Engineering Technologies in Practice

The NIOSH experience

By Hongwei Hsiao

ENGINEERING RESEARCH has a great history of integrating the principles and laws of physics and the science of human form and function to develop theories and hypotheses; after a series of validations, these theories are then transformed into technologies. Through the Research to Practice (r2p) initiative, NIOSH engineers have moved many engineering technologies to product design practices, standardization and commercialization. While these efforts are associated with different industrial sectors and have taken different approaches to ensure successful industrial acceptance and use, they share a common goal to reduce workplace hazards and prevent worker injuries. A general procedure for implementing engineering technologies, with four examples, is presented to demonstrate the progress and impact of r2p efforts on various safety applications at workplaces.

Implementing Engineering Technologies

Figure 1 presents a general procedure for implementing engineering technologies for injury prevention; it includes the steps of research, design, standardization and commercialization. While an injury incident can be simply characterized as a situation in which the environment and task demands exceed a person's capability at a given moment, the underlying reasons for an injury incident are typically multifactorial. For example, if a roofer fell to the ground while he transited from an elevated platform to an extension ladder, several influential factors may have contributed to the incident; these may include roof steepness, icy spots on the roof, inappropriate ladder setup or poor ladder configuration.

Hongwei Hsiao, Ph.D., *is chief of the Protective Technology Branch of NIOSH's Division of Safety Research, where he supervises 30 staff members and manages seven laboratories for human factors and safety engineering research. He holds a B.S.E. from National Cheng Kung University (Taiwan), an M.A. from Cornell University, and an M.S.E. and a Ph.D. from the University of Michigan. Hsiao is a Fellow of the Ergonomics Society (U.K.), an Honorary Fellow of the Human Factors and Ergonomics Society and a member of the ASSE Foundation Research Committee. He received the International Ergonomics Association Liberty Mutual Prize in 2002, the NIOSH Alice Hamilton Award for Excellence in Occupational Safety and Health in 2006 and the NIOSH Bullard-Sherwood r2p Award in Transfer of Knowledge to Practice in 2006.*

If one or more of these factors are effectively controlled, the incident-initiation chain can be broken, thereby reducing the likelihood of an injury incident.

Researching the Problem

Safety engineering research typically seeks to devise engineering solutions to control these influential factors and minimize the possibility of workers taking actions that could exceed their capabilities. These solutions may include new work strategies, improved tools, enhanced products or modified protective gear. This engineering-research and solution-seeking effort is the first stage of the process in implementing engineering technologies for injury prevention.

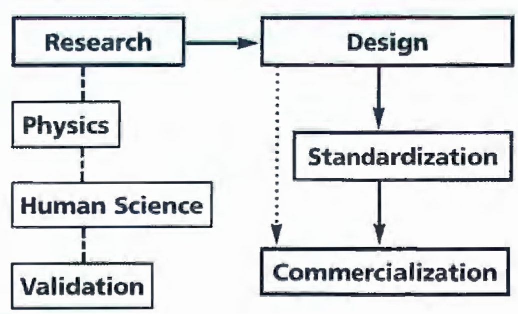
Knowledge Transfer

Transferring research knowledge and engineered solutions into technological products represents the

Figure 1

Implementing Engineering Technologies

The process of implementing engineering technologies for injury prevention typically consists of research, product design, standardization and commercialization. The research component usually involves the integration of physics and human science with a series of validation studies.

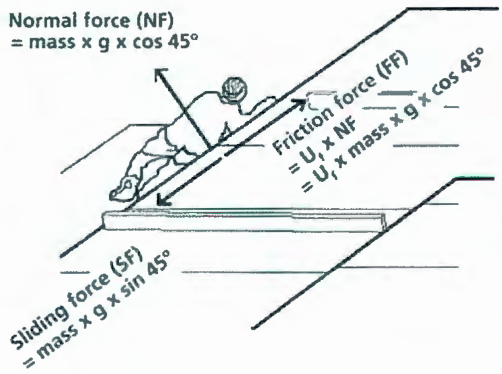


second stage of the process. Although this technology-transfer stage is generally well accepted by SH&E professionals and users, it can be challenging. For example, airbags have become a standard safety device for reducing vehicle-crash-related injuries and fatalities. The airbag concept, however, was not immediately accepted by the industry or the general public (e.g., in terms of cost, reliability and availability). Establishing a partnership among industries, user groups and government at the early stage of the product development cycle may help to overcome product-development hurdles and increase the efficacy of product design.

Figure 2

Roofer Fall Scenario

By knowing worker body mass, roof pitch and the coefficient of friction between the worker and roof, the initial descending force of a fall incident can be estimated by subtracting the friction force from sliding force for effective guardrail design in withstanding a loading force.



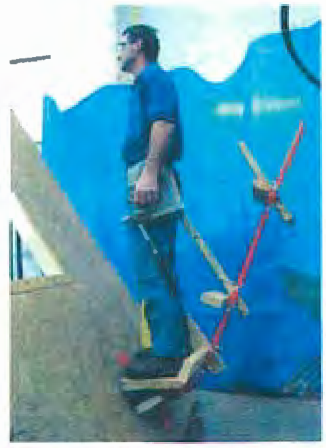


Photo 1: NIOSH developed an adjustable roof-guardrail assembly to protect workers from falls from roof edges, roof holes and existing skylights. It can accommodate a roof pitch range of 27° to 63°.

Standardization

Standardization is the third stage of the process. While some engineering solutions must meet the standards of safety regulations (e.g., safety guarding and age-related operation restrictions related to compactors and balers), engineering technologies for injury control typically achieve employer and employee acceptance through voluntary standards. Examples include ANSI Z87.1-2003, Occupational and Educational Personal Eye and Face Protection Devices, a consensus standard for safety eyewear, and the American Society of Agricultural and Biological Engineers (ASABE) X599 consensus standard concerning automatic deployable rollover protective structures (AutoROPS).

These standards have grown from engineering research outputs toward performance-based criteria. Innovative, stylish eyewear and farm-tractor ROPS that are cost-effective can be developed; the result is increased protection and increased acceptance and use in the workplace. NIOSH delegates were invited to participate in the committees that prepared the draft versions of these standards for final public review and full committee ballot.

Commercialization

Engineering technology in practice cannot be fully functional without an adequate commercialization process—whether done by manufacturers or trade and labor organizations. Factors such as reasonable cost, user friendliness and durability can directly or indirectly affect the commercialization of a technology. Again, a partnership between industries, user groups and government at the early stage of product development may increase the efficacy of product commercialization. Voluntary standards that specify product-performance requirements or physical-safety specifications can promote product value and minimize product liability concerns, factors which, in turn, will accelerate technology commercialization.

Technology-in-Practice Examples

Controlling Falls from Roofs

Falls from roofs are a leading cause for work-related fatalities and are a major cause of serious nonfatal injuries in the construction industry. In 2004, 174 workers were killed and more than 3,260 workers were seriously injured after falling from roofs (BLS, 2005a, b). Research to understand human fall mechanisms and to identify preventive measures is critical to the reduction of fall-from-roof incidents.

Research

Temporary guardrails offer a solution for protecting workers from falling to a lower level during roofing work. By knowing worker body mass, roof pitch and the coefficient of friction between the worker and roof, safety engineers can estimate the initial descending force of a fall incident as well as the dropping force of a roofer at the edge of the roof.

For example, in a roofer fall scenario, a roofer was sliding down from a 45° pitch roof (Figure 2). The normal force (NF) against the roof can be mathematically described as NF = mass x g x cos 45°, where mass is that of the individual and g is the force of gravity (9.8 m/s^2). The friction force (FF) between the individual and the roof can be presented as FF = U_f x NF = U_f x mass x g x cos 45°, where U_f is the coefficient of friction between the individual and the roof. Furthermore, the sliding force (SF) of the individual can be described as SF = mass x g x sin 45°. Therefore, the initial descending force (DF) can be estimated by subtracting the friction force from sliding force [DF = SF – FF = mass x g x (sin 45° - U_f x cos 45°)]. By knowing the initial fall location in relation to the roof edge, the dropping force of a roofer at the edge of roof can be further estimated for effective guardrail design purposes.

Design & Standardization

The human-descending-and-dropping-force information is also critical for setting safety standards or regulations. OSHA regulations require that guardrails, safety nets or fall-arrest harnesses be used for tasks performed above 6 ft. OSHA 29 CFR 1926.500(f)(iv) requires that the completed guardrail structure be able to withstand a load of at least 200 lb applied in any direction at any point on the top rail. Most current guardrail systems are designed to han-

Abstract: *Engineering research provides the basic methods for developing innovative tools, methods and practices for occupational injury control. Determining the best methods to translate engineering research results into industrial practice is a key element of effective occupational injury prevention. Through NIOSH's Research to Practice (r2p) initiative, engineers have increased their range of research and development activities and now routinely consider methods to move outcomes toward adoption as accepted industrial practice. This article provides four examples of the r2p process to demonstrate the value of joint efforts among SH&E professionals, industry partners and government.*

A telescoping AutoROPS offers tractor rollover protection while allowing the tractor to be operated in low-clearance settings (Photo 2, top) such as orchards and animal confinement buildings. AutoROPS can be used on farm tractors (Photo 3, center) and commercial lawn mowers (Photo 4, bottom).

dle low-roof-pitch environments. NIOSH has developed an adjustable roof guardrail assembly that can accommodate a roof pitch range of 27" to 63" (Photo 1, p. 29).

Commercialization

NIOSH had a public meeting to transfer the guardrail assembly to practice and is finalizing agreements with partners to commercialize the design. It can be used to protect workers from falls from roof edges, roof holes and existing skylights.

Protecting Against Tractor Rollover

Another example is AutoROPS that can be used on farm tractors and commercial lawn mowers.

Research

From 1992 to 2000, more than 990 farmers died as a result of tractor overturns (Myers, 2003). Nearly all of these deaths could have been prevented with the ROPS and proper use of a seatbelt. However, about half of the 4.7 million tractors in service in the U.S. lack the appropriate rollover protection (Myers). Tractor operators have noted low-clearance situations, such as orchards and buildings, as a reason for not having ROPS on their tractors (Etherton, McKenzie, Lutz, et al., 2004).

Design

NIOSH developed AutoROPS to address low-clearance situations (Photo 2). This device is a passive control. It stays in a lowered position until a rollover condition is determined, at which time it deploys to a fully extended and locked position (Powers, Harris, Etherton, et al., 2001).

Standardization & Commercialization

Over the past few years, the NIOSH ROPS research team has worked with a manufacturer and a powered lawn care equipment manufacturer to facilitate transfer of this device to industry (Photos 3 and 4). In addition, NIOSH has worked with equipment manufacturers, academia and standards committees to develop a performance standard for the AutoROPS. This committee is currently named X599 and operates under ASABE's administration. This research-design-standardization process is expected to streamline the commercialization of the technology and, thus, reduce rollover injuries and fatalities involving tractors and lawn mowers. The technology has a high potential to be transferred to the military as well to protect soldiers from combat vehicle rollover incidents.

Enhancing Harness Fit

The next example is the development of anthropometric criteria for harness design and improvement of harness sizing schemes to enhance the harness fit among the workers—tall and short, heavy and thin, and diverse body shapes.

Research

Falls from height are a leading cause of death in the construction industry; in 2004, 437 U.S. construction workers died due to falls-from-height incidents (BLS, 2004a). In addition, more than 20,950 construction workers were disabled in work-related falls from height in the same year (BLS, 2004b). Fall-arrest harnesses provide the last line of defense to the 6.3 million construction workers in areas where fall-from-height hazards cannot be completely eliminated (Hsiao, Bradtmiller & Whitestone, 2003).

Review of historical anthropometric sources for commercial harness sizing reveals that the sizing is based on dimensions derived from U.S. military population databases collected in the 1970s and 1980s (Bradtmiller, Whitestone, Feldstein, et al., 2000). The harness manufacturing industry, SH&E professionals and trade associations have a pressing need to reassess the current sizing schemes—anthropometric data for military populations do not represent the civilian worker population because of relatively strict anthropometric entry requirements for the armed forces and height/weight guidelines for troop retention (Hsiao, et al., 2003). Furthermore, workforce diversity and body dimensions have changed significantly among the U.S. civilian population in recent decades (DHHS, 2001).

The NIOSH Harness Research Team has used a rapid 3-D scanning technology to digitally capture worker-harness interfaces (Photo 5, p. 31) and developed scientific theories to quantify human torso shape and size. For example, a bounding-box procedure, which originated in the computer graphics field, was used to extract the maximum breadth (side-to-side distance), depth (front-to-back distance) and height (top-to-bottom distance) of both the upper-torso volume space and the lower-torso volume space (also known as "torso bounding boxes") from 3-D scan images. These dimensions were then used to explore the interaction of the general body shape and dimensions with harness fit.

Design

Using these theories, the research team has further derived and tested practical harness design criteria to advance knowledge about reducing the risk of injury that results from poor harness/user interface, improper size selection or the failure to don the harness properly (Hsiao, et al., 2003; Hsiao, 2004). The team has also worked with the harness manufacturing industry to formulate harness-sizing schemes and harness designs for various populations, especially women and minorities, to ensure the required level of protection, productivity, and comfort of harnesses to workers (Hsiao, Whisler, Kau, et al., 2005).

Standardization & Commercialization

Several professional organizations and standards committees have testified, in various forms, to the urgent need for this r2p effort. Two leading U.S. harness manufacturers (MSA and DBI-SALA) have actively participated in the NIOSH research and are using the research results to modify current harness designs as well as to develop the next-generation harnesses. A national committee on fall protection equipment has also expressed interest in incorporating the study results to possibly establish national harness-sizing standards.

Developing Safer Scissor Lifts & Work Practices

The last example involves collaborative research with a scissor lift manufacturer to develop safer scissor lifts and work practices. Scissor lifts are frequently used in the construction industry thanks to their time-saving benefit and ability to reduce exposure to fall hazards. However, some scissor-lift tipover incidents have been reported.

Research

McCann (2003) examined the deaths of 339 construction workers due to personnel lifts, using data for the years 1992 to 1999 from the BLS Census of Fatal Occupational Injuries. He found that 19% of these fatal incidents were associated with a single type of lift—the scissor lift; 65% of these incidents were worker falls and lift collapses/tipovers. A review of NIOSH Fatality Assessment and Control Evaluation reports from 1985 to 2002 and the OSHA incident investigation records from 1990 to 2003 also identified tipover as the most frequent type of fall incident involving scissor lifts (Pan, Hoskin, Lin, et al., 2005).

Design

NIOSH has signed a letter of agreement with SkyJack Inc. to develop safer scissor lifts and work practices. The research team is working to develop a validated computerized model that can be used to analyze the impact of the load (such as worker, tools and building materials), size, weight and location on the scissor lift platform at different heights and operator activities (e.g., pushing or pulling wires). The partner has provided two scissor lifts and related engineering support to the NIOSH research team.

The research team is performing static and dynamic experiments on the changes to center-of-mass of the scissor lift under various work scenarios in which workers might engage, using volunteer participants. Specifically, the studies involve dynamic curb test, depression test, and driving and stopping (jerking) at a range of heights and with a range of loads on the platform.

Standardization & Commercialization

The study results will provide critical information for international standard committees relating to scissor lifts to develop revised standards. These committees include the main ANSI A92 Aerial Platforms Committee and various A92 subcommittees, the U.S. Technical Advisory Group to ISO Technical Committee 214, Elevating Work Platforms, and the Canadian Standards Association's B354 Elevating Work Platforms Technical Committee. This joint research effort will ensure the commercialization of new safety features once successful tests are achieved.

Conclusion

The process of implementing engineering technologies for injury prevention typically encompasses the steps of research, product design, standardization and commercialization. The four r2p examples described involve research on innovative approaches to reduce workplace hazard exposures as well as efforts to develop practical solutions and designs to prevent occupational injuries. Working closely with industry partners, NIOSH has advanced technologies into standards and commercialization, which is a cornerstone for effective occupational injury prevention. As these examples show, the NIOSH experience provides a roadmap for the global safety engineering community to follow. ■

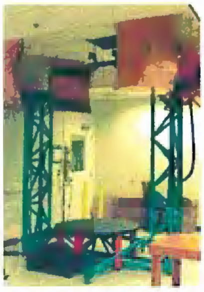


Photo 5: A Cyberware WB4 3-D full-body scanner was used to register the interface between human torsos and fall-arrest harnesses while the subject was in both the standing and suspended postures.

References

Bradtmiller, B., Whitestone, J., Feldstein, J., et al. (2000). Improving fall protection harness safety: Contributions of 3-D scanning. *Proceedings of the Industrial Congress on 3-D Digitizing, Paris, France*, 117-128.

Bureau of Labor Statistics (BLS). (2004a). *Census of fatal occupational injuries: Event or exposure by major private industry division, 2004.* Washington, DC: U.S. Department of Labor, Author. Retrieved Feb. 28, 2006, from http://www.bls.gov/iif/oshwc/cfoi/cftb0204.pdf.

BLS. (2004b). *Case and demographic characteristics for work-related injuries and illnesses involving days away from work: Detailed industry by selected events or exposures, 2004.* Washington, DC: U.S. Department of Labor, Author. Retrieved Feb, 28, 2006, from http://www.bls.gov/iif/oshwc/osh/case/ostb1514.pdf.

BLS. (2005a). Census of fatal occupational injuries in 2004. Washington, DC: U.S. Department of Labor, Author. Retrieved Oct. 2, 2006, from http://www.bls.gov/news.release/pdf/cfoi.pdf.

BLS. (2005b). Case and demographic characteristics for work-related injuries and illnesses involving days away from work: Supplemental tables; Table 8—Cases involving falls to lower level. Washington, DC: U.S. Department of Labor, Author. Retrieved Oct. 2, 2006, from http://www.bls.gov/iif/oshwc/osh/case/ostb1506.pdf.

Etherton, J., McKenzie, E., Lutz, T., et al. (2004). An initial farmer evaluation of a NIOSH AutoROPS prototype. *International Journal of Industrial Ergonomics, 34*(3), 155-165.

Hsiao, H., Bradtmiller, B. & Whitestone, J. (2003). Sizing and fit of fall-protection harnesses. *Ergonomics, 46*(12), 1233-1258.

Hsiao, H. (2004). Anthropometric procedures for design decisions: From flat map to 3-D scanning. In P.T. McCabe (Ed.) *Contemporary Ergonomics* (pp. 144-148). Boca Raton, FL: CRC Press.

Hsiao, H., Whisler, R., Kau, T., et al. (2005). Constructing new harness fit charts using 3-D anthropometric information. In P.D. Bust and P.T. McCabe (Eds.) *Contemporary Ergonomics* (pp. 3-7). New York: Taylor & Francis.

McCann, M. (2003). Deaths in construction-related to personnel lifts, 1992-99. *Journal of Safety Research, 34*(5), 507-514.

Myers, J. (2003). Tractor occupational safety and health update. *NIOSH Agriculture Centers workshop: Record of tractor-related injury and death meeting, Pittsburgh, PA*, 5-23.

Pan, C., Hoskin, A., Lin, M., et al. (2005). Incidents due to aerial work platforms [Abstract]. *Proceedings of the XVIIth World Congress on Safety and Health at Work, USA.*

Powers, J., Harris, J., Etherton, J., et al. (2001). Preventing tractor rollover fatalities: Performance of the NIOSH AutoROPS. *Journal of Injury Prevention, 7*(Suppl I), i54-i58.

U.S. Department of Health and Human Services (DHHS). (2001). *The surgeon general's call to action to prevent and decrease overweight and obesity.* Washington, DC: Author, Public Health Service, Office of the Surgeon General. Retrieved Oct. 2, 2006, from http://www.surgeongeneral.gov/topics/obesity/calltoaction/CalltoAction.pdf.

Disclaimer: *The findings in this presentation are those of the author and do not necessarily represent the views of NIOSH.*