing the acoustic models of noise distributions and noise exposures. Sound pressure levels are dependent upon the room acoustics, the distance of the receiver to the source and the orientation of the receiver with respect to the source. Sound power is the appropriate metric for labeling the noise output of machinery. The problem is getting the consumer

to understand what sound power is and how it can be used.

Lastly, George Maling gave a brief introduction to "Buy-Quiet" programs. Maling noted that NIOSH promoted Buy Quiet policies in its Criteria document [3], NASA developed a comprehensive Buy Quiet program in 2009, and that an international workshop was held in July 2011 in Paris, France. Buy Quiet programs can reduce noise, save money, improve speech communication in the workplace, reduce worker fatigue and stress, while at the same time improve workers' concentration, comfort, and productivity in their jobs. One of the impediments to implementing Buy Quiet programs is the lack of requirements in the U.S. for product noise labeling. The Acoustical Society of America S12 standards for noise working group published an ANSI/ASA Standard for Declaration and Verification of Noise Emission Values of Machinery, Equipment, and Products [8].

1.3. Engineering for Noise Control in Manufacturing

The next section of the workshop focused on Engineering for Noise Control in Manufacturing. The presented papers included the following: progress and failures in U.S. manufacturing noise reduction; reducing employee noise exposures; noise control in the textiles, tobacco and woodworking industries; noise reduction and productivity improvement for a paper shredding operation; noise reduction at a conduit manufacturer; and benefits of noise reduction in a manufacturing environment.

Robert Bruce relayed an example of the development of quiet steam valve technology for submarines. Controlled Components Inc. was able to identify a noise control and collaboratively developed the product through funding from the United States Naval Research Laboratory. The resulting technology is now broadly available from major valve companies. Sponsorship from government programs can focus on specific noise control methods. As more noise data is made available, manufacturers can incorporate this information into Buy Quiet programs and Quiet-By-Design efforts to produce quieter manufacturing environments without sacrificing power.

Eric Wood presented steps that can be incorporated in consulting jobs: meet with your constituents; document the concerns and goals; identify and measure the noise in the target areas; identify the noise sources; prepare a plan of action; implement noise abatements; evaluate the solutions and make adjustments; and finally document the results. Every noise abatement program must be owned by someone within the company otherwise it runs the risk of being an irrelevant, wasted effort. Senior management must support the program and see how it fits within their responsibility to provide a safe and healthful workplace. Plant managers and engineers have a responsibility to maintain and own the program. Management is not alone in the ownership, workers in production and maintenance need to understand the importance of keeping the noise abatement solutions functional. If the solutions are complex, then management needs to know when their expertise is inadequate and bring in the expert noise control engineers.

Noral Stewart described the history of noise control during the 1970s within North Carolina's main industries: textiles, tobacco, and woodworking. In the textiles industry, looms with hundreds of spindles rotating at speeds up to 13,000 rpm proved to be a dominant source. Intentionally loose spindles that facilitated manual replacement during operation were one significant noise source on the looms. As machinery became more automated, spindles could be tightened on the shafts and the noise was reduced. Fly-shuttle looms proved to be challenging noise control projects. Today's modern looms are significantly quieter. The tobacco industry took a different approach. They developed some proof-of-concept noise controls for filter-making machines and then approached the manufacturers of the equipment with an ultimatum to reduce the noise on these machines or lose the opportunity for continued contracts to provide machinery. Stewart concluded that retrofitting old equipment is not always practical. New equipment that meets the desired noise specifications may be a more expedient approach, especially if such capital equipment will be replaced within four or five years. With respect to the hierarchy of controls in Figure 1, substitution of quieter equipment for noisy equipment is highly effective. A company can continue to use their current investment in machinery and spread the cost of becoming quieter over several years.

In a second presentation, Stewart provided a detailed case study of an engineering noise control solution for a paper shredding machine. The original machine was prone to clogs resulting in excessive delays and backlogs while workers halted production to unjam the shredder. The project had several goals: 1) reduce the time-weighted average exposure of workers to 88 dB or less; 2) increase productivity of the machine; 3) minimize the impact on the nearby loading dock and 4) minimize the non-recoverable costs. Stewart and his colleagues damped machine surfaces to reduce noise exposures by about 5 dB. Small cyclones replaced vacuums and separated the shredded paper confetti better than the vacuums. Conveyors were used to move material into the shredder, allowing workers to be further away from the noise source. The modified machines were quieter and had fewer clogs. Noise exposures were reduced from the mid-90's to about 86 to 84 dB while improving production rates at the same time.

Scott Brueck reported the NIOSH Health Hazard Evaluation Program and an effort to evaluate and reduce noise at a metal conduit manufacturer [9]. The noise exposures were determined to be primarily from the rolling or dropping of the conduit pieces onto another conduit, metal-on-metal contact of parts striking other parts of production equipment, operation of the production equipment, and a steam cannon used to clear fluid from inside the conduit. The steam cannon produced brief high-level impulses with peak sound pressure levels between 100 to 135 dB in the production areas. Metal-on-metal impacts could produce similar levels as well as reverberant decay of the impact noise. Noise control solutions incorporated ultra high molecular weight materials where conduits might strike the metal stops. The distances that conduits were dropped could be reduced by having adjustable racks that were sensitive to the weight of the parts stacked on it. The steam cannon operators needed to be isolated from the noise. The hearing conservation program needed to follow workers more closely because some employees exhibited hearing threshold shifts. A follow-on visit showed that the company had implemented the recommendations and consequently workers were at less risk of developing noise induced hearing loss.

Michael Roberto described the efforts to reduce noise at the General Dynamics' Ordinance and Tactical Systems plant. As a part of a corporate commitment to safety, the noise abatement program reduced operating costs, improved product quality, and improved the working environment and productivity. One example was the investment in a new injector drill with an enclosure for deep drilling operations. The enclosure reduced the noise by 15 dB and resulted in a noise level of 95 dBA in that area. Reducing the noise translated into less of a hearing hazard for their workers. Other reductions that proved to be effective were changing the compressors from older, noisy and inefficient compressor models to newer, low-noise models. Air-leaks in compressed air lines resulted in lost pressure and increased operating costs. The connections were changed from hose clamps to crimp-style connections and the air nozzles were changed to increase efficiency. The experiences at General Dynamics demonstrate how a strategic plan to address noise issues can improve the work environment, reduce operating costs, and improve hearing health for workers.

1.4. Innovative Techniques for Engineering Noise Control

Engineering noise control has traditionally relied upon isolation and enclosures to reduce vibrations and sound transmission into the workplace. The workshop heard from several presenters about advanced techniques to identify noise sources, perform computational acoustics, and develop innovative manufacturing methods.

Earl Williams provided an overview of several advanced methods for noise source localization. The development of microphone arrays has allowed more accurate evaluation of noise sources. Acoustic cameras, a combination of a video and acoustic source mapping system, are commercially available from several companies. Images of the acoustic sound pressure levels or sound intensity can be displayed with a false color map to identify the sources in an environment. As well, the spectral content of the sources can be ascertained to facilitate the understanding of what frequencies need to be considered when designing controls. Spherical microphone arrays can be useful to identify the

direct and reflected source paths. In Figure 3, the spherical microphone array and camera can be seen and the noise source (paper shredder) on the left panel. In the right panel, the false color of the noise levels are displayed over an image of the room. The reflection of the source from the ceiling was evident, something that would not be apparent with single microphone measurement by a sound level meter. Williams noted that advanced technologies include a wide range of microphone arrays that can be used for beamforming, wave expansion methods and inverse methods such as near field acoustic holography.

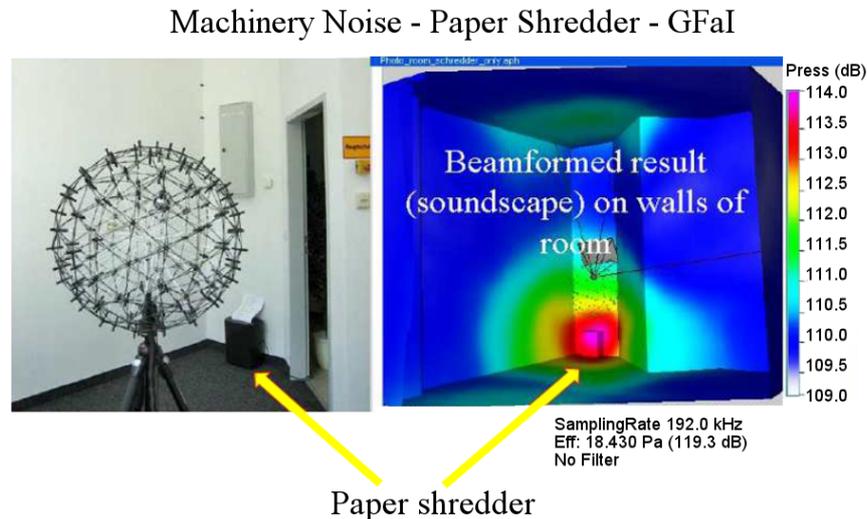


Figure 3: Soundscape from a paper shredder. Image credit: Earl G. Williams

Michael Lucas described how engineering teams could take advantage of modeling and simulation tools to decrease the product development time, improve reliability and performance. One example from computational fluid dynamics (CFD) was the development of a moving mesh to model rotating machinery such as compressor pumps. Standard fixed mesh methods could not account for the interactions of the aerodynamic and acoustic fields. The moving mesh must be adapted at each time step to minimize the introduction of numerical errors. In some cases, it was necessary to overlap meshes to accurately simulate flow and acoustic radiation. As improvements in computer power and implementations of CFD solvers continue, the costs for noise predictions using CFD will decrease and the accuracy of noise predictions will become better, leading to less expensive products in the future.

In a second talk, Lucas described the “design intent” process followed by new product development teams at Ingersoll-Rand. At the initiation of the design, a development agreement is drawn between the marketing and engineering departments that contains the product’s performance specifications. The key topics addressed manufacturing costs, reliability, power, efficiency, and noise. He described some of the noise control techniques that Ingersoll-Rand applies. Chief among these were acoustical enclosures that consider how air flow is used to control heating as well as noise that might be radiated from the compressor. Fan noise, speed, size, cost, and air flow are a part of the decision process. The optimal operating regimes and varied levels of efficiency have to be considered when selecting fans. Multiple styles of mufflers (e.g. perforated tubes, reactive, and active pressure pulsation dampeners) may be required for the inlet and outlet of the compressor or enclosure. Ingersoll-Rand tests compressors according to two standards: ISO 2151 and ISO 3744 sound power methods [10, 11].

Robert Anderson reviewed the fundamental issues surrounding noise control in industry. Table 1 describes the different facets of the engineering noise control problem when considered by the established heavy manufacturing industries compared to the green technology manufacturing

industries. Larger established industries have a more entrenched corporate culture that often times have to consider the demands of unions when making noise control decisions. Smaller firms that are not necessarily unionized will tend to make decisions based on the costs of the proposed engineering controls. In contrast, companies in green technology manufacturing are more likely to have programs that consider noise emissions and controls from the outset. Because their facilities tend to be newer, the problems associated with retrofitting are not as prevalent. Anderson made the case that low-noise manufacturing processes are more cost-effective. Buy-quiet programs are an effective means of implementing progressive noise control engineering in manufacturing. Training for the supplier and end-user is an important element to realizing success in reducing occupational noise exposures.

Table 1: Drivers of noise controls.

Type of Manufacturing	Size of Company	Influencing Factors	Program Emphasis	
			Buy Quiet	Retro-fit
Established Heavy Manufacturing	Large	Control Costs, Unions Compliance, Medical Costs	Yes	Minimal
	Small	Control Costs Compliance	No	No
Green Technology Manufacturing	Large	Workplace Conditions, Global Uniformity / Compliance, Medical Costs	Yes	Yes
	Small	Workplace Conditions, Compliance, Medical Costs	Yes	Yes

James Barnes discussed examples of noise control technology available in manufacturing equipment. For instance, the use of gearboxes that have been designed with quiet operation specifications from the outset are now commonly available. Gearboxes and drive shafts can be replaced with direct drive systems and rotary motion has been favored over reciprocal motion. One example of a successful implementation of a Buy Quiet program was the replacement of a waterknife tool. The new tool was 30-dB quieter than the old tool through a redesign of the noise source mechanisms as opposed to an application of noise-control treatments or materials. Barnes noted that future manufacturing methods may employ active noise control processes and make extensive use of automation that removes the worker from the noise hazard.

Shashikant More described the ongoing efforts at Cummins Inc. to develop and make reduced-noise power generation sets (Gensets) for use at their facilities. A typical Genset is installed within an enclosure and employs a range of noise treatments such as mufflers at the inlet and outlet of the enclosure, absorptive materials within the enclosure, and a high performance muffler for the engine. Vibration isolation between the Genset and the enclosure is critical to reducing the radiated noise. As one can see in Figure 4, the possible permutations within the Source-Path-Receiver model are numerous and attention must be paid to the holistic nature of the problem rather than developing tunnel vision to reducing a single path from source to radiated volume.

Rebecca Taylor from the National Center for Manufacturing Sciences recounted an incredible

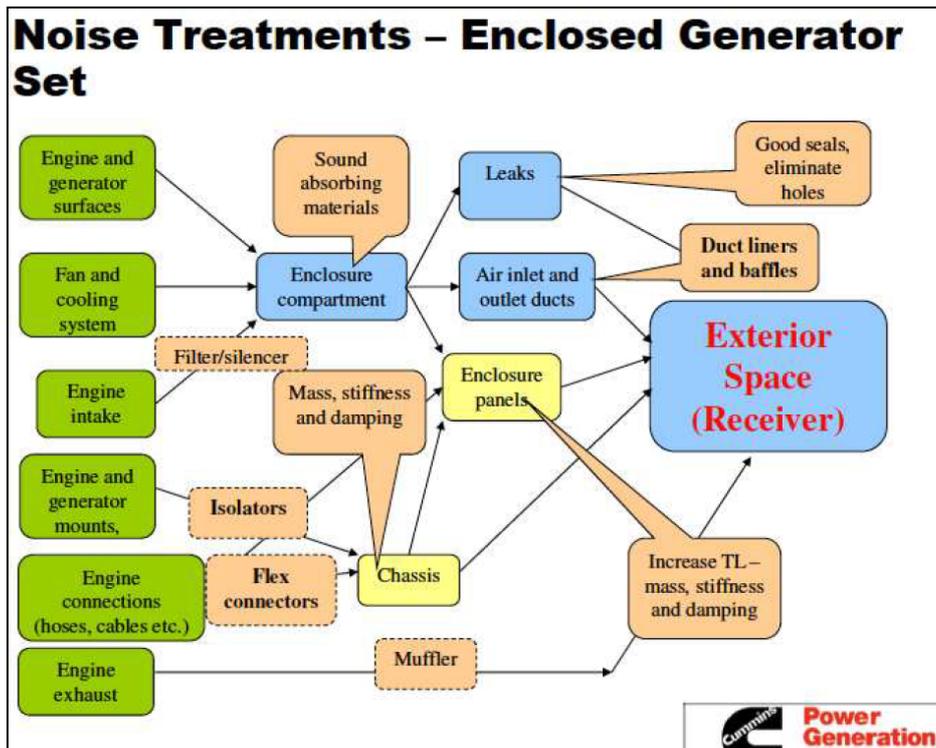


Figure 4: Diagram of representative noise treatments for a typical enclosed generator set. Potential noise sources are highlighted with green boxes. Noise control technologies are indicated in peach boxes. Volumes into which noise is radiated are indicated with the blue boxes and elements of the enclosure are shown in yellow boxes. Image credit: Cummins Inc..

success story for redesigning a rivet removal process. Repairs for the F-22 Raptor aircraft involve removing panels that were riveted in place and in the manual punch/drill/replace cycle of maintenance, upwards of 20% of rivets could end up being damaged irreparably due to slips with the tools. A new process was developed that uses an electrode to erode the rivet cleanly. The new method reduced the damage rate from 20% to 0.01%. Cycle times for the repairs were decreased by 50%. Ergonomic and eye injuries were dramatically reduced by 79.4% and 98.8%, respectively. The repair cost savings amounted to \$175,000 per year for the Navy and the turn around time was reduced from 1.5 days to about 3 hours.

James Barnes gave a somewhat sweeter taste of noise control, the changeover of a candy manufacturer from reciprocal to rotary motions. The company focused on replacing the original equipment with tools that utilized rotary motions. The production rate was increased along with a decrease in maintenance, downtime, and noise. Through the use of well-designed enclosures, additional noise reductions were realized. Barnes concluded that modernization has benefits beyond just noise reduction. The new equipment was more reliable and productive. Investing in noise control and modernization is an investment in the continued future of the candy company.

1.5. The Manufacturing Workplace of the Future

The NAE hosted the workshop and Kate Whitefoot from the NAE provided an overview of efforts to promote new ideas and innovation in manufacturing. During a 2012 workshop, several important themes were presented:

1. The U.S. is experiencing an increase in productivity while simultaneously experiencing a decline of manufacturing employment.

2. Traditional lines between manufacturing and services are becoming blurred. For instance, Apple still manufactures phones, tablets, computers and wearables but they have branched into providing services and entertainment content allowing them to generate revenue across different manufacturing and services domains.
3. The nature of the work on the factory floor and throughout the manufacturing chain has been transformed due to a combination of advancing technologies and business processes. Advances in materials science, robotics and sensors, together with increasing speed of product development schedules and integration of software and services all play a role.
4. Many U.S. companies would benefit from upgraded practices. Many opportunities still exist to generate more innovation and boost job growth.

Daniel Lilley discussed the efforts of Manufacturing Extension Partnership (MEP) to strengthen American manufacturing. MEP runs projects through partnerships and cooperative agreements funded by federal, state, and local governments and industries. Industries pay a fee for the services and gain access to information, technical expertise and cost management. Small businesses are one area of focus for the MEP. Larger businesses have the resources to undertake challenging large-scale manufacturing problems. The MEP has migrated to the idea of technology transfer to improve operations and productivity for smaller businesses. Addressing these needs will present a challenge for U.S. manufacturing in the years to come.

Rebecca Taylor presented a futuristic view of manufacturing. The prior and possibly the current view of manufacturing is one of a dirty, repetitive environment where workers are essentially drones tending to the machines. As the U.S. has become the host for manufacturing facilities from other countries with more advanced approaches to manufacturing, we are learning that cleaner and healthier factories can be achieved. Greater automation will be the wave of the future meaning that human workers can be further removed from the noisy operations. One advancement is in the area of additive manufacturing. As these technologies develop, greater emphasis will be needed to create the programs that drive these tools. Visualization tools are going to become essential to digital manufacturing. Taylor concluded that workers will need more education and new skills to continue to keep our manufacturing workforce competitive with those from other countries.

Finally James Barnes recounted an experience with a company that wanted to integrate executive, management, engineering, and marketing on the factory floor. As one can imagine, factory noise could be problematic. Management empowered workers to consider how noise and safety could be improved on the production line. Through an iterative process, noise goals were established. Ultimately, the primary solution was installing prefabricated rooms on the factory floor to allow office personnel to work in a quieter environment. A mutual goal was to bring cohesiveness across the entire workforce.

2. CONCLUSIONS

The 2014 INCE Foundation / NIOSH workshop promoted the use of new techniques to implement noise control in manufacturing. Several of the examples illustrated the application of the hierarchy of controls (Figure 1) and how considerations of noise control can not only improve the workers' environment but also reduce the manufacturing costs. Lower costs, better environment, happier and healthier workers are a prescription for an improved workplace.

DISCLAIMER

The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease

Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH, CDC.

REFERENCES

- [1] Maling Jr., G.C., Wood, E.W., Lotz, W.G., Lang, W.W., *Reducing Employee Noise Exposure in Manufacturing: Best Practices, Innovative Techniques, and the Workplace of the Future*. USA: Institute of Noise Control Engineering. (2016).
- [2] Colgate, *Environmental Health and Safety Policy Statement*, accessed April 30, 2021 (2021).
- [3] NIOSH, *Criteria for a Recommended Standard: Occupational Noise Exposure Revised Criteria*. DHHS-CDC-NIOSH, Publication No. 98-126, Cincinnati, OH. (1998).
- [4] Themann, C., Suter, A.H., Stephenson, M.R. *National Research Agenda for the Prevention of Occupational Hearing Loss – Part 1*. Semin Hear. **34**, 145-207, (2013).
- [5] European Union (EU). *Directive 2003/10/EC of the European Parliament and of the Council on the Minimum Health and Safety Requirements Regarding the Exposure of Workers Arising from Physical Agents (Noise)*. Seventeenth Individual Directive within the Meaning of Article 16(1) of Directive 89/391/EEC. Geneva, Switzerland: European Union; 2003
- [6] NIOSH, *Using Total Worker Health® Concepts to Address Hearing Health*, by Themann C.L., Morata T., Afanuh S., DHHS-CDC-NIOSH Publication No. 2019-155, Cincinnati, OH. (2019).
- [7] DataKustik, *CadnaR® Prediction of sound inside rooms* DataKustick GmbH Gilching, Germany, accessed April 30, 2021 (2021).
- [8] ANSI/ASA S12.61-2020, *American National Standard Declaration and Verification of Noise Emission Values of Machinery, Equipment, and Products*, Acoustical Society of America, Melville, NY. (2020).
- [9] Rodriguez, M., West, C.A., Brueck, S.E., *Evaluation of Worker Exposures to Noise, Metalworking Fluids, Welding Fumes, and Acids During Metal Conduit Manufacturing*. Health Hazard Evaluation Report. HETA 2006-0332-3058. April (2008).
- [10] ISO 2151:2004, *Acoustics – Noise test code for compressors and vacuum pumps – Engineering method (Grade 2)*, International Organization for Standardization, Geneva, Switzerland. (2004).
- [11] ISO 3744:2010, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane*, International Organization for Standardization, Geneva, Switzerland. (2010).