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The Broader Context

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Knowledge Management in Occupational Hygiene: The United States Example

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Knowledge management is an emerging field focusing on assessing the creation, transfer, and utilization of knowledge to address specific challenges. Generally, knowledge management has described efforts within and between companies to consider knowledge as a manageable asset. In this paper, we suggest that occupational hygiene knowledge can be considered a manageable asset by businesses and that the entire field of occupational hygiene in the USA can be appraised in terms of knowledge management. The knowledge cycle creates a foundation for knowledge management. Knowledge creation (research, recognition and evaluation), transfer (distribution, dissemination and diffusion), and utilization (risk management and control) make up the key elements of the knowledge cycle. Defining and understanding the roles of knowledge cycle elements facilitate the application of knowledge management to problems, systems, and situations in individual companies and in the field of occupational hygiene in general. Examples of current, effective knowledge management practices within occupational hygiene in the USA are described, and recommendations for further utilization of knowledge management principles are also presented.

Keywords: dissemination; knowledge; management; occupational hygiene; transfer; utilization

'Information is everywhere; knowledge is hard to find' (Abeytunga, 2003).

INTRODUCTION

Knowledge management is an emerging field that has created a conceptual shift in the way we understand and use 'knowledge'. The term knowledge here is distinct from the terms data and information. Data are unorganized facts and observances; information is data plus context; and knowledge is information and judgement (FCIOC, 2001). The hierarchy of 'what we know' is generally considered to have knowledge at the top, and it is what makes information (just below knowledge in the hierarchy) work—knowledge is used to recognize, identify, analyze, interpret and evaluate information; to synthesize, assess and decide; and to adapt, plan, implement and monitor—to act (Wiig, 1999b).

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Knowledge, as the term is used here, is intangible, but it is exactly what you hope will develop when you hire a new employee; it is what develops in an employee who has been in a job for a long time and it is what you do not want to lose when the employee leaves. It is what you do not want to sacrifice when experts communicate across a distance or time. It is what a researcher learns from doing research but which does not go into the journal article. This knowledge is a valuable asset, and like any asset, it works best if it is well managed. Because knowledge in a company about how to do something well (or better than competitors) is sometimes an intangible asset, it is often neither recognized nor managed, yet it is vital to an organization's long term success.

Information, unlike knowledge, is found in databases, filing cabinets, libraries and the internet. Knowledge, however (often referred to as 'institutional memory'), develops out of the experience of applying information to a unique problem. Unless that experience is somehow recorded or transferred,

the knowledge gained will be lost, or at best distributed in people's heads across the organization. When knowledge is not managed, problems once solved are repeated. Knowledge gained in one part of an organization may be lost to others because there is no way to track it. The field of knowledge management offers some guidance in helping an organization 'know what a company knows', by harvesting knowledge, by storing it and especially by sharing it.

These ideas represent something of a paradigm shift in thinking for scientists in at least three ways. First, scientists are accustomed to a linear concept of scientific development: basic research supports applied research, which results in devices, interventions or policies. Invention, innovation and diffusion are seen as separate stages in an essentially linear process (Edge, quoted in Louw, 1998). Knowledge management, on the other hand, is not linear. As we will see, the process is complex and iterative. Secondly, scientists frequently work in competitive environments, where publishing first is considered an asset and sharing knowledge might threaten primacy. Finally, scientist objectivity is a prerequisite of Newtonian-type science. Because tacit knowledge (the knowledge inside people's heads) by definition requires the messy involvement of humans and context, it may not be a valued aspect of the profession.

However, tacit knowledge is important to all professions, scientific or otherwise. It seems especially relevant to occupational hygiene because the science is so practical. Unlike other scientific fields, occupational hygiene research topics are often identified through direct human experience in the workplace, and the results of the research are often immediately applicable to the solution of a problem. In problem solving, tacit knowledge can be very valuable. However, as shown in the August 2003 volume of *The Annals of Occupational Hygiene*, the relationship between tacit knowledge and accurate exposure assessments is questionable. On one hand, Ramachandran *et al*. (2003) concluded that subjective 'expert judgement' concerning nickel speciation is at least as precise as sparse measurement data and that there is a body of specialized knowledge that experts draw on to reach similar judgements. On the other hand, Friesen *et al*. (2003) found only moderate correlation between expert judgement and exposure to coal tar pitch volatiles, and concluded that even when exposure measurements are available, the 'expert judgement' exposure assessments are significantly different than measurement-based exposure assessments.

Despite the growing interest in knowledge management studies, its theories have not been applied to the field of occupational hygiene. The utility of applying a knowledge management perspective to the field of occupational hygiene is in direct response to conclusions reached in two international meetings. The XV Congress of Occupational Safety and Health in 1999 concluded that the number one challenge in the next decade is to transfer what we know about safety and health and working conditions to practical terms (International Labour Office, 2001). Similarly, an international workshop on research dissemination (convened as a part of the Swedish Work Life 2000 effort) concluded that 'one of the greatest problems in the occupational safety and health community is the lack of appropriate emphasis on the research involved in dissemination, adaptation, and utilization of information' (Lagerlöf, 2000).

This paper is a first step in the process of applying knowledge management principles to the field of occupational hygiene. Its objectives, therefore, are to discuss the importance of knowledge management as an effective business practice and to assess how this practice is performed in the field of occupational hygiene. The concept of the knowledge cycle is introduced, and examples of specific elements of the cycle that pertain to occupational hygiene in the USA are presented. Knowledge management applications for occupational safety and health challenges are described, including tools for identifying and addressing knowledge gaps in occupational hygiene.

Background and previous work

The intellectual antecedents of the knowledge management field include the long and rich tradition of epistemology (study of the nature and origin of knowledge) through to the post-World War II developments in management theory, sociology and artificial intelligence. Although the identification of knowledge workers and the information economy was described earlier (Bell, 1974), Wiig (1997) is generally acknowledged to have coalesced the phrase 'knowledge management' in 1986, when he addressed the International Labour Office meeting and counseled that knowledge needed to be considered a corporate asset and must be managed if organizations are to be successful.

It was not until 1990 that macro-economic theory formally incorporated knowledge in models of economic growth (Romer, 1990; Johnston and Blumentritt, 1998). Against these academic and theoretical backgrounds, knowledge management arose as a substantive response to social and economic trends, including globalization, organizational restructuring, ubiquitous computing and increased knowledge composition of manufacturers' goods (Sheehan and Tegart, 1998; Prusak, 2001).

Knowledge management in business and industry

Principles of knowledge management have primarily been applied to businesses and industry, and the selling point for practicing knowledge management

is that knowledge is a selling point—it is an asset, and it increases efficiency and therefore profitability. Broadly speaking, the role of knowledge management within any enterprise is to provide effective capabilities, activities and an environment that support building, accessing and using knowledge competitively to promote sustained success and viability (Wiig, 1999b). This particularly pertains to building and leveraging intellectual capital (the knowledge that each company has and generates, be it personal, infrastructural or market related) to become, and remain, a highly effective enterprise.

Businesses of all sizes invest time and resources dealing with work-related safety and health issues. Investigations are conducted, controls are applied and reports are prepared. Over time, corporations gain a significant amount of knowledge. This knowledge, which includes staff experience, represents a valuable yet intangible optimized corporate asset. Although the knowledge management literature has focused on efforts within and between companies to consider knowledge about products and processes a manageable asset, occupational hygiene knowledge can also be considered one such asset, and is therefore also very important to preserve. With retirements, transfers and other personnel turnover, knowledge resources are shifted accordingly. The roles of knowledge capture and retrieval become essential. Consequently, organizations are called to task by one occupational hygiene practitioner (Brackensiek, 2002) with the following query: 'Is your organization's critical environmental health and safety knowledge walking out the door?' Brackensiek describes knowledge management tools for environmental health and safety, and discusses the responsibilities of an organization's 'knowledge engineer' in performing knowledge capture and maintaining knowledge systems specific to environmental health and safety. These knowledge systems can be best understood through the framework of the knowledge cycle.

THE KNOWLEDGE CYCLE

The actual practice of managing knowledge is complex, and can require the services of an expert. Some companies even have a full-time knowledge manager. Here, we begin with the most basic concept of the field of knowledge management—the knowledge cycle. Although many have written about the knowledge cycle (e.g. Marquardt, 1996; Holsapple and Joshi, 1997; Van der Spek and Spijkervet, 1997), the knowledge cycle used in this paper contains three elements: the creation, transfer, and utilization of knowledge. The following sections will apply the knowledge cycle to the field of occupational hygiene, which will provide opportunities to see the synergy among different functions, organizations and approaches within the field in order to identify opportunities for partnership, collaboration and leverage.

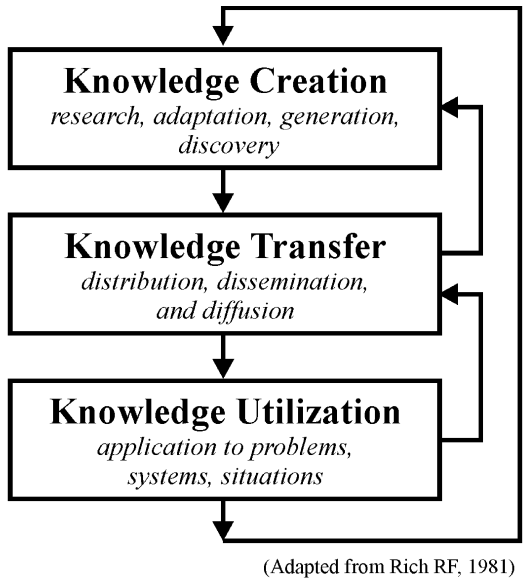

Fig. 1. The knowledge cycle.

The knowledge cycle shown in Fig. 1 is an interlinked series of functions. Knowledge creation involves the research, adaptation, generation and discovery of knowledge. Knowledge transfer is the distribution, dissemination and diffusion of knowledge, while knowledge utilization is the application of knowledge to problems, systems and situations. The knowledge cycle has both feedback and feedforward aspects. Knowledge is fed forward as needs and gaps in existing knowledge are identified, while feedback occurs every time knowledge is applied and new knowledge is created. Although data, information and knowledge are usually thought of as part of a hierarchy, with data on the bottom and knowledge on the top, that model fails to capture the dynamic relationship between the three terms. The knowledge cycle suggests this dynamic: new data create new information, which can lead to new knowledge; this then stimulates the need for new data and so forth.

Knowledge creation in occupational hygiene

Figure 2 illustrates knowledge creation and the processes that lead to and from it in the occupational hygiene field. In this field, knowledge is created through three pathways: a research pathway, problem solving and a path that involves synthesizing information to make recommendations. Surveillance flows directly into the three pathways and is the process of collecting data, and analyzing and disseminating occupational safety and health information. It can occur at the plant, company or geographical level,

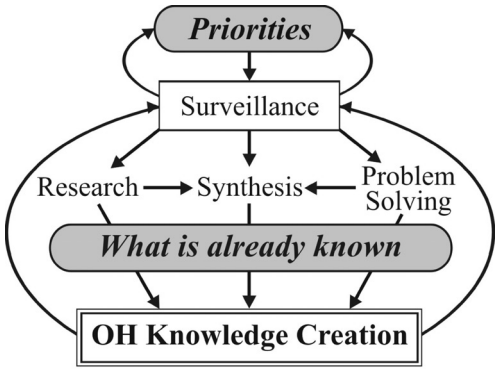

Fig. 2. Occupational hygiene knowledge creation.

and leads to recognition of a problem. In fact, surveillance is usually thought of in terms of endpoints of interest, specifically disease, injuries, and hazards (Baker and Matte, 1992). Because surveillance is the first step in all pathways of occupational safety and health knowledge creation, its place in the field of occupational safety and health is important.

The US history of knowledge creation through occupational disease surveillance goes back to the Illinois Occupational Disease Commission Survey of 1910. Today, the main occupational morbidity and mortality surveillance efforts within the USA are the Bureau of Labor Statistics' assessments of fatalities, injuries and illnesses. Other important surveillance efforts, such as the World Respiratory Disease Reports by the National Institute for Occupational Safety and Health (NIOSH), the Integrated Management Information System by the Occupational Safety and Health Administration (OSHA) and various states' workers' compensation databases, are useful tools.

Collecting and using occupational safety and health statistics are critical to the national effort to set priorities for occupational hygiene research and intervention. Changes in these statistics are a measure of how effective these efforts are. Also important are efforts of insurers and workers' compensation carriers to use individual and group workplace injury and illness rates to set costs and drive preventive and control practices.

Surveillance alone may not lead to advancing new knowledge on etiology and control, however. By setting priorities from surveillance that identify frequently occurring occupational diseases, injuries, and hazards, knowledge can be focused on solving salient problems. The National Occupational Research Agenda (NORA), which began in 1996 as a way to set priorities through partnerships and effective use of limited resources, incorporates the views of a broad range of social sectors and stakeholders in identifying 21 priorities that can be classified in three broad areas: diseases and injuries, work environment, and research methods (NIOSH, 1996). To implement NORA, interdisciplinary and intersectorial teams were established in each of the 21 priority areas. The teams initially focused on identifying needs and gaps in the knowledge on the topics. Additional resources were marshaled within NIOSH and extramurally, through targeted grants and cooperative agreements, to design research to fill knowledge gaps. NORA was initiated to address the problem of limited available resources to address occupational safety and health problems, but it became a systematic means of knowledge generation.

Critical in the creation of new knowledge in the occupational hygiene area are gatekeepers at each end of the process. At the initiation end, research, much of which is federally funded, generally is selected by NIOSH's Occupational Safety and Health Study section, which provides a vigorous assessment of grant applications. Occupational hygiene expertise has always been a part of this effort. At the other end of the research process, the editorial staff and boards of various journals that publish occupational hygiene research maintain the quality of information and knowledge the journals provide to readers.

At the corporate level, disease, injury and hazard surveillance also occurs. Businesses recognize direct and indirect costs of these outcomes through workplace morbidity and mortality reports (such as OSHA 300 logs), workers' compensation costs and other insurance ratings, worker productivity and morale, absenteeism, and other measures. Using these surveillance tools, businesses focus research efforts on identifying contributing factors to injury and illnesses. Developing an understanding of these factors and the context in which hazards in the workplace occur is an example of knowledge creation through the research pathway.

Knowledge creation in occupational hygiene, while driven by surveillance, is also based upon measurement. It is the unique nature of occupational disease that makes measurement of causative environmental factors, without imposing a serious economic burden upon industry, so indispensable to disease prevention (Frederick, 1956). Risk assessments and characterizations, as well as recommendations for control, all depend on knowledge gained from assessing exposure measurements and health outcomes. The quality of measurements is maintained throughout the field of occupational hygiene by applying information obtained through Proficiency Analytical Testing involving $\sim$1000 laboratories in 20 countries (Grunder, 2002).

Knowledge is also created during the synthesis of information for recommendations. This involves qualitative and quantitative risk assessment, literature reviews and evaluation, and application of judgment to occupational safety and health information in the process of developing occupational exposure limits

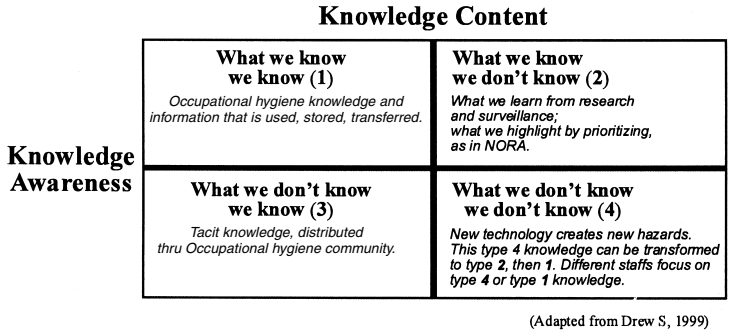

Fig. 3. Pragmatic classification of occupational hygiene knowledge.

such as threshold limit values (TLVs) set by the American Conference of Governmental Industrial Hygienists (ACGIH), NIOSH-recommended exposure limits (RELs), OSHA and US Mine Safety and Health Administration permissible exposure limits (PELS), American Industrial Hygiene Association (AIHA) workplace environmental exposure limits (WEELs), corporate exposure limits, and various consensus standards from American National Standards Institute. As these levels are applied and additional surveillance conducted, new knowledge about effects at various exposure levels is created, as is knowledge about gaps in the information and literature.

Knowledge storage

Once knowledge is created it must reside somewhere. Knowledge storage is the function of standard operating procedures, company guidelines, textbooks, journal articles, databases, government documents, organizational publications, academic institutions, and websites. These are also channels for conveyance, but they act primarily as storage repositories. Some knowledge has a discrete life span and requires periodic updating. Many of the classic American texts in occupational hygiene have been frequently updated. For example, *Industrial Ventilation: A Manual of Recommended Practice* is in its 25th edition (ACGIH, 2004). Increasingly, knowledge storage in websites and other electronic repositories affects how well it can be accessed. The term 'information architecture' describes the way information and knowledge are classified, labeled, tagged, and stored in computer accessible formats. On the internet, this is manifested in the number of clicks to reach the information sought.

Figure 3 illustrates a way the knowledge stores can be assessed and classified. By classifying knowledge according to content and access, four categories result: (i) 'What we know we know' pertains to knowledge that is taught and practiced. It is also the focus of much of the corporate knowledge management literature. The CEO of Hewlett-Packard has been reported (Drew, 1999) to say that 'If we knew what we knew, we would be 30% more productive'. (ii) The category 'knowing what we do not know' is what is targeted in efforts such as NORA—to focus research to address knowledge gaps. (iii) 'Not knowing what we know' is an area of potential mistakes or problems. For example, regarding the national effort to respond to the recent US anthrax crisis, former NIOSH Director Donald Millar (Millar, 2002) lamented the absence of academic industrial hygiene knowledge being brought to bear on the problem. Finally, (iv) 'Not knowing what we do not know' represents a perennial area of philosophical exploration (Caws, 1998). In occupational hygiene, it represents the challenge of anticipating the conditions under which practitioners might operate in the future. This is well discussed in the final chapter of *Occupational Environment—Its Evaluation and Control*, where Birkner and McIntyre-Birkner (1997) discuss the generation of various scenarios, key factors and driving forces which will shape the evolving practice of occupational hygiene.

KNOWLEDGE TRANSFER

The full value of knowledge comes from its transfer and utilization. The transfer of knowledge involves the distribution, dissemination and diffusion of information and knowledge (Fig. 4). Transfer of knowledge occurs in many ways, both formal and informal. The three main routes of knowledge transfer in the field of occupational hygiene are via communities of practice, training and the internet.

Communities of practice

Traditional thinking about knowledge is in terms of subjects, but has come to include 'communities of practice', which are informal groups linked by various ideas, aspirations, objectives and techniques (Wenger, 1998). Knowledge is transferred and

Routes of Transfer

	Communities & Practice	Training	Internet
Distribution ("units" of information)	Journals Newsletters Literature	University degree Worker training	Journals Newsletters Literature
Dissemination (Scatter widely, promulgate)	Professional standards Exams Accreditation & labs Certification	OSHA standards Education Resource Centers	Newsletters News reports
Diffusion (Spread)	Networking Conferences Awards	Management & worker commitment	Interactive components Websites in general Listservs

Fig. 4. Occupational hygiene knowledge transfer.

standards maintained within these groups that provide similar services or expertise but which are not formally linked. It is therefore appropriate to consider the occupational hygiene field as a community of practice, and examine how knowledge, information, values and practices are shared, conserved, transformed and manipulated within this community.

The occupational hygiene community of practice in the USA is linked by professional and trade associations, non-governmental organizations, committees and consultants (smaller communities of practice) that establish and support the norms of the profession. In the USA, various non-governmental organizations, such as the ACGIH, AIHA, American Society of Safety Engineers and National Safety Council, are responsible for much of the occupational hygiene knowledge transfer, particularly through journals such as *American Industrial Hygiene Association Journal*, *Journal of Safety Research*, *Professional Safety* and *Applied Occupational and Environmental Hygiene* (now merged with *American Industrial Hygiene Association Journal* to become *Journal of Occupational and Environmental Hygiene*). These organizations also shape and transfer the mores, culture, mission and professional codes of conduct that distinguish the occupational hygiene field as a community of practice.

The organizations and agencies described above also fill an important role as stewards of knowledge in the USA: non-governmental organizations such as the American Board of Industrial Hygiene, the American Society of Safety Engineers and the Board of Certified Safety Professionals ensure a consistent, high level of competency for occupational hygiene practitioners by setting and maintaining professional standards and examinations for certified industrial hygienists, certified hazardous materials managers and certified safety professionals. Another key function in this knowledge stewardship involves the accreditation of analytical laboratories and other services as performed by the AIHA. These functions promote the development of knowledge resources (i.e. trained professionals) through recruitment, training, and routine validation (benchmarking of laboratory services). Assistant Secretary of Labor and OSHA Director John Henshaw has emphasized the importance of these elements in his agency, both at the American Industrial Hygiene Conference and Exposition and the National Safety Congress (Henshaw, 2003) with a push for the certification of OSHA personnel, in particular compliance officers eligible to earn certification as industrial hygienists or safety professionals.

Knowledge is also transferred in the deliberations and guidance of various US advisory committees. These include the Advisory Committee on Construction Safety and Health, the Marine Advisory Committee on Occupational Safety and Health and the National Advisory Committee on Occupational Safety and Health, which give guidance to OSHA, NIOSH and the Mine Safety and Health Administration.

Often the occupational hygiene knowledge that a company applies to problems comes not from within, but from consultants retained for such purposes. In this case, clearly the knowledge and expertise of the consultant is a marketable asset that the consultant, by definition, manages.

Occupational hygiene consultants, who comprise a sizeable percentage of the US professionals in this field (~16% of respondents in the AIHA 2000–2001 membership survey; AIHA, 2003), are perhaps the quintessential knowledge managers. When businesses contract for the services of occupational hygiene consultants, they rely upon the consultant's expertise. This expertise is founded upon maintaining a level of competency and a reserve of occupational hygiene knowledge that can be brought to bear upon relevant occupational safety and health challenges. These knowledge reserves are sought when businesses lack knowledge resources in-house, have failed to identify sources of knowledge within their

organization or are seeking an independent and objective third-party to bridge knowledge gaps. In any case, utilization of consultants' services is one method of knowledge management and transfer involving an implied cost–benefit analysis to determine the value of the knowledge services in exchange for the consultants' fees.

Critical to the effective function of the field and individual companies and organizations is replacing lost knowledge that results when people retire or change jobs. Maintaining institutional memory in companies and organizations is a difficult problem, and active measures to capture and retain knowledge that might be lost are needed. One way to maintain the institutional memory of the occupational hygiene field both in the USA and internationally is achieved by the Cummings, Smyth and Stockinger awards and lectures. In these lectures, the rich knowledge of the field is transferred and highlighted.

Training

Across the field of occupational hygiene, non-governmental organizations, OSHA, various universities, labor unions, employers and professionals all conduct professional training and education. The current cadre of occupational hygiene and safety professionals in the USA, for the most part, benefited from public investments through NIOSH Education and Research Centers and Training Program Grants. There are currently 16 Education Research Centers and some 40 Training Program Grants. Between 1977 and 2003, 4663 occupational hygiene masters degrees and 397 occupational hygiene doctoral degrees were awarded. There were also 1516 occupational safety masters degrees and 108 occupational safety doctoral degrees awarded. Approximately 10 recognized programs throughout the USA offer undergraduate degrees (bachelors or associates) with emphases in occupational hygiene and safety, some of which are also supported by NIOSH.

The previously mentioned system of professional occupational hygiene certification for individuals is overseen by the American Board of Industrial Hygiene, formed in 1960 (Smyth, 1966). Formal accreditation of academic occupational hygiene programs by the Accreditation Board for Engineering and Technology began in 1989, and provides for quality control of trainers and educators as well as continuation of the educational process.

Training of managers and workers is also a major means of knowledge dissemination. Business invests extensively to train workers and managers in health and safety, although such investment may be a function of company size. Within companies, occupational health knowledge transfer and utilization depend on the top management commitment to using such information and middle management and employee compliance.

More than 100 OSHA standards for controlling workplace hazards contain requirements for worker training, making training one of the largest knowledge management investments and approaches currently in use. Continuing lifelong learning is becoming more of a requirement of all work; hence, training will continue to grow. A wide range of groups, including employers, labor unions, insurers, government agencies, academia and advocacy organization, conduct training. This training utilizes information and knowledge to bring about prevention, risk management and control in the workplace environment.

The internet

Increasingly, training and education as well as information and knowledge transfer in general are performed via the internet (Carlson and Olson, 2001), and virtually all organizations involved with occupational safety and health have websites. While the growth of the internet has fueled the growth of knowledge management practices, and knowledge management could not be easily accomplished without technology, simply using information technology does not wholly constitute knowledge management. In addition to the vast benefits of transferring knowledge and information over the internet are a number of problems. For instance, the large number of websites with health information in general and occupational safety and health information in particular has resulted in an information overload: the sheer volume of information that needs to be assessed when looking for an answer to a question can be overwhelming. A potential consequence of overload is decreased efficiency, as greater amounts of time are required to sift through multiple references to identify the most relevant information and knowledge sources, separate unbiased from biased information and avoid overlooking the most relevant information.

Another problem exacerbated by the internet is the shifting customer base for occupational safety and health information: customers who formerly primarily comprised occupational safety and health subject specialists now include a huge audience of people from many backgrounds. For technology and information to be of real use, close working relationships must be developed and maintained between the information providers and the customers. Some charge that this has not yet been done in the occupational safety and health community (Abeytunga, 2003).

Transferring knowledge and information via the web is not free, and costs and investments can be significant. Knowledge and information on the web

requires resources and effort, because the material must be constantly maintained and updated. Additionally, the function of a website over time may change. For example, NIOSH originally considered the web as primarily a publishing and archival resource. The goal was to get its printed material reproduced on the web. However, information seekers not only want copies of documents, they also want the considered opinions of authoritative organizations—they want a synthesis of information, because the task of assembling information by searching through individual materials is time consuming, and questions arise concerning whether old documents are still current policy of an organization. NIOSH has addressed this by considering that in addition to a publishing and archival function, the NIOSH website also has a public health function. This resulted in a section of the website called Topic Pages, which are topic-specific amalgamations of the best information with the current NIOSH position. These efforts need periodic inspection and updating which require the time of information specialists as well as content experts. Some websites, such as the OSHA site, have expert systems that provide tailored knowledge to a requestor based on characteristics of a situation provided by that requestor (see www.osha.gov for examples).

Increasingly, the occupational hygienist will be called upon to help employers, clients, co-workers, students and colleagues use the web. Knowledge management skills in support of solving occupational hygiene related problems will be in growing demand. The shifting user base of the web will mean that website managers will have to consider the range of audiences they ultimately are trying to reach or who consider their homepage a searchable website. Material will need to be developed for various target groups, whether occupational hygiene professionals or other health professionals, policy makers, employers, workers, or the general public. The organization of materials and guidance on the OSHA website pertaining to the construction industry is a good example of information presented for multiple audiences.

How people use the web is becoming a focus of study in various fields. More information is needed as non-occupational safety and health professionals get information in general and use the web in particular. More studies on usability of websites are needed, as are ways of reaching people through the web. Historically, in marketing and communications, audiences were segmented by demographics, behavior and location. A new type of web-based segmentation based on how people act while on the web has been developed to provide different strategies for reaching different types of users (Rozanski *et al*., 2001). The testing of this approach for occupational safety and health information may be warranted. There also appears to be a demand for interactive websites where a user can enter various descriptors and parameters of problems and obtain specific guidance. The OSHA website has examples of such interactive components, in particular the online OSHA Advisor software series (e.g. asbestos advisor, hazard awareness advisor).

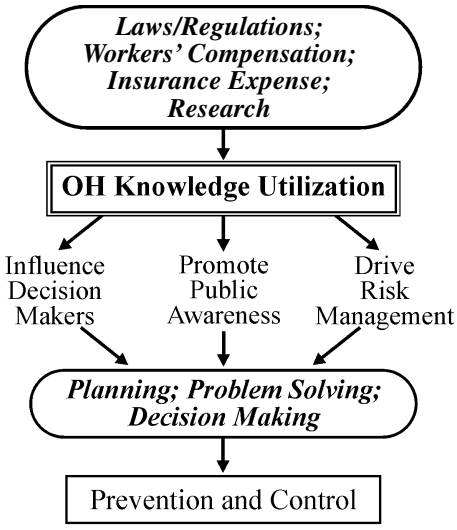

Fig. 5. Occupational hygiene knowledge utilization.

KNOWLEDGE UTILIZATION

Utilization of knowledge and information is intended to lead to prevention and control (Fig. 5). Knowledge is also used in occupational hygiene practice to influence decision makers, promote public awareness, and drive risk management.

Laws and regulations, workers' compensation and insurance expenses, and other factors drive knowledge utilization in occupational hygiene in the USA. The legal and regulatory framework for occupational safety and health has been established through the Social Security Act (1935), the Walsh–Healy Act (1936), various mining acts (1966, 1969, 1977) and, most of all, the Mine Safety and Health Act (1969) and the Occupational Safety and Health Act (1970). Other laws that prescribe authority for agencies such as the Environmental Protection Agency, the Department of Energy and the Department of Agriculture also add to the legal framework for occupational safety and health. Additionally, the Supreme Court decisions involving Benzene [*Industrial Union Department v. American Petroleum Institute, 448 U.S. 607, 1980*] and cotton dust [*American Textile Manufacturers Institute v. Donovan, 452 U.S. 490, 1981*] impacted knowledge creation and utilization (Mintz, 1988). New kinds of information and knowledge were required by the court to address risk assessment and technical and feasibility issues. The tension between specification of

established means for compliance and performance (outcome-based) requirements in laws and regulations also puts demands on how knowledge is utilized, as well as created and transferred. Increasing emphasis on voluntary response in lieu of regulations may heighten the need for knowledge utilization about controlling workplaces given the unique variables of each workplace.

An important aspect of knowledge management is the ability to monitor knowledge transfer and use. In the USA, NIOSH, along with other federal agencies, is attempting to measure the public impact of its research and documents. Performance metrics are being developed to assess quality, relevance and usefulness. These efforts will allow for feedback to the knowledge creation stage.

Occupational hygiene knowledge is also put into use in problem solving situations, in planning, and in decision-making. Increasingly, workers themselves request to be actively involved in occupational safety and hygiene decisions and in training. This puts the worker's often tacit knowledge to use in new ways, and as the knowledge is put to use, it may become more valued by management.

Another growing illustration of knowledge utilization includes the growth of control banding concepts, such as those derived from the UK Control of Substances Hazardous to Health regulations (Russell *et al*., 1998). This approach represents a coherent set of occupational hygiene practices that range from traditional control banding to expert applications (Day *et al*., 2004).

CONDUCTING OCCUPATIONAL HYGIENE KNOWLEDGE MANAGEMENT

There are a number of knowledge management techniques in the literature, such as those described by Wiig (1995) and Tiwana (2000). Some of these techniques are already in general use in the occupational hygiene community, whereas others are not common. A brief review of both types will focus thinking on occupational hygiene in terms of managing knowledge.

One commonly practiced knowledge management technique evident in the occupational hygiene community of practice is the large number of occupational hygiene organizations previously mentioned. Another commonly practiced technique is that knowledge creation, transfer and utilization are enhanced by conferences and conference roundtables. Roundtables are similar to 'Knowledge Cafés' in the knowledge management literature because they serve the same function of generating innovative thinking and knowledge sharing through 'cross pollination' with other experts. The occupational safety and health community also generally tries to maintain expert networks, which provide access to experts for help. NIOSH examples of expert networks include the toll-free telephone information service, and the Health Hazard Evaluation service, where NIOSH specialists conduct site visits at the request of workers or employers. Occupational health and safety specialists are also experts at knowledge discovery through research, which involves knowledge generation from identifying patterns and cause–effect relationships from data.

Knowledge management techniques that could be used more frequently by the community include the practice of knowledge mapping or auditing. For most companies, occupational hygiene is not the product or service the company sells but is one of the core competencies in which mastery must be maintained. One approach to identifying core competencies is to develop knowledge maps and audits for processes in an enterprise. A knowledge map illustrates the 'sources, flows, constraints, and sinks (losses or stopping points) of knowledge' (Grey, 1999)—both current and future—within an organization. A knowledge map can:

- encourage knowledge reuse, and prevent reinvention
- uncover 'islands' of expertise, and emerging communities of practice, and suggest ways to connect them
- enhance information location, problem solving, decision making, and customer response
- highlight opportunities for learning and leverage of knowledge
- provide an inventory and evaluation of intangible assets and tacit knowledge (Grey 1999).

Knowledge maps can show how the company uses occupational hygiene information and knowledge, where in the organizational structure the occupational hygiene group reports, what role occupational hygiene plays in development of new facilities and processes, and with which other competencies the occupational hygienist interacts. A knowledge audit determines what is needed and available to achieve specific objectives or functions. One product of a knowledge audit can be a knowledge map (FCIOC, 2001) but knowledge maps can be constructed without completing an audit.

Knowledge maps can also help with another knowledge management technique, Lessons Learned Systems. This technique identifies and documents lessons learned from a notable situation, such as a mishap or failure, or a solved problem or sudden opportunity. These lessons contain accumulated knowledge that when properly organized and made available can be accessed by employees and decision-makers when situations arise (Wiig, 1999a). A related technique is the After Action Review, which can be summarized by the questions: what happened? Why did it happen? What should we do about it? An additional technique is Capture of Decision

Reasoning—recording the explicit reasons why a certain decision was proposed and selected.

Other techniques relate to capture and transfer of knowledge from experts and top-performers to other personnel, or from departing experts to those remaining. This can involve a whole range of activities, from mentoring, apprenticeship and shadowing to creating mental models or videos, or involving a knowledge management professional.

DISCUSSION AND CONCLUSIONS

The knowledge management literature speaks of a shift in organizations and businesses from hoarded knowledge to shared knowledge (Liebowitz, 1999). However, in all professions, including occupational hygiene, there are long-standing barriers to sharing knowledge. One of these is the mistaken belief that hoarding knowledge increases a person's importance in an organization and protects him/her against downsizing. There is a need for incentives to encourage employees to share their knowledge, processes and tools, and to make sharing simple and part of the workplace culture (FCIOC, 2001); the extent to which occupational hygiene knowledge is considered a corporate asset might, in some cases, limit such sharing among competing companies.

Another barrier to information sharing is the interdisciplinary nature of occupational hygiene. While a strength of occupational hygiene is its inherent interdisciplinary nature, that focus requires practitioners to be able to communicate across boundaries of component disciplines.

A third barrier is the increasingly global nature of knowledge creation, transfer and use. International standards development and the global harmonization of hazard classification and labeling systems are examples of initiatives to facilitate consistent and universal exchange of knowledge and information resources in occupational safety and health. Specifically, the latter effort stems from an international mandate to develop a globally harmonized system for hazard classification and labeling adopted in 1992 at the United Nations Conference on Environment and Development, commonly referred to as the Earth Summit. The objectives of this effort were to develop a globally harmonized hazard classification and compatible labeling system, including material safety data sheets and easily understandable symbols, initially by the year 2000, with international implementation and compliance by 2008. Such a development will provide the underlying infrastructure for the establishment of comprehensive and universally consistent chemical safety programs.

How knowledge is stored, transferred and used has not been well characterized in the occupational hygiene field in general. There are, however, extensive resources in other disciplines, including information theory, health communications, social marketing, diffusion of innovations, sociology of knowledge, and individual and organizational behavior, that could be applied (Todd, 1999; Schulte *et al.*, 2003). Using techniques from these areas to conduct research and disseminate knowledge could make advances in knowledge management in the field of occupational hygiene. Additional benefits would derive from efforts to engage specialists from those fields in collaborative projects to apply theories and research to occupational hygiene questions.

While there is growing recognition in the business community of the importance of managing knowledge, the concept of knowledge management in general is nascent. At least 10 different frameworks have been identified and, while linked to the knowledge cycle for the most part, all suffer from limitations in the knowledge field. These limitations include (i) comparatively little attention to the dimensions of knowledge resources; (ii) no standard way of characterizing knowledge manipulation activities; (iii) no standard way of characterizing influences on the conduct of knowledge management; and (iv) no individual knowledge management framework which subsumes the others (Holsapple and Joshi, 1999).

Despite the lack of consensus on knowledge management frameworks, there are some knowledge management approaches that may be beneficial for individual companies and some that may benefit the field of occupational hygiene. Individual companies may benefit from knowledge management approaches by valuing occupational hygiene knowledge as a corporate asset, conducting occupational hygiene knowledge audits within the company, and developing plans to retain and share occupational hygiene knowledge within the company.

In the field of occupational hygiene, four approaches may be useful. These include strengthening efforts to stimulate new people to enter the field, continuing the move toward certification of all practitioners (Burdorf, 1995), supporting the incorporation of occupational hygiene knowledge in core competencies for jobs in the general workforce, such as the National Skill Standards (Palassis *et al.*, 2004), and linking the curriculum content for occupational hygiene with the changing nature of work.

The field of occupational hygiene is undergoing significant changes, making knowledge management skills more important than ever for occupational hygiene professionals. The area of occupational hygiene knowledge transfer and use has not received the attention that research and surveillance initiatives have. There is a need for strategic thinking in this regard, with assessment of resource allocation and planning in these areas to determine where more resources should be focused.

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