Toward a Typology of Dynamic and Hazardous Work Environments[a]

Ted Scharf,[1] Charlie Vaught,[2] Pamela Kidd,[3] Lisa Steiner,[2] Kathleen Kowalski,[2] Bill Wiehagen,[2] Lynn Rethi,[4] and Henry Cole[5]
[1]Work Organization and Stress Research Section, Div. of Applied Research and Technology, NIOSH, Cincinnati, OH; [2]Mining Injury Prevention Branch, Pittsburgh Research Lab, NIOSH, Pittsburgh, PA; [3]College of Nursing, Arizona State University, Tempe, AZ; [4]National Personal Protective Technology Laboratory, NIOSH, Pittsburgh, PA; [5]Department of Educational and Counseling Psychology and Department of Preventive Medicine, University of Kentucky, Lexington, KY

ABSTRACT

The most hazardous work environments share one feature in common: constant change. Many different, but constantly changing hazards are found in agriculture, construction, mining, and transport. This dynamic feature of workplace hazards varies by: (1) degree of control, (2) predictability, (3) visibility, (4) movement, and (5) degree of speed and force. In some cases the actions of the dynamic hazards are required for production to take place, and in many cases,

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[a] This paper is respectfully dedicated to the firefighters, police, and other emergency responders doing their jobs on September 11, 2001. In particular, we remember the hundreds of emergency workers who lost their lives while rescuing others in the collapse of the World Trade Center towers in New York City. We also remember the thousands of office workers, airline passengers and crew, and many others who were injured or killed on this tragic day.

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several different hazards may overlap and interact. Finally, whether intentional or unintentional, some dynamic hazards are human generated. These are some of the features that distinguish dynamic and hazardous work environments across a variety of industries.

The authors propose a preliminary typology of dynamic and hazardous work environments, along with a schema to systematically observe the dynamic characteristics of these hazards. The implications of this typology are considered with respect to worker training, hazard awareness, and safe work practices. For example, the implementation of the Hierarchy of Control is shown to require active worker involvement at every level in the hierarchy, except where an environmental hazard has been completely eliminated.

OBSERVATIONS

Mining, fishing, logging, farming, construction, and transport: by most measures, these are the most hazardous jobs in the United States. These findings are regrettably consistent and robust (*e.g.*, Figures 2-7 and 2-8, rates of fatal injuries by industry and occupation, 1980-1995, NTOF, NIOSH 2000).

The basic data are familiar to readers of this journal: (1) drowning is the principal cause of death among fishers; (2) airplane crashes kill most pilots; (3) being struck by a tree or limb kills timber cutters; (4) falls from heights kill construction workers; (5) highway crashes kill truck drivers; (6) roof falls and heavy equipment strike and kill miners; and (7) tractor overturns kill farmers (Toscano and Windau 1998). These causes of death are some of the more ubiquitous and persistent examples of the seemingly intractable workplace hazards extant in these jobs. These causes of death provide a few examples of the tragedies that maintain mining, fishing, logging, farming, construction, and transport among the most hazardous jobs in the United States.

Homicides during robberies, assaults on co-workers, terrorism, and other intentional human-made disasters (Kowalski and Vaught 1999) are the one recent exception to this consistent trend. The terrorist attacks on the World Trade Center and the Pentagon on September 11, 2001 have made salient the extraordinary hazards and extreme risks taken on by firefighters, police, and other emergency responders every day that they report for work. Terrorism and the security measures necessary to prevent terrorism are beyond the scope of this paper. However, the characteristics of the dynamic and hazardous environments to which emergency personnel must respond are central to this discussion.

Common Factors among the Most Dangerous Jobs

What really makes a job dangerous? Death rates measuring traumatic fatalities provide a salient, but somewhat limited perspective. (See Toscano 1997 for a more general approach to this question.) The same jobs are ranked highest on fatalities year after year. Yet, the causes of these fatalities are related to each of the jobs in very specific ways and appear to have no relationship across different jobs and industries.

Further, the highest-ranking causes of death seem to be particular to each occupation and industry. Thus while all of these work environments are hazardous, the specific types of hazards present are very different across the different industries.

We hypothesize that there is one key feature present in all of these hazardous workplaces: the work environments are under constant change. The central thesis of this paper is that the requirement to continually adapt and respond to a dynamic and hazardous work environment places workers in these jobs at high risk, regardless of the specifics of the hazards. The constantly changing hazards require a skilled and vigilant workforce that can quickly adapt to the new hazards and changing risks. It is important to note that this is not a covert restatement of a "blaming-the-victim [worker]" hypothesis (Ryan 1976). Rather it is an attempt to identify commonalities in the interaction between environment and behavior, across a variety of dynamic and hazardous work environments.

One of the earliest expressions of the interaction of environment and behavior in occupational safety and health was developed in mining. Sociotechnical Systems Theory was first hypothesized in British coal mining when the introduction of the longwall process changed the organization of work for the miners and produced a number of unintended consequences (Trist and Bamforth 1951; Trist *et al.* 1963). In a more recent example, the introduction of remotely operated mining machinery in the U.S. (a technological innovation) has placed the operators and other miners at risk of being struck by the equipment. Yet one of the principal reasons for converting to remote operation was to eliminate the risk to the operator of being trapped inside the machine by a roof fall (Steiner *et al.* 1997; Vaught *et al.* 1999).

Informal observations from agriculture, construction, and mining suggest that workers evaluate changing hazardous situations in similar ways, even though the specific hazards may be quite different. Translated into a research hypothesis: Are there commonalities that can be identified across different, dynamic and hazardous work environments? More specifically, since the industrial hazards are very different: Are there common qualities about the dynamic nature of the hazards that can be identified?

The term "hazard" is used in this paper to refer to features of the work environment. "Risk" refers to a worker's degree of exposure to the hazards in the work environment. These terms refer to a large and complicated literature going back many decades (Haddon *et al.* 1964). The use of these terms in this paper is intended to clarify the distinction between (1) environmental features with the potential to cause harm: a hazard, and (2) the amount of potential harm to which a worker is exposed: his or her risk. For example, a building fire presents many hazards. However, a firefighter is not at risk, until he or she crosses the outside perimeter toward the fire. The dedication and willingness of firefighters to place their lives at risk to rescue others highlights one goal of this paper: to explore how we can reduce risk in a dynamic and hazardous work environment where the hazards cannot be removed, isolated, or completely controlled.

TOWARD A TYPOLOGY OF DYNAMIC AND HAZARDOUS WORK ENVIRONMENTS

Two questions are implied: (1) What makes an environment hazardous? and (2) What makes a work environment dynamic? Known workplace hazards are usually eliminated or controlled during the engineering and design phase of a new manufacturing process. But the nearly 200-year history of industrialization in the U.S. shows that most hazards have been identified because workers were made ill, injured, or killed on the job (Stellman *et al.* 1998). Determining that anything that harms workers is a workplace hazard leads to a very dissatisfying tautology; there is no predictive value for improving worker safety or for identifying new hazards. Nevertheless, new manufacturing processes, machines, and chemicals are being introduced on a daily basis. Consequently, new workplace hazards are likely to continue to be identified empirically. Thus, whatever harms workers remains the principal response to the first question, above.

A literature search for the terms, "dynamic work environment," and "changing environment," identified a number of references in management, organizational development, artificial intelligence, robotics, decision-making, environmental psychology and other areas. Most commonly, the term "dynamic environment" is used to imply a fast-paced and exciting business or managerial environment.

The literature on risk and decision-making includes the concept of dynamic environments, but the emphasis appears to be focused on dynamic decision-making in response to a changing environment (Brehmer and Svenmarck 1995; Pascoe and Pidgeon 1995). The literature in environmental psychology provides a starting point for this investigation, (Sundstrom 1987). Environmental change is most often addressed through post-occupancy evaluations of indoor environmental design, which examine the effects of a one-time, major change in the office environment. However, the idea of a continuously changing environmental hazard does not appear to have been addressed in this literature.

Only Steiner *et al.* (1997) and Karwowski (1991) have used the term "dynamic work environment" with reference to human/worker interaction with a physical work environment that is constantly changing. Steiner *et al.* (1997) has provided an important focus for the discussion and development of the ideas presented here. In addition, the present paper has its roots in a variety of separate investigations in agriculture, construction, and mining by one or more of the authors, going back more than ten years. This paper attempts to continue and expand this approach, including: (1) the properties of the physical environment undergoing constant change, and (2) the interactions of workers with this environment. The focus of this typology is on the changing nature of the physical environment and how these forces are controlled. A few key features regarding workplace hazards are proposed.

Key Features of Dynamic and Hazardous Work Environments:

1. ***Controllability and Degree of Control***: Control has two, interrelated dimensions: (a) controllability, *i.e.,* whether a hazard or process can be brought under full engineering control, and (b) the degree of engineering control that can be exercised over a hazard or process. Controllability reflects current technology. What is fundamentally uncontrollable today may come under engineering control sometime in the future. The degree of control refers to the level or proportion of engineering control over each identified hazard when the available controls are functioning properly.

For example, underground mining applies engineering controls to moderate and restrict the forces of the earth, but these forces are fundamentally uncontrollable. The rock strata above an underground mine move in obedience to the geologic structure and stresses in the earth. We can study and try to predict earth movement. However, these estimates are limited by the current state of geologic science, including correct identification of hidden faults and other geologic structures deep within the earth, as well as the correct application of the available engineering controls (Beauchamp 1998).

2. *Predictability*: The ability to predict future changes in an environment, especially changes in hazardous features of a setting, is a critically important corollary of control over those features. The general process and structure of an environmental hazard may be well understood, but a specific instance usually has too many variables for accurate prediction. To be useful, the predictions must be sufficiently specific that some intervention or avoidance is possible. Uncontrollable, dynamic environments may be partially predictable with respect to selected features, and they may be highly predictable at a very general level, *e.g.,* through the application of chaos theory. But at a moment-by-moment level of analysis, such environments are often unpredictable. For example, describing a 33-knot wind, gusting to 40 knots, with 20-foot waves, and a period of 11 seconds, provides fairly precise information (NOAA 2001). However, these data from a marine buoy cannot be easily translated into the second-by-second pitch, roll, and yaw of the deck of a fishing boat working through such swells.

3. *Hidden, Obscured, Difficult to Detect, Unexpected*: Hazards may be obscured by clutter or other equipment or may blend in with the background such that they disappear into the normal scene. Such environmental features are termed *degraded hazards, i.e.,* the image of the hazard is obscured or degraded in some way (Kowalski *et al.* 1995; Perdue *et al.* 1994). Such hazards can cause the greatest problems when a worker sees what he or she expects to see and does not identify the hazard as a feature requiring focused attention. Unstable, unsupported, or cluttered ground or structures are important examples in many different settings.

Not only may hazards be hidden and difficult to detect, they also may be unexpected, unlikely, and therefore difficult to predict. A veteran worker has learned to anticipate, seek out, and identify hidden and unexpected hazards. One problem is that this level of vigilance is difficult to maintain hour after hour. The occupation of *truck driver* is perhaps the best example of a job requiring extended vigilance.

4. *Moving or Movable — Fixed or Unrestricted Path*: Most dangerous machinery in a factory is usually bolted down or permitted to move in a fixed track. By contrast, in construction some equipment may be set up, operate for a day or two, and then be moved to the next location. Such a movable hazard requires workers to adjust to the hazard's location at the start of every work period. Different portions of the work environment may change without warning and at different rates of speed, requiring constant vigilance. Similarly, drivers generally follow the lane markers on a highway, but except on the new "smart highways," there is no physical or engineering restraint to prevent a vehicle from leaving the marked path. In other words the potential exists for a vehicle to proceed unrestricted in any direction.

5. *Speed, Force, and Rate of Change*: Severe weather can rapidly and unpredictably change speed and force. Wind shear has only recently been identified as a major hazard for aircraft. Ocean winds and waves can be predicted on average, but may exert great force unpredictably.

6. *A Dynamic Work Process as a Hazard*: In some hazardous work environments, one or more of the hazards may be required as part of the production process: the hazard is necessary for the job or task to be completed. For example, in underground longwall mining, miners establish a dynamic tension such that the tremendous pressure of the unsupported but uncollapsed roof makes it easier to extract the coal. Without this pressure, the shearing drum will overheat and production must be periodically halted to allow the drum to cool. In this example, the unsupported roof is integral to the production process.

It is also necessary that the unsupported roof collapse into the mined-out area at the proper rate. When there is insufficient roof collapse behind the shields and too much roof pressure is exerted on the longwall face, bursting of the coal face and other hazards may result. Whether confined to a small area or extending over a large section, outbursts of coal or rock are catastrophic events (Beauchamp 1998). A delicate, dynamic balance must be struck between a sufficient amount of roof compression on the face to facilitate the mining process while preventing coal outbursts and keeping the pressure on the shields (protecting the miners) within manageable limits. The hazard presented by the unsupported roof is required for the work to take place and is not separable from the task of mining the coal. For a general description of longwall mining, see: chap. 7, Stefanko (1983).

Longwall mining uses the forces of the earth to facilitate the mining process. A more mundane example in which the dynamic hazard facilitates the work process can be found in every kitchen: a cook uses a gas flame or hot electric coil to prepare food. Regulated use of the hazard is integral to the food preparation process.

7. *Multiple, Interacting Hazards*: Hazardous work environments may often contain a primary hazard, but most such environments contain additional hazards that must be managed as well. In addition, the work processes may change the nature or intensity of one or more hazards and may introduce new hazards into the work environment. Technology designed to eliminate one hazard may introduce new, unanticipated hazards (Vaught *et al.* 1999).

Complications arise when the hazards interact and overlap. One hazard may require a certain set of safe work practices that constrain the response to the other hazards. For example, each construction worker is actively changing his or her environment. But when many different workers are all making changes simultaneously, unpredictable and unexpected hazards may be created. Constant vigilance is required just to remain aware of one's immediate surroundings.

8. *Human-Generated Hazards*: This category includes both intentional, volitional, human-caused hazards (*e.g.,* criminal behavior) as well as the unintentional action by a co-worker or other person that might serve to exacerbate the impact or force of an existing hazard. The focus of this paper is on physical features of the work environment. The complex motivations and decisions of people, especially people considering violent crime, are beyond the scope of this paper. For example, the terrorist events of September 11, 2001, and the security issues raised by these events must be considered elsewhere. However, the rapidly changing and extremely hazardous environments created by this terrorism may be examined by the typology proposed here. Further, to whatever degree physical environments can be designed to prevent the consequences of unpredictable or violent human behavior, the approach may be similar to the control other workplace hazards.

Haddon's Matrix

With respect to the classic Haddon matrix (Haddon 1968, 1980; Haddon *et al.* 1964), the discussion in this paper focuses on the pre-event row (of the matrix), primarily on the physical and socio-economic environment, and on the environmental agent. This paper also considers the interaction of the work environment with the host (*i.e.*, the worker). To facilitate the discussion of the typology presented above, Table 1 describes two examples: (1) underground longwall mining — focus-

Table 1. Dynamic hazard typology. Sample Job Hazard Assessment.

TYPOLOGY	Longwall Mining: Underground Coal Example: unanticipated roof falls.	Truck Driving Example: highway crashes.
Controllability, including type(s) of control (hierarchy)	Complete engineering control not possible; limited engineering controls include roof bolts in entries and shields at the face.	Control limited by vehicle speed, maneuverability, and brakes; vehicle weight, speed, and operator reaction time dictate stopping distance.
Predictability	Limited; experience with comparable rock strata is very useful; previous shift progress on the longwall is a helpful indicator; continuous monitoring of coal face and roof is required.	Limited; environmental conditions are predictable only as far as vision, radio, or signage may provide up-to-date information.
Hidden, unexpected	Only the exposed surfaces of the coal face and roof are visible; many cues for incipient problems are auditory.	Constantly changing visual environment presents cues, which must be deciphered accurately and rapidly.
Moving, unrestricted path	Once the longwall panel is established, the path of the shearer or cutting drum is predictable; however, the pressures on the coal seam are not uniform and can create difficulties in unexpected places.	Highways are marked by visible lines (*i.e.*, administrative controls); vehicles and other hazards may create blockages quite suddenly and from unexpected directions.
Speed, force, change	Planned roof collapse behind the longwall usually proceeds at a steady pace and is required. Roof falls and rockbursts that are unexpected may be quite sudden and release many tons of earth over a wide area.	Varies with the speed of the vehicle, the topography, and friction of the highway surface; other vehicles may create sudden hazards.
Work process hazard	Balance of forces required for optimal production and least amount of heating on the cutting drum; moderate roof pressure facilitates coal extraction.	Maintaining speed is essential to meet schedules, but it will increase stopping distance and may increase the risk of serious problems.
Multiple & interacting	Roof pressure on the coal face, methane, air flow, dust, noise, and other factors all combine at the production face of the longwall.	Speed, weight of the load, weather, road conditions, visibility, traffic, and other factors contribute to the complexity of the interacting hazards.
Human-generated	Unintentional errors or mistakes may create a new problem or exacerbate an existing problem.	Other traffic may create unexpected hazards; driver fatigue may cause errors in judgment or a slow response; intentional actions include "road rage."

ing on hazards associated with roof falls, and (2) truck driving — focusing on hazards associated with highway crashes. These are very brief examples, presented to help illustrate the use of the typology. We have not attempted to address every possible hazard found in these occupations that may be relevant to the typology or to Haddon's more comprehensive matrix.

Dynamic Work Environments that are Extremely Hazardous

This typology predicts that the most hazardous work environments will have the following features:

1. ***low degree of control***: engineering systems may attempt to manage the hazardous forces, but it is difficult or impossible to actually control the hazard;

2. ***low predictability***: the dynamic processes of the hazard may be understood in a general sense, but key elements of the hazard are not predictable;

3. ***hidden, obscured, undetectable, unexpected***: workers must consciously search or examine the environment for the presence of the hazards, all the while maintaining the work process;

4. ***unrestricted movement***: the hazard or hazardous process can move unpredictably in three dimensions;

5. ***high speed, great force, and high acceleration***: the hazards are powerful and sudden;

6. ***a balance of dynamic hazards*** is required for the work process to take place;

7. ***many different hazards*** are present and interacting with each other, thereby constraining the ability to respond to the requirements of individual hazards; and

8. ***intentional, violent or criminal behavior*** that releases or exacerbates a hazard.

Except in war, few hazardous work environments are likely to contain *all* of the worst components of the environmental features described in this typology. As we begin to consider what interventions and controls can be brought to bear upon these hazards, the fundamental inadequacy of such interventions becomes apparent. Well-known to industrial engineers and hygienists, the classic hierarchy of control (Raterman 1996; OTA 1985) prescribes a clear order of such interventions (see Table 2).

THE HIERARCHY OF CONTROL

The primary purpose of the hierarchy of control is to identify and promote engineering modifications to either eliminate or fully control hazards in the work environment. Administrative controls are secondary to engineering, and personal protective equipment (PPE) is a last resort when no other controls are possible (OTA 1985). Administrative controls and PPE are viewed as less desir-

Table 2. The hierarchy of control.

- I. **Engineering Controls**
  - A. Eliminate the hazard
  - B. Substitution of material, equipment, or process
  - C. Isolation of hazard, *e.g.*, barriers and/or removing the worker(s)
  - D. Ventilation of airborne contaminants
- II. **Administrative Controls to reduce exposure**
  - A. Reduced work hours
  - B. Employee education and training
    - 1. Improved hazard recognition
    - 2. Improved work practices
- III. **Personal Protective Equipment (PPE)**

Adapted from Raterman (1996) and OTA (1985).

able solutions than engineering controls because they often focus on controlling worker exposure rather than on controlling the hazard itself. What is not well recognized is that worker education and training is required to operate and maintain virtually every type of control in the hierarchy, except where the work process has been re-designed to completely eliminate the hazard(s) from the environment.

One of the key features of the types of work environments considered in this paper is that many of the dynamic hazards are fundamentally uncontrollable or cannot be adequately controlled. Engineering controls are certainly applied, but not in such a way as to eliminate or fully isolate the hazards. And workers must maintain the existing engineering controls. Thus, worker education and training (an administrative procedure in the hierarchy) is essential to operate the environmental controls that are available. Further, except where hazards can be fully isolated, personal protective equipment that is properly used and maintained is required to reduce worker exposure to the hazards. Realistically, worker participation is required at every level of the hierarchy, except where the hazard is completely eliminated.

Expanding the Utility of the Hierarchy of Control

As originally conceived and implemented, this is a fairly strict hierarchy. One selects a lower level of control when a higher level in the hierarchy has been shown to be unavailable or ineffective (OTA 1985). However, the examination of occupational environments described in this paper suggests that several levels in the hierarchy should be selected at the same time — more like a simultaneity than a strict hierarchy. In fact, except where a hazard can be completely eliminated from the work environment, it is likely that a number of the solutions proposed by the hierarchy will be required to function in concert. Engineering controls that restrict a hazard must be monitored and maintained in proper working order, requiring worker intervention. Workers may have to enter the hazardous area, requiring the use of PPE. New workers must be trained to control the hazards and to be aware of situations created by a possible breakdown in these controls. Where engineering control is limited or not available, workers must be trained to recognize and avoid the hazards. While the hierarchy lists a preferred order in developing engineering solutions to manage or control hazards, in practice it often does require a multifaceted approach that involves the workers in implementing just about every step.

This brief discussion shows that the range of worker involvement in understanding, interpreting, and implementing safe work practices is extensive. In most work settings, workers are exposed to hazards while they are fully involved in completing a job assignment. A worker's attention is often divided between the production processes and hazardous elements of the job even where the principal task is to monitor the work flow. Thus, to the degree that each worker's attention is divided between production and hazard, he or she may be at increased risk.

Maintaining safe work practices under hazardous conditions requires vigilance, focused attention on competing features of the environment, good judgment, quick decision making, and adherence to established practice within an acceptable range of variability. As the hazards change, the safe work practices must be modified. The traditional hierarchy of control does not address the issue of what may be an appropriate or acceptable degree of variability in response to hazards — particularly as those hazards undergo change. Perhaps most important, workers in these dynamic settings must be free to adapt their work practices to meet the changing requirements of the environmental hazards.

An important corollary to the preceding is that the hierarchy of control addresses hazards one at a time. The implicit, untested assumption is that the workplace hazards, as well as the controls brought to bear on the hazards, are independent of one another. Yet, engineering controls that respond to one hazard may create a new hazard or exacerbate an existing one. As noted above, the introduction of remotely operated mining machines reduced the risk of being trapped in the machine by a roof fall and increased the risk to the operator of being struck by other mining equipment, including other remotely operated machines (Steiner *et al.* 1997; Vaught *et al.* 1999).

In addressing hazards one at a time, the hierarchy of control also confines its focus almost exclusively to an individual worker. Hazards are typically considered with respect to their effects on individual workers, and the engineering solutions introduced are considered to be somewhat independent of the workforce. This may be an overgeneralization. Nevertheless, work group and organization-level processes are not simply the sum of the individual workers' activities. Different work groups may have different reactions to a given workplace hazard and thus a different interaction with the engineering controls placed on that hazard. Organizational decisions can exert a major influence on how effective and safe the standard operating procedures turn out to be. To be effective, the hierarchy of control must consider that workplace hazards exist in a dynamic physical and social work environment. The controls selected for a given hazard must be responsive to these multilevel systems.

This discussion suggests an additional measurement for the controllability feature in this typology: “What different means of control in the hierarchy are available with respect to a given hazard?” Since administrative controls concern standard operating procedures and other work practices, we see that this portion of the hierarchy of control is squarely situated within a *worker –work environment* interaction.

THE INTERACTION OF ENVIRONMENT AND BEHAVIOR

The hierarchy of control is not simply a checklist of engineering approaches to work environment hazards, it is a structured, ordered approach to maintaining safety under the conditions of a continuous worker-hazard interaction. Stokols *et al.* (2000) describe this interaction as “people-environment transactions,” albeit without focusing on hazardous settings. The use of the term “transaction” implies a dialectic of *people-environment* relations, which can change or transform the entire relationship. The authors note that these transactions may occur at the individual, organizational, and community or societal levels.

The present examination of dynamic and hazardous work environments has not made any distinctions between individual, organizational, and community approaches to work tasks. The records of workplace fatalities referenced at the beginning of this paper describe individual events. Yet, many of these events may have been the result of a complex set of systemic- and individual-level failures. To investigate work organizations in sufficient detail, it seems appropriate to consider both the whole organization and the crew or work group within the organization, yielding four levels of analysis: (1) individual, (2) work group, (3) organization, and (4) community.

The inclusion of a community level may seem problematic for most work settings. However, in rural communities (*e.g.,* in many farming, fishing, logging, and mining regions) the work culture and safety climate of the industry may be shaped as much by the community as by the type of work performed, (Cole 2001; Cole *et al.* 2001).

This focus on multiple levels of analysis suggests the possibility of a matrix to examine and rate workplace hazards using the typology of features in dynamic and hazardous work environments. By examining the hazards at multiple levels of analysis, we may begin to identify opportunities for safety and health interventions through these additional venues.

Table 3 presents an example of this matrix applied to a farming community and focusing on the hazard of tractor overturns. Tractors may overturn quite suddenly: (1) when a stream bank falls away, (2) when a sharp turn is attempted at too high a speed, (3) during wet or icy conditions, (4) while towing a heavy load, (5) when encountering a hidden stump or other hazard, (6) during highway travel or as a result of a collision, (7) on steep slopes, and (8) under numerous other conditions. On highways, tractors towing equipment present unexpected hazards to automobile drivers who are unfamiliar with tractor operations (Murphy 1992).

Table 3. Dynamic hazard assessment matrix. Example: tractor overturn.

	LEVEL OF ANALYSIS			
TYPOLOGY	**Individual**	**Work Group**	**Organization**	**Community**
Controllability, including type(s) of control (hierarchy)	Operator must avoid potential overturn situations; no control is available during an overturn; ROPS and a seatbelt are injury prevention measures.	Tractor drivers install ROPS & seatbelt, discuss likely locations for an overturn, and plan work to avoid overturn situations.	Family/farm-wide safety climate: all tractors have ROPS; operators always wear seatbelt and prohibit extra riders.	Community-wide standard: promotion of ROPS and seatbelt on every tractor; prohibit extra riders; retro-fit or replace older tractors without ROPS.
Predictability	Overturns more likely on steep slopes, near streams and ditches, while towing, in rain or ice, during highway travel, and at high speed; most overturns not anticipated.	Plan work & equipment needs to minimize overturn risks; assess operator experience level; train and supervise younger workers.	Busy seasons increase the risk of overturns: every family member is working long hours and moving equipment back and forth on highways.	Community awareness of overturn risk improved in advance of busiest seasons; instruct auto drivers to slow down to tractor speed before trying to pass.
Hidden, unexpected	Hidden or unexpected hazards are a major cause of overturns; proper lights and markings are essential for highway operation.	Operators share information on potential overturn hazards; debrief close calls.	Preventive maintenance on equipment including lights & markings; remove hidden hazards; inspect roads & banks.	Publicize neighbors' experiences with close calls or overturns; train auto drivers re: tractor movement on roads.
Moving, unrestricted path	Tractor movement is unrestricted; topography or collision impact will determine direction of an overturn.	Establish high-hazard off-limits areas; avoid highway travel during rush hour.	Operators demonstrate proficiency and safe operation over farm terrain.	Operator training for local conditions through Cooperative Extension.

(Table 3 continued on the next page.)

There is no effective engineering control to prevent a tractor overturn. However, a Rollover Protective Structure (ROPS) — essentially a rollbar for a tractor — and a fastened seatbelt will help protect the tractor operator from serious injury. The ROPS is an injury prevention engineering control that establishes a zone of protection for the operator. The fastened seatbelt assures that the operator will remain inside the zone of protection during an overturn. Once a tractor tips to the point of no return, the overturn is usually completed in less than two seconds (Murphy 1992).

Future Work

The sample dynamic hazard assessment matrix (Table 3) provides a starting point for testing these hypotheses while investigating workplace injuries, fatalities, and "near-miss" events. Events can be examined with respect to the hazards that are

Table 3. (continued)

TYPOLOGY	Individual	Work Group	Organization	Community
Speed, force, change	Principal overturn force is gravity; centrifugal force while turning; collision impact on highways.	Not applicable.	Not applicable.	High speed of autos on hilly or twisty rural roads creates a major hazard; driver education essential.
Work process hazard	Speed can increase risk of overturn; overturn not useful in farming.	Not applicable.	Not applicable.	Not applicable.
Multiple & interacting	Topography, speed, type of operation (*e.g.*, towing), weather, tractor design and weight, and other motor vehicles.	Regular maintenance of the farm's tractors improves reliability in bad conditions; operators restrict speed to conditions.	Workload planning is necessary to allocate appropriate tractors to each required task and to operator experience.	Community-level awareness enhances appreciation of complex causes of overturns; other vehicles on highways.
Human-generated	Fatigue and temporary errors in judgment can increase an overturn risk; other drivers may cause a collision on highways.	Rest and meal breaks in busy seasons; good communication among tractor operators.	Workload planning is necessary to avoid tractor operation while fatigued.	Sharing stories helps farmers appreciate that every tractor operator is at risk; driver education to slow overtake speed and prevent collisions.

present and the topics that are addressed in the matrix. The research question is, Can the components in this preliminary typology lead to greater insight into dynamic and hazardous work environments? Specifically, can this typology suggest more focused and detailed questions for injury investigations?

This typology makes some specific predictions about the kinds of problems workers encounter in hazardous work environments. Further, although these predictions have been based on an examination of the four most hazardous industries in the U.S., the empirical tests proposed here can certainly extend to include a wide variety of hazardous work settings (*e.g.,* manufacturing). Then, if investigations from several different hazardous industries begin to yield similar findings, there will be empirical evidence that workers face similar problems in dealing with very different workplace hazards. Such evidence may lead to a more precise understanding of the *worker–work environment* interaction that can place workers at risk.

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REFERENCES

Beauchamp L. 1998. Ground control in underground mines. In: Stellman JM, McCann M, Warshaw L, *et al.* (eds). Encyclopaedia of Occupational Health and Safety. 4th ed., vol 3, pp74.28-74.32. International Labour Office, Geneva, Switzerland

Brehmer B and Svenmarck P. 1995. Distributed decision making in dynamic environments: Time scales and architectures of decision making. In: Caverni JP, Bar-Hillel M, Barron FH, *et al.* (eds.), Contributions to Decision Making – I, pp 155-74. Elsevier Science B.V., Amsterdam, The Netherlands

Cole HP. 2001. Cognitive-behavioral approaches to farm community safety education: A conceptual analysis. In: Agricultural Safety and Health Conference: Using Past and Present to Map Future Actions, Baltimore, MD, USA, March, 2001. Proceedings available at: http://www.age.uiuc.edu/agsafety/conf.htm

Cole HP, Piercy L, Struttmann T, *et al.* 2001. The Kentucky Community Partners for Healthy Farming ROPS Project Notebook. University of Kentucky, Lexington, KY, USA

Haddon WJr. 1968. The changing approach to the epidemiology, prevention, and amelioration of trauma: The transition to approaches etiologically rather than descriptively based. Am J Public Health 58(8):1431-8

Haddon WJr. 1980. Advances in the epidemiology of injuries as a basis for public policy. Public Health Reports 95(5):411-21

Haddon WJr, Suchman E, and Klein D. 1964. Accident Research: Methods and Approaches. Harper & Row Publishers, Chicago, IL, USA

Karwowski W. 1991. Complexity, fuzziness, and ergonomic incompatibility issues in the control of dynamic work environments. Ergonomics 34(6):671-86

Kowalski KM and Vaught C. 1999. Issues regarding the safety and health of emergency workers. Conference Proceedings. The International Emergency Management Society Conference, Delft University, The Netherlands

Kowalski KM, Barrett EA, and Fotta B. 1995. Modifying behavior to improve miners' hazard recognition skills through training. In: Tinney G, Bacho A, and Karmis M (eds), Proceedings Twenty-Sixth Annual Institute on Mining Health, Safety and Research. Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Murphy DJ. 1992. Safety and Health for Production Agriculture. American Society of Agricultural Engineers, St. Joseph, MI, USA

National Data Buoy Center, NOAA (National Oceanic and Atmospheric Administration). 2001. Available at: http://www.ndbc.noaa.gov/index.shtml

NIOSH (National Institute for Occupational Safety and Health). 2000. Worker Health Chartbook, 2000. Department of Health and Human Services (DHHS), Centers for Disease Control and Prevention. DHHS (NIOSH) Publication Number 2000-127. Cincinnati, Ohio, USA. Available at 13, http://www.cdc.gov/niosh/00-127pd.html

OTA (Office of Technology Assessment, U.S. Congress). 1985. Preventing Illness and Injury in the Workplace, pp173-85. OTA-H-256. Washington, DC, USA

Pascoe E and Pidgeon N. 1995. Risk orientation in dynamic decision making. In: Caverni JP, Bar-Hillel M, Barron FH, *et al.* (eds.), Contributions to Decision Making – I. pp 301-21. Elsevier Science B.V., Amsterdam, The Netherlands

Perdue CW, Kowalski KM, and Barrett EA. 1994. Hazard recognition in mining: a psychological perspective. U.S. Dept. of the Interior, Bureau of Mines Information Circular 9422. Pittsburgh, PA, USA

Raterman SM. 1996. Methods of control. In: Plog BA, Niland J, and Quinlan PJ (eds), Fundamentals of Industrial Hygiene, 4th ed, pp531-52. National Safety Council, Itasca, IL, USA. Revised from: Olishifski JB. 1988. Methods of control. In: Plog BA, Benjamin GS, Kerwin MA (eds), Fundamentals of Industrial Hygiene, 3rd ed, pp 457-74. National Safety Council, Chicago, IL, USA

Ryan W. 1976. Blaming the Victim. Vintage Books, New York, NY, USA

Stefanko R. 1983. Coal Mining Technology Theory and Practice. Society of Mining Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc, NY, NY, USA

Steiner L, Turin F, and Cornelius K. 1997. A method for evaluating system interactions in a dynamic work environment. In: Das B and Karwowski W (eds), Advances in Occupational Ergonomics and Safety II, pp 603-6. Proceedings of the Annual International Occupational Ergonomics and Safety Conference, Washington, DC, USA, June 1-4, 1997. IOS Press, Amsterdam, The Netherlands

Stellman JM, McCann M, Warshaw L, *et al.* (eds). 1998. Encyclopaedia of Occupational Health and Safety, 4th ed. International Labour Office, Geneva, Switzerland

Stokols D, Clitheroe HC, and Zmuidzinas M. 2000. Modeling and managing change in people-environment transactions. In: Walsh WB, Craik KH, and Price RH (eds), Person-environment Psychology: New Directions and Perspectives, 2nd ed, pp 267-96. Lawrence Erlbaum Associates, Mahwah, NJ, USA

Sundstrom E. 1987. Work environments: Offices and factories. In: Stokols D and Altman I (eds), Handbook of Environmental Psychology, vol 1, pp733-82. John Wiley & Sons, NY, NY, USA

Toscano G. 1997. Dangerous Jobs. Compensation and Working Conditions. Summer, 2-2:57-60. Available at: http://www.bls.gov/special.requests/ocwc/oshwc/cfar0020.pdf

Toscano GA and Windau JA. 1998. Profile of fatal work injuries in 1996. Compensation and Working Conditions. Spring, 3(1):37-45. Available at: http://www.bls.gov/special.requests/ocwc/oshwc/cfar0024.pdf

Trist EL and Bamforth KW. 1951. Some social and psychological consequences of the longwall method of coal-getting. Human Relations 4:3-38

Trist EL, Higgin GW, Murray H. *et al.* 1963. Organizational Choice: Capabilities of Groups at the Coal Face Under Changing Technologies; The Loss, Re-discovery and Transformation of a Work Tradition. Tavistock Publications, London. Series: Brief AP, (ed) 1987. Ancestral books in the management of organizations. Garland Publishing, Inc., NY, NY, USA

Vaught C, Wiehagen WJ, Steiner LJ. *et al.* 1999. A sociotechnical approach to the unintended consequences of technical design in mining. In: Proceedings of the 28th International Conference of Safety in Mines Research Institutes, vol II, pp 687-97. Sinaia, Romania