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Potential Uses of Technology to Communicate Risk in Manufacturing

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ABSTRACT

Technological advances already implemented in other systems can be used to design and deliver warnings and other risk communications in a variety of occupational settings, including manufacturing environments. This article discusses technologies that could be used to design and deliver risk communications. Examples are discussed in terms of potential applications and protocols. As with many advancements, there are new challenges, including ethical considerations both inside and outside the workplace environment. These issues are discussed along with initial approaches to resolve expected ethical conflicts and implement advanced risk communication systems (ARCS). © 2004 Wiley Periodicals, Inc.

1. INTRODUCTION

Technological advances not only affect the approach to work but also the way managers and employees think about work processes (Orlikowski, 1992). Advances such as flexible and integrated manufacturing have led to new challenges to the safety of workers and consumers who benefit from the outcomes of these new processes. Safety hazards can be introduced by design errors, human errors, or component failures (Jaervinen, Vannas, Mattila, & Karwowski, 1996), and the challenge to risk communication designers is to identify these hazards in the early stages of system design so that effective communications can be developed (Wogalter & Conzola, 2002). In the last two decades, these advances have diffused to many segments in the manufacturing environment. With the growing use of technologies, many applications are no longer as cost prohibitive as they were a decade ago. This rapid diffusion has led to a need to use a more macroergonomic approach to understanding new work systems to produce more compatible risk communication. Macroergonomic approaches emphasize joint optimization of work systems within a larger operational context (Hendrick & Kleiner, 2001). Risk communication research and design should be driven by a thorough understanding of the work system.

One of the most critical features of contemporary manufacturing is the work force. The employee system needs to be capable of processing large and varying amounts of information (Warnecke, 1993). The assumption that increasing complexity and automation reduces human involvement and exposure to hazards is not accurate. As manufacturing increases in complexity, systems become more dependent on humans for intelligent flexible operation and maintenance (Wobbe & Charles, 1994). Adapting manufacturing systems to fit production, employment, marketing, and governmental requirements introduces uncertainty and makes effective revisions difficult. In addition, safety protocols can be highly complex to implement and maintain. For example, they can become less effective over time without change, which increases the importance of communicating risks in the form of warnings and training (Kjellen, 1984).

According to Rogers' (1995) model of diffusion, risk communication designers are relatively late adopters of the technological advances that are already driving processes in the workplace, particularly in manufacturing. The challenge to the late adopters is to gain knowledge of the advanced technologies rapidly, identify design principles to develop new applications relevant to their discipline, and then embed those applications in the environments that have already implemented similar technologies. This approach recognizes the need for designing advanced risk communication systems (ARCS) that are compatible and easily coupled with existing work systems in part due to cost and relatively easier implementation. However, one of the major problems in work systems based upon flexible manufacturing is the number of accidents or injuries that occur due to system design.

There are several technologies that can be applied to research, design, and evaluation activities related to advanced risk communications. The traditional methods mostly include paper-based delivery and face-to-face safety training in class or on the shop floor. However, ARCS may result in better delivery protocols by providing solutions to several challenges posed by traditional delivery of risk communications. These challenges include:

1. *Constant presence:* Paper-based risk communications may be difficult to locate when needed or can be thrown away. Not all print media can be consistently displayed in the immediate work environment (e.g., posters and placards).
2. *Continuous salience:* Traditional risk communications, including auditory interfaces, become less effective with repeated presentation using the same format or may fade in color, legibility, or perceived intensity over time.
3. *Adaptation:* Since advanced manufacturing environments are dynamic and often employ such practices as cross-training and job rotation, risk communications need flexibility to fit the changing work environment.
4. *Customization:* There are individual differences that affect the degree to which workers are influenced by risk communications. Traditional risk communications are difficult to customize based upon worker profiles and, if customized, introduce several other challenges such as cost.

Risk communications incorporate new technologies as the media for delivery have the potential to resolve the aforementioned challenges. Some of the potential uses and applications are discussed in the following sections.

2. TECHNOLOGIES RELEVANT TO ARCS

2.1. Internet

One of the most significant advances that has and will continue to affect risk communications is the Internet. The Internet supports Web-based delivery of risk information, including training materials. A combination of passive and active design can be used to communicate risk using Web-based tools.

A passive approach is to make available information on paper such as Material Safety Data Sheets (MSDSs), which are required in U.S. workplaces containing hazardous chemicals. Other approaches include changing operating procedures and updating to comply with new training or certification requirements related to a particular hazard within the work system. Organizations can provide workers with updated information related to hazardous processes, equipment, or chemicals in the work environment. The latter approaches are mostly passive in that workers may not be provided with the information, and even so, they may not access or use the information.

An active approach would involve the use of an interactive tool to train workers and then assess their knowledge and risk judgment. An interactive tool can support a system to collect and analyze critical incidents reported by workers and provide solution-based reports to supervisors. This tool also can track employee usage through collection of log-on/log-off data of server use, and could alert supervisors if a particular worker has not completed a required training or procedural module before they become involved in a work system with a new hazard. Given the advances in multimedia tools and the ease of incorporating Web media objects such as audio/video and animation, applications can be developed in a relatively short time frame. In addition, with increasing globalization of manufacturing, organizations with branches in other locations can modify their Web-based programs in ways appropriate to location and culture.

2.2. Nontraditional Interfaces

Advances in computer hardware, including microprocessor technology, have driven human–computer interface design and functionality. These changes have led to a focus on smaller interfaces as well as nontraditional interfaces. Hand-held and palm-top devices are currently employed in adverse medical-event reporting in several healthcare systems throughout the United States (Bates, 2000). Because healthcare workers are not consistently positioned in the same area of the "shop floor," the use of portable devices to support reporting of safety-related critical incidents has enabled the ability to capture potential problems in real time to support rapid intervention to prevent further adverse events. This same technology can be implemented within dynamic manufacturing systems. Workers, production engineers, and/or shop floor supervisors can be provided palm-top devices or multifunction cellular phones not only to report problems when they occur but to access and check risk communications or safety-related operating procedures when they encounter a hazard.

Research supports the effectiveness of delivering warnings that are proximate or immediate to the hazard (Frantz & Rhoades, 1993; Wogalter, Barlow, & Murphy, 1995). This suggests that a palm-top device could act as an onsite, immediate-decision aid and reminder system when a situation arises involving a potential hazard exposure. In some time-critical cases, this information delivery system could increase the chances that workers would be apprised and more likely employ safe practices. A production engineer could be standing on the shop floor and determine how a change in production output could affect safety or error probabilities with powerful hand-held devices.

Although small interfaces have gained prominence in personal and transportable human–computer interfaces, several developers are deviating from tradition in a manner that is unrelated to size. One such example is the move to nonvisual and socially based interfaces.

One type of nonvisual interface is the speech interface. Voice presentation of risk communications would be effective in most manufacturing settings that are visually demanding. For example, Conzola and Wogalter (1999) found that speech warnings can lead to greater compliance compared to print warnings.

Walk-up touch-screen-information kiosks can be developed to allow ease of access to risk communications and to report critical incidents as soon as they occur. Well-designed interfaces would be those that could be easily used by persons with minimal knowledge of computers.

A socially based interface employs interface objects that are natural to human interaction, such as faces and gestures (Turk, 1998). Using database software, applications could be developed for information kiosks that allow workers to query the system when there is a question regarding a hazard or potential hazard exposure. The system can then deliver a warning or other risk communication to prevent exposure or provide the worker with protective protocols.

Turk (1998) introduced a deviation from the traditional graphical user interface (GUI) known as the perceptual user interface (PUI). According to Turk, PUIs can process operator gestures as commands. Gesture sets (hand gestures and head gestures) can be developed to query a risk communication database such that workers could avoid the need to use complex commands to interact with it. This type of application can move the workplace environment from a passive, hazard-filled environment to an active, protective environment—in other words, a smart workplace.

2.3. The “Smart” Workplace

There are a number of technologies that have been implemented in emerging smart systems. These systems are ubiquitous in that their presence and activity are relatively covert. A smart system is one that has the following features:

1. The ability to recognize and monitor users within an operational environment.
2. The ability to use and expand a knowledge database using an intelligent agent.
3. The ability to adapt to information gained from users.
4. The ability to customize information when presented to users.

Smart systems have been applied to the development of home-based, medical monitoring of patients with unstable health conditions (Ogawa & Togawa, 2000), and prototype systems continue to be developed and tested. Kwahk, Smith-Jackson, and Williges (2002) developed a prototype from a conceptual model derived from participatory design (Figure 1) that shows the processing scheme of a smart monitoring system called *Senior Healthwatch*, which was designed for seniors or persons with disabilities living alone.

With slight modification, these technologies also can be used in the workplace. Sensor and bioscanning technology presents a number of possibilities. For example, motion and pattern recognition sensors can support the monitoring of movement within the workplace. Data from sensors can be transmitted to a computer that will then translate the inputs into outputs revealing problems such as errors in sequence or action (e.g., not completing a lock-out/tag-out maneuver) and unauthorized entry into hazardous areas. Wogalter, Kalsher, and Racicot (1993) used an infrared photoelectric detection device to activate the presentation of a warning when individuals entered a high-risk area. Conzola

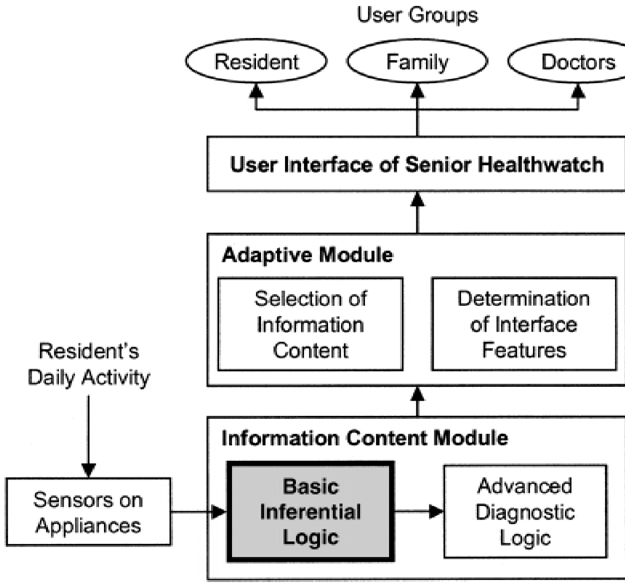

Figure 1 Conceptual model of Senior Healthwatch (from Kwahk, Smith-Jackson, & Williges, 2002).

and Wogalter (1999) used a simple, spring-loaded movement detector to sense the opening of a corrugated box of equipment in an installation task. The sensor elicited a voice warning delivered by an inexpensive digital voice chip and miniature speaker. Compliance to the warning information was greater in this condition compared to without the voice warning. More specific detection and recognition systems might use bioscanning and bar-coding technology to identify and admit certain employees into restricted areas, or keep track of what warnings were presented at earlier times.

An important characteristic of smart systems is their flexibility and adaptability. These systems can adapt to human variation, such that information presented could be tailored to worker characteristics. Similarly, an important factor in warning design is relevance. Warnings that are more relevant to the task and to the individual involved in the task are more likely to be effective. Wogalter, Racicot, Kalsher, and Simpson (1993) presented participants with personalized signs consisting of the person's name and warning information. The personalized signs led to higher compliance rates compared to signs that were not personalized. Another study by Racicot and Wogalter (1995) applied Bandura's (1977) observational theory that suggests that models having similar characteristics as the observer are more likely to be imitated. Racicot and Wogalter showed videotaped models using personal protective equipment (donned mask and gloves) in a similar task situation as the participant and compared participants' resulting behavior to participants presented a conventional static sign with a pictorial-symbols warning that protective equipment be used. Compliance was higher for individuals who watched the video compared to the conventional warning sign. Thus, it would seem possible to develop a smart workplace that presents warnings and related information to users based on the task and individual differences (worker experience, behavioral tendencies, age, language, etc.). Research has shown that visual and auditory components of warning displays can influence the level of perceived hazard (Barzegar & Wogalter, 1998, 2000; Hellier, Wright, Edworthy, & Newstead, 2000; Wogalter, Kalsher, Frederick, Magurno, & Brewster, 1998). Inputs to the smart system and the resulting knowledge base could be used to change message content, color, or other physical features based upon the user or the situation. The warning components and their composite connoted meaning could be changed dynamically to signal changing levels of hazard. For example, the color of the warning could be dynamically changed from yellow or orange to red, thereby increasing the level of perceived hazard compared to using other colors (e.g., Smith-Jackson & Wogalter, 2000). Conversely, a dynamic display can be used to present colors in a decreasing level when the situation becomes less hazardous. A smart system could monitor these activities and alter the display as necessary.

Auditory-based displays also could be used to present information as needed. Belz, Robinson, and Casali (1998) presented auditory icons in a driving simulation task. Auditory icons were effective in enhancing driver performance compared to visual-only displays. Another application of dynamic displays relates to speech-based warnings. Some researchers have used certain dynamic characteristics of speech to influence risk perception. The use of dynamic speech characteristics is consistent with the notion captured by the changing-state hypothesis (Jones, 1993). This notion suggests that the attention-capture capability of voice communications is partially dependent upon the variability in the speech. Thus, risk communications delivered in a variable and distractive fashion, above the constant drone of machines or workers' voices, could be useful in capturing and sustaining attention. A speech-based warning could change in frequency or intensity from background sound if sensor information suggests that a worker is entering a hazardous area or is about to be exposed to a hazardous system (Barzegar & Wogalter, 2000; Hollander & Wogalter, 2000). Voiced warnings could change on the basis of intonation as a worker's proximity to the hazard decreases. Barzegar and Wogalter (1998) manipulated voiced signal words on the basis of voice style or intonation and sound level, and measured the extent to which individuals would behave cautiously. At equal sound levels, signal words delivered with emotional intonations had higher hazard connotations than monotone or whispered signal words. Participants also assigned higher carefulness ratings to female voices compared to male voices. The higher pitch and changing intonation of an "emotional" appeal may reduce the chances that a warning will be missed.

2.4. Virtual Environments

Use of technologies based on advances in virtual reality and immersive systems provides numerous training opportunities, and eliminates the possibility of training-related accidents. Organizations have already begun to apply virtual reality training to their safety activities. For example, Reid, Reid, and Sykes (2001) described a virtual reality training system that can introduce virtual hazards while operators are completing virtual tasks. In this environment, workers have the opportunity to actively engage in a relatively realistic setting. Modeling of these systems and the degree of immersion or "fidelity" should be considered and be based on training goals. For example, a transport environment and the simulation may need a motion platform to simulate movement of a machine or forklift, but the motion apparatus is probably not needed in simulations supporting lock-out/tag-out procedures or chemical hazards. Glover and Wogalter (1997) presented participants a task of trying to leave ("escape" from) a virtual coal-mine environment. As they moved through the coal mine, participants came upon signs that gave directional information and warnings. Signs that were more salient resulted in better "escape" performance. This and similar techniques in virtual environments can be used to train without injury-producing risks present.

3. HUMAN PROCESSING LIMITATIONS

Manufacturing environments have experienced an increase in the information that must be processed by workers to engage in continuous work activities (Colosky, 2001). Careful considerations in the design of systems are critical for ensuring that safety is enhanced rather than compromised by new technologies. Because of the sheer amount of information, it has become increasingly important to ensure that the information is presented well—particularly, risk information.

The potential for information to be conveyed inadequately to users should be considered when introducing warnings and prioritizing types of information to be presented. ARCS designers using advanced technologies must understand the capabilities and limitations of the human information processor, and particularly, human information processing in complex manufacturing environments. Wogalter, DeJoy, and Laughery (1999) proposed the Communication–Human Information Processing (C-HIP; Figure 2) model to support design of risk communications based on a convergence of empirical research on communication and cognition. Very few empirical studies have specifically applied the C-HIP model to ARCS. Although some studies are under way (e.g., Wogalter & Conzola, 2001), more descriptive and predictive studies should be conducted to understand how the C-HIP model can be applied to technology development and diffusion models to enhance our understanding of ARCS. This model depicts the human processor as actively using cognitive mechanisms and imposing prior attitudes and beliefs to assign meaning to risk communications. The model serves as a useful method to design and evaluate from a user-centered perspective.

The increased complexity of manufacturing environments also has increased the complexity of the sociotechnical structure of these environments. Consequently, an important

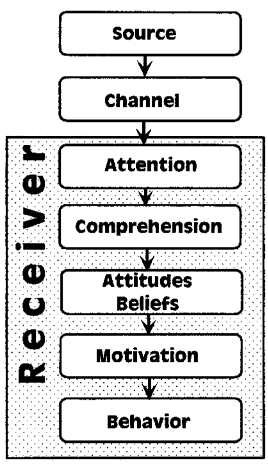

Figure 2 Communication-Human Information Processing (C-HIP) model (Wogalter, DeJoy, & Laughery, 1999).

question in sociotechnical systems design relates to function allocation (Hendrick & Kleiner, 2001). How much of the duty to warn is allocated to the advanced system, and how much is allocated to the employer? Operators have a propensity to overrely on advanced systems after they have developed trust in those systems (e.g., Bahr, 1997). Thus, a potential problem with ARCS in manufacturing environments is an overreliance on the machine and less allocation of duty to warn to the employer. This overreliance could result in decisions to reduce training programs or reduce safety monitoring. But, even with appropriate monitoring, ARCS may influence human behavior and produce unexpected outcomes. In particular, new types of errors may occur simply because of the new and different demands placed upon the operator. However, despite the unexpected errors that are likely to arise, there are a number of preexisting models that can be used to predict at least some of the potential problems. These predictions can then direct the types and content of risk communications necessary to reduce the likelihood of occurrence. Once such model is Reason's Generic Error Modeling System (GEMS, Figure 3). GEMS is a guide to conduct preliminary assessments of errors as well as antecedents and can be used before systems are implemented. Special attention should be directed to the portion of the model that relates to familiarity. In the context of new technologies, in rule-based problem situations, operators will initially apply known rules if the pattern seems familiar; in other

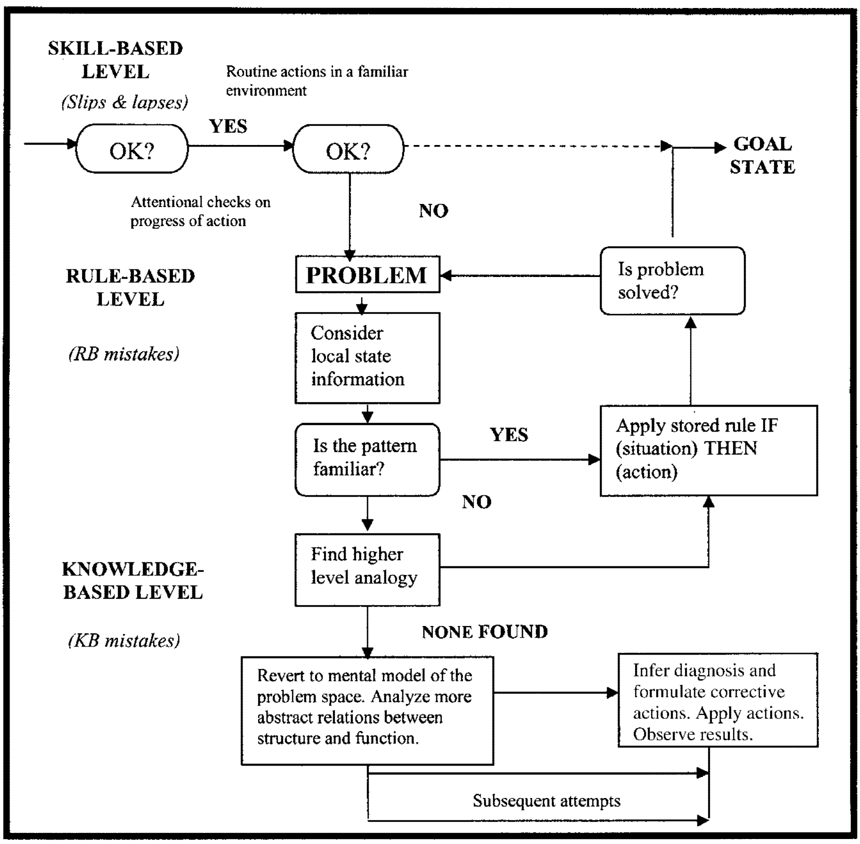

Figure 3 Generic Error Modeling System (GEMS; Reason, 1990, p. 64).

words, their mental models of a previous system relates to the problem situation. However, if the pattern deviates from previously known rules, operators will search for high-level schemas (e.g., more global mental models of the general problem space) or analogies to identify an action. By using GEMS, evaluators can map possible responses and adaptations as well as potential problems requiring risk interventions. In this case, risk communications can be designed concurrently with assessments that are based on GEMS.

4. ETHICAL CONSIDERATIONS

Main (2002) suggested that safety issues including those that are based on ethical considerations should be addressed during conceptual design. Although ARCS such as speech-based warnings could reduce hazard exposure, the exposure to emotional stimuli (in the form of strongly intoned words) could result in a stress reaction or residual arousal. For example, the higher pitch and changing intonation of an "emotional" voice warning may be useful for attracting attention and enhancing the perceived hazardousness. However, it also may produce undesirable side effects in the work environment. The resulting stress or arousal states may contribute to increasing mental workload or emotional or physical reactions, and consequently, increase the probability of error. Workers would have to be educated regarding the potential negative consequences resulting from risk communications that are delivered via advanced technologies, and possibly also coping strategies.

The right to privacy is a central tenet of human rights in the United States and other countries. Smart workplaces could monitor workers by processing inputs from sensors and video monitors. Employers could monitor conversations over company-owned phones and computers. In this environment, "big brother" really is watching. The increasing use of video monitoring presents privacy conflicts. Ethically, workers would have to be informed of the capabilities of a smart work system. Ethical dilemmas surrounding the extent to which organizations can constantly monitor their employees while protecting their privacy rights would have to be weighed against the need to protect workers from hazards. Protection from hazards is right mandated by the OSHA Act of 1970 and must be considered when examining the benefits of smart work systems and privacy. Are the protection benefits offered by the advanced technology more important than the employee's right to privacy? These questions will have to be addressed by legislation and the courts.

5. COST

Although the costs of many advanced technologies have decreased over the last decade, access to those technologies is still cost prohibitive for many small organizations. Early adopters of any technology, including ARCS, are more likely to be comprised of organizations with more resources. Similarly, work environments that can initially employ advanced warning systems would likely be entities that already use extensive work-safety practices. The potential for disproportionate use of advanced warning systems may be an undesirable consequence. This inequity or gap in access would likely not reduce the incidents of hazard exposures among lower socioeconomic status workers (Harrell, 1990; Loomis & Richardson, 1998). Designers of ARCS need to consider technology adoption and access inequity to provide employee protection in small businesses or in developing countries.

6. CONCLUSION

Technological advances have afforded the opportunity to develop risk communication systems that are more effective in preventing injuries or illnesses. Warning and risk communication designers should make use of these advances so that risk communication design can parallel the increasing complexity of manufacturing systems. Manufacturers should make use of these systems to benefit the safety and welfare of their workers.

It is important to note that safety and risk management efforts are increasingly tied to organizational management, social and political structures, and environmental conditions and resources. ARCS that are designed for one culture and transferred to another may, in fact, introduce new hazards if decisions are made without regard to the macroergonomic issues (Cernavin & Lemke-Goliasch, 2001). Thus, it is necessary to conduct culturally centered hazard assessments before making transfer decisions and to determine the necessary modifications. Using archival methods such as reviewing injury data or relying on global summaries of accident data will not be sufficient since countries differ in their definitions of and methods for recording accident and injury data (Batra & Ioannides, 2001), and these differences may lead to misinterpretation.

Many researchers have provided protocols to implement new systems within existing operational contexts. Among the numerous recommendations, one of the most important is to identify a "user champion" (Eason, 1991). Senior safety managers would be the ideal user champion of ARCS. A senior safety manager should be assigned direct responsibility and accountability for implementation of ARCS. First, the buy-in from management is an absolute necessity for successful implementation, and a senior safety manager's positive attitude will strongly influence the rest of the organization. Second, a senior safety manager could effectively lead the effort with a team of manufacturing and production engineers to develop a diffusion plan that incorporates the necessary safety, technical, organizational, and social considerations. Finally, a senior safety manager along with an organizational management group would be able to select and apply the most appropriate implementation model.

There are several implementation models from which to select, and the most appropriate model depends upon the context. Some of the more familiar implementation models include the Greenfield site, Big Bang, Parallel Running, Phased Introduction, Trial and Dissemination, and Incremental Implementation models (Eason, 1991; see our Table 1). Each model is relevant to specific contexts and systems. Unlike many other new systems that can be implemented in a manufacturing environment, ARCS has a strong potential to introduce risk of injuries or fatalities if implemented poorly. Thus, of the possible alternatives, those requiring the easiest adaptation are the most appropriate. Eason (1991) described the ease of user adaptation for each implementation model (Figure 4). The last three—Phased Introduction, Trials and Dissemination, and Incremental Evolution—would place the least adaptive demands on workers. For example, a phased introduction could be used such that portions of the organization could receive familiarization or orientation to the ARCS, and this test group could then operate for a short period of time with data collection occurring during operation. The easiest approach from the perspective of the user and the best from a safety perspective is incremental implementation. This approach requires a gradual change over time, and continuing incremental change could be led by workers/users. However, incremental implementation should be planned rather than conducted haphazardly.

TABLE 1. Implementation Strategies (Eason, 1991) and ARCS-Related Examples

Strategy	Description	ARCS-Related Example
Greenfield Sites	Select an entirely new work system in which to implement the target system (new system).	A new factory is built, and the ARCS is implemented only in the new factory. All existing factories maintain traditional risk communications.
Big Bang	Traditional system is ended one day, and the new system is implemented the next day.	Plant is shut down at the end of a designated day. Traditional risk communications are removed, and the ARCS is installed and enabled the next day.
Parallel Running	Introduce the new system concurrently with the old system.	Maintain traditional risk communications, but install and enable ARCS. Both will run concurrently until a safety performance criterion is reached. Then, traditional is gradually phased out.
Phased Introduction*	Changes are phased in over a selected period of time.	ARCS components could be phased in individually, rather than an entire system. Only certain types of information are made available through a kiosk with a touch-screen interface. All other risk communications must be accessed in the traditional manner. After a criterion is met, additional components are introduced.
Trials and Dissemination*	A major trial is conducted to identify problems, which are then addressed before moving to full-scale implementation.	ARCS system could be tested in trials outside of normal operation. Problems could be identified, resolved, and tests repeated as needed.
Incremental Implementation*	Gradual change in very small increments. No major changes are experienced by users/workers.	All risk communications could be initially arranged in a variety of different areas that are easily accessible. Other types of information such as operating instructions also could be physically localized. Over time, those areas could be replaced by a desktop computer access system for all information. After some usage period, the access protocol could be transferred to a kiosk with a touch screen, which is then applicable to all types of information.

*Indicates strategies that can be reasonably considered in the context of safety and risk management.

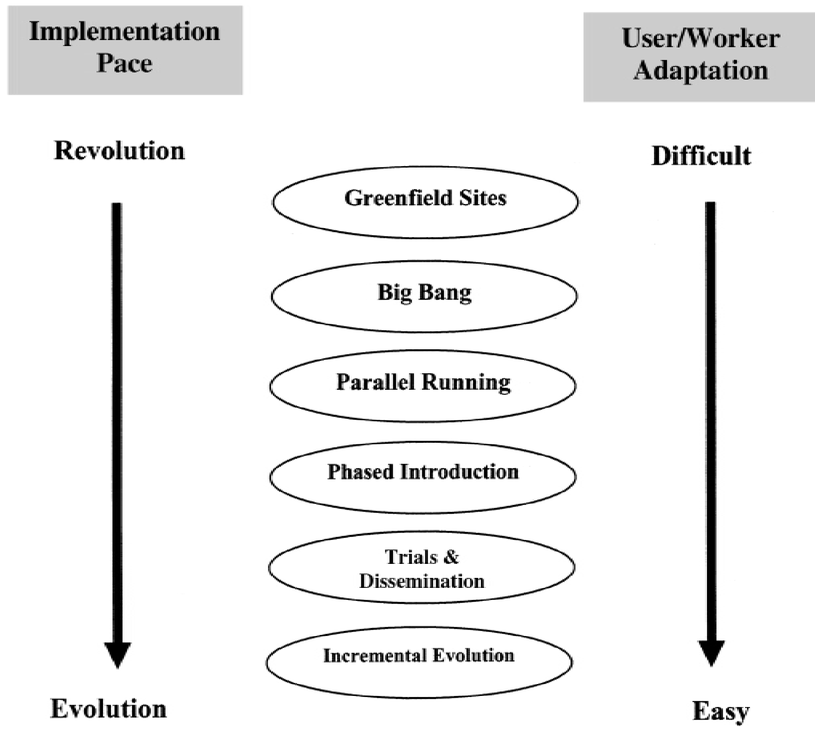

Figure 4 Implementation models. Adapted from Eason (1991; cited in Wilson & Corlett, 1991, p. 837).

Although diffusion of ARCS should be led by a senior safety manager, this recommendation does not preclude the requirement to include workers in the diffusion process, including selection and customization of potential ARCS. User involvement is a very important part of any system change process, regardless of organizational and cultural context, and should be built into the diffusion plan.

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