

WORKING NEAR THE EDGE: A NEW APPROACH TO CONSTRUCTION SAFETY

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ABSTRACT

Construction safety has substantially improved, but has reached a plateau. Further improvement will come from spreading Best Practice throughout the industry, or from Breakthrough that transcends Best Practice. We are working on Breakthrough and propose that what is needed is a new theory of accidents. Current Best Practice is described along with its underlying theoretical assumptions. An alternative theory is proposed, based on the work of Jens Rasmussen, a leading thinker on risk management in dynamic environments. A research program is proposed to test that theory and to develop a new approach to safety management.

KEYWORDS

Accident, accident theory, decision making, hazard, risk, safety

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INTRODUCTION

Lean advocates minimizing waste and continuously improving. Incidents that disrupt the flow of work or lead to injury are waste, so the relationship between lean and safety is clear. Ohno's rule that a worker stop the line rather than release a defective part downstream also resonates. It is one thing to focus on the worker facing a hazard (a hole in the deck) and another to require the person who completed the previous work to assure such hazards are not left open before allowing the next crew onto the deck. Making work flow more reliable seems an obvious way to reduce unexpected events, but so far there is only limited evidence that more reliable planning does reduce incidents.

We have long understood the 'soundness' quality criterion for assignments as applied in the Last Planner System to include consideration of safety issues. A number of proposals have been put forward to make such consideration more explicit. For example, if a pre-task hazard analysis were required before an assignment was released, both inspection and root cause analysis would be improved. Inspectors who found people in hazard could take the appropriate immediate steps and then determine if the hazard had been identified in planning or not. If not, the planning should be improved and reasons for ignoring the plan could be investigated and action taken to reduce recurrence.

Improving safety remains a priority but despite innovations that reconceive the relationship between planning and safety, no systematic theory or practice has yet been developed. In 1996, the fatality rate in the U.S. construction industry was 13.9 deaths per 100,000 workers and the injury rate was 9.7 injuries per 200,000 labor hours. By 2000, fatality rates had fallen to 12.9 and injury rates to 8.2. OSHA legislation, increased litigation, and increasing worker medical expenses and compensation insurance costs gave the advantage to safer contractors. People at every level became less willing to accept the carnage. Construction users began to include safety performance in selection criteria and contractors began to take action. With increased attention on safety, company wide safety programs became the norm. Many employ full time safety officers or employ consultants to assure legal requirements are met and hazards and incidents are reduced. These programs paid off but the industry remains one of the most dangerous. Construction still kills or injures more than eight percent of its workers each year. There has been insignificant further improvement in safety since 1996.

Further improvement in national statistics can be achieved by spreading Best Practice throughout the industry. The larger, more sophisticated companies have much better safety records than the national averages. For example, OSHA reports that in 2,000, the injury rate for construction companies with more than 1,000 employees was 4.3 while the construction industry rate was 8.2.

But spreading Best Practice will not help those using Best Practice. For them, significant improvement requires a new approach, a breakthrough beyond current best theory and practice. Of special concern are accidents that occur through workers putting themselves at risk, which are resistant to current approaches. This paper briefly reviews the state of theory and current practice, and argues that a new theory is needed, which we propose to take from the work of Jens Rasmussen. A new approach is developed and described, and experiments are proposed to test the new approach in action.

ACCIDENT THEORY

The most prominent and widely disseminated causal models include the domino theory developed in 1930 by Heinrich. The five dominoes in sequence are; ancestry and social environment; fault of person; unsafe act and/or mechanical or physical hazard; accidents; injury. His work has been updated to focus on management's responsibility. Other models evolved based on Heinrich's work can be classified as behavior, human factors, systems, epidemiological, and decision models. (Heinrich 1980). Workers are the main cause of accidents in behavior models because people make errors. A number of efforts have devoted great time and effort defining and categorizing human error (e.g. Petersen 1982).

Accident proneness is a foundation of most behavior models (Klumb 1995). The main idea is that some people have a characteristic that makes them more likely to have an accident, and it is true that a small number of people are involved in multiple accidents (International Labor Organization 1983). Examples of the many other behavior models have been forward (Kerr 1957, Alkov 1972, Peterson 1982).

The human factors approach holds that human error is the main cause of accidents and that the design of workplace and tasks also contribute. These models study the effect of a particular situation or environment on human performance and their limited ability to perform. Examples of human factor models include, the Ferrel Theory (Heinrich 1980), and others (Peterson 1982, McClay 1989, DeJoy 1990). Cooper and Volard (1978) state environment and human characteristics including physical and psychological overload contribute to accidents and to human error.

Significant research effort has tried to categorize accidents and how they happen (Goldsmith 1987, La Bette 1990, Helander 1991, Hinze 1997). Set against the approach offered in this paper, these investigations do not identify the root cause of accidents, and despite the contributions of various models to understanding accidents and current safety programs they are unable to prevent the kinds of accidents that plague the industry.

BEST PRACTICE

The Lean Construction Institute research workshops focus on various project and production management issues including a recent workshop devoted to safety. Documents and descriptions from that workshop are the basis for this description of current practice, in which contractor safety programs are the norm. All of the construction companies supporting the Lean Construction Institute maintain active programs. These programs have similar approaches and components, although each is unique in its application. All of these companies have shown significant improvement and are well under the average rates experienced in the industry.

A TYPICAL PROGRAM

A medium sized mechanical contractor working in a large city provided this description of their safety program.

“A full time Safety Director (SD) was hired as the company grew and it became apparent that safety performance needed greater attention. Prior to that safety was a part time concern of the safety “manager” who also worked in purchasing. The new SD is a safety professional by education and has years of experience in safety with a major contracting and construction management company.

The SD reports directly to the CEO. He works with each department to service their unique safety related needs, as well as with the overall company safety program. Coincident with arrival of the SD, the CEO instituted a Safety Committee (SC), comprised of employees representing the various levels and job functions in the company. The SC worked with the SD to develop a comprehensive safety program. This program started with formal training by job and function includes:

- Targeted formal training (OSHA 10 Hr, plus required number of 1-hour safety seminars per year, based on employee's role in the company). All taught internally and supplemented at times by outside sources such as the power company on overhead power line safety.
- Toolbox talks reviewing tool use, project hazards and accident reports
- Bimonthly safety review meeting chaired by the CEO and SD discuss current performance and special safety issues. Participants include substantially all management and supervisory level employees.
- An incentive system that includes both spontaneous "ataboy" recognition for observed good safety performance, and a company wide monetary reward safety "lottery" for eligible people on project teams that meet or exceed the formal safety objectives for the lottery period.
- A citation program where both good behavior and bad behavior can be cited by "tickets" is issued to all supervisors.
- InspectProceedings IGLC-10, Aug. 2002, Gramado, Brazil and visits by safety professionals. The company SD visits sites soon after mobilization. He also visit when safety concerns or problems are identified. The project manager regularly walks the project. Inspections by the General Contractor (GC) and owner safety representatives are becoming more common. GCs often use OSHA consultation aimed at solving problems rather than enforcement actions.
- Post incident analysis is conducted by the SD with the project manager and supervisors to prevent recurrence. These efforts document the accident and provide feedback to the planning, training and toolbox components.

The first end of year review showed clear improvements in terms of reduced incidents and revealed that incidents were occurring because people chose to perform tasks in an unacceptable manner. Some of these cases people thought they were doing either themselves and/or the company a favor by cutting corners. For example a worker unable to reach something from their ladder climbs above the allowable level because it will take extra time and effort to find another ladder. As a result, more rigorous pre-task safety planning and hazard analysis, and root cause investigations have been instituted.

DISCUSSION

The program described above contains the essential elements of most safety programs; i.e., training, responding to regulation, motivation, planning, investigation and incident analysis. This section will discuss these elements and argue that they rest on an implicit worker centered causal theory as described in the Accident Theory section. Worker

training and motivation is assumed to be the key to prevention. Typical program elements include a person assigned to manage the program, a multi-level and cross functional steering committee, training, both carrot and stick motivational techniques, awareness, pre task hazard planning, inspection, and incident analysis and prevention planning.

A variety of other techniques are employed in other companies, but most fall within the categories apparent here. For example, one company conducts an annual “Safety Art” for the young children of employees. A calendar is prepared using the 12 winning entries and distributed to all employees. This company links employee safety to their family with the reminder that “Your Families Love You”. Some companies “brand” the safety program and provide work shirts and safety equipment with a logo stressing awareness.

A more sophisticated approach to pre-task hazard analysis is reported by another company. Their safety program is aimed at convincing employees that the acceptable level of risk on site is much lower than employees accept working at home. Since this level of risk can't be quantified, the company considers this a cultural issue. The level of acceptable risk is developed and communicated through pre-task hazard analysis. It works like this: The pre-task safety analysis prepared by the foreman is reviewed by the supervisor to determine if hazards that pose risks beyond those considered acceptable have been identified and preventive action is taken.

Other companies use more formal and detailed approaches to identify root causes of incidents. A variety of forms are used but most appear to focus on the situations where hazards exist and on the actions of the workers. For example, a plumber installing fixtures falls to his death through an unprotected opening on a floor deck. One identified cause is the existence of the opening and the other is a worker's failure to see it while walking backwards. Of course both the situation and the behavior contribute to the incident but no mention is made in the analysis as to why the worker was on such a deck, the failure of the person creating the hazard to correct it instantly or to “lock out” workers from the area, or the failure of the worker's partner to alert him to the danger.

While there is no standard practice for identification of root causes, the practice is common and provides feedback to training and planning functions. Some companies distribute abbreviated accident reports to every crew on the morning following each incident. While it seems an obvious idea, we have not yet found safety programs that evaluate the quality of pretask planning against the root cause analysis.

From the research perspective, root cause analysis provides important insight into how incidents and their prevention are understood. In current practice, root cause analysis often determines that an incident resulted from an error. The concept of an error as a deviation from normal practice makes sense in well structured systems where a correct sequence can be identified. But such well structured systems are not common in construction and while correct procedures may be developed for the use of tools, they are very difficult to prescribe for construction work which often takes place in complex, dynamic conditions. In these circumstances, the specific sequence of steps can rarely be predicted and controlled precisely. It is not possible to establish rules for how to behave in every possible condition in less structured situations. Thus tracing incidents to the root cause of failure to follow standard practice is often impractical.

Jens Rasmussen argues in “Cognitive System Engineering” that there are no objective stop rules for tracing the upstream causes for downstream events (Rasmussen 1994). Rather, the analysis stops once an explanation makes sense to the analyst from their perspective or because the trail of information goes cold. The perspective of the analyst

going in limits the range of potential “causes”. Rasmussen identifies six common perspectives (Page 138, Rasmussen 94).

- The Common sense explanation of what happened. Analysis stops when the act or event is identified that offers a reasonable explanation and is familiar to the analyst.
- Understanding human behavior: The Scientist’s perspective. This approach seeks to understand the inner mechanism of human behavior. The stop rule is to identify any actor in the flow of accidental events that did not maintain control even though they may not have started the flow and then to explore their cognitive processes. But even these inferences depend on the psychological approach taken. A number of distinctions internal to this approach are also made, such as the difference between a slip which is the wrong execution of a proper intention, and a mistake which is the correct execution of a wrong intention.
- Evaluating human performance: The reliability analyst’s perspective. This approach attempts to predict the effects of likely errors on larger system performance. Tracing here moves downstream to assure dangerous outcomes do not follow from likely errors. This approach requires highly structured work situations as in power plant operation. It is very difficult to apply in less structured work and is made more complex because humans adapt to the situation and often push for performance beyond that predicted by the designer.
- Improving performance: The therapist’s perspective. The availability of a cure determines when the search for cause stops. The bias of the therapist will likely affect the selection – trainers will see the problem as a lack of training, while the psychologist or safety officer may see it as a lack of motivation or awareness. Of course, it is possible for more than one such stance to be “correct” within limits.
- Finding somebody to punish: The attorney’s perspective. The stop rule is to identify a person who was in control of their behavior and therefore guilty of the act.
- Improving system configuration: The designer’s perspective. The job here is to find changes in the work system that will improve its performance. This is tricky business as the system are “designed” by a number of people with different perspectives from legislators to machine designers. Reports on single accidents do not provide good models of the system and repetition of the precise sequence is rare. The ability of people to adapt makes this task even more difficult.

The examples of root cause analysis provided by LCI members were prepared from the therapist and attorney’s perspective and offered little direction for significant improvements in the design of the work itself. Safety programs such as those described above appear to rest on the following beliefs:

- Rules and procedures can be developed which if followed will keep people safe.

- Incidents happen because of worker error; i.e., failure to follow the rules.
- Reducing incidents will flow from improved motivation and training; i.e., getting people to follow the rules.

We do not argue that worker motivation and training are unimportant, or doubt that people make mistakes and choices that lead to tragedy. But we do not believe that the worker centered cause and effect model, coupled with the violation of procedures, explains how incidents occur or provides the leverage required for further improvement. Additional reasons for moving beyond a worker centered model include:

- Motivation and training have been a primary focus of efforts to improve productivity beginning at least since 1970. We now find that redesigning the production system using lean theory has greater impact.
- Programs in general make us suspicious. More than a few corporate programs have been created to solve a problem without requiring deeper change. Productivity programs were tried extensively beginning in the 1970's but made only modest gains and rarely caused a fundamental shift in the way work was done. It has been said that all programmatic fixes to organizational problems eventually pass away; they either cause a change in the fundamental practice they were chartered to affect or they become obviously impotent and are cancelled. We expect safety programs will continue because they are almost required by regulation, and no better approach is yet apparent.
- There appears to be a more powerful theory and approach.

A NEW THEORY FOR CONSTRUCTION SAFETY

In a modern dynamic environment where discretionary decision making to a large degree is replacing routine tasks, definition of a correct or normal way of doing things is difficult, and the focus of research should be on understanding of the way in which features of the work environment shape human behavior and the conditions under which normal psychological mechanisms result in unsuccessful performance. The aim in the present context, therefore is not to analyze human errors and to create data bases so as to remove errors by proper work system design but, instead to design work systems that support the actors in coping with the effects of their actions when their performance under particular circumstances turns out to be unsuccessful. In this respect, we have found that a better understanding of the relationship between human adaptation to dynamic environment and human errors is required. (Page 143, Rasmussen 94)

The framework proposed by Jens Rasmussen in *Cognitive Systems Engineering* offers a broader and more powerful view of the relationship between individual and work environment, and of the primary factors that lead to incidents. In this model, represented in Figure 1, the way work is done migrates away from the organization's boundary (fear) of economic failure and the individual's boundary of (distaste for) excessive effort (Figure 6.3 page 149, Rasmussen 94). Accidents, defined by Rasmussen as "loss of control," occur when work migrates to the boundary of functionally acceptable behavior and control is lost.

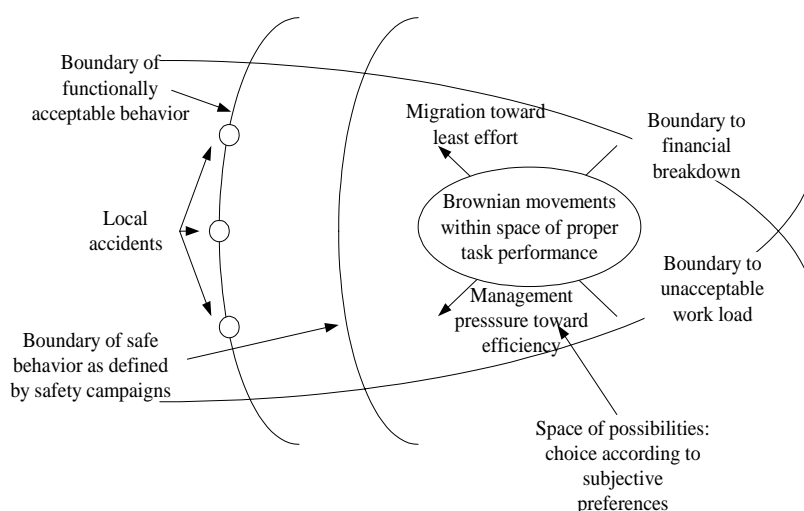


Figure 1: The migration of work toward loss of control. (Figure 6.3 Rasmussen 1994)

This process was reflected in the last paragraph of the description of the Mechanical Contractor's program. Rasmussen argues that "[...] the result will very likely be a systematic migration toward the boundary of acceptable performance and, when crossing an irreversible boundary, work will no longer be successful due to "human error."⁵ (Page 149, Rasmussen 94). Safety programs are designed to counter the pressure to move into an area where control can be lost.

This model challenges current safety program practice on a number of fronts, including the concept of error based on standard procedure (described above). But the fundamental difference flows from the recognition that both individual tendencies and organizational factors push people to work in risky circumstance. Recognizing the inexorability of the forces at play, it appears necessary to develop coping behavior at the edge of control. This challenges the notion that workers can be kept in the safe zone and should never enter the zone where control can be lost. Rasmussen's approach recognizes that people adapt to the circumstances and suggests that helping them develop and apply their judgment will be more successful than following rules. Rasmussen's model for causation leads to a three step approach to safety as shown in Figure 2. The actions taken in each zone are described in relation to an incident where a worker was injured when a wrench slipped while removing a toilet.

Zone 1 - IN THE SAFE ZONE: Enlarge the safe zone through planning the operation.
NB: Identifying hazards in an operation assumes that the operation has been designed.

Zone 2 - AT THE EDGE: a) Make visible the boundary beyond which work is no longer safe (a hazard can be released) and teach people how to recognize the boundary. (Don't use an open end wrench on stuck nuts.) b) Teach people how to detect and recover from errors at the edge of control. (Increase pressure slowly when nuts are stuck or use a striking wrench to break them loose.) This may require practice in "simulators".

⁵ Rasmussen argues that accidents occur at the boundary in this model but in the text of chapter 6 he also notes that psychologists distinguish slips or lapses that occur when one makes an incorrect execution of a proper intention from mistakes that occur when people correctly execute an improper intention.

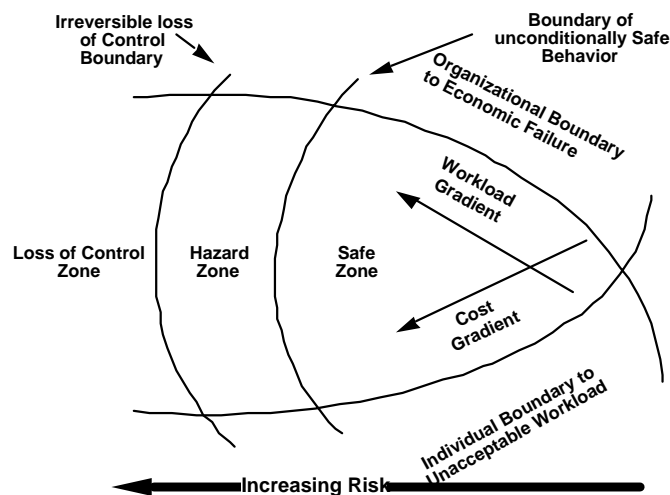


Figure 2: Three Zones of risk.

Zone 3 - OVER THE EDGE: Design ways to limit the effect of the hazard once control is lost. (Plan for what will happen if the nut breaks loose suddenly or the bolt breaks. Wear gloves.)

This model requires definition of “hazard” that recognizes its latent nature, how it becomes active and propagates to injury. Typical definitions such as "A condition or set of circumstance that has the potential of causing or contributing to injury or death" (Christensen 1987) are insufficient. We propose that a hazard is a condition, which if released can lead to injury unless the worker is able to detect and avoid it without increasing exposure to another hazard. This definition recognizes that the hazard is related to both the worker and the situation. Is a road hazardous? A mountain road? An icy mountain road? Under this definition, an icy road is in itself no more hazardous than a dry one if the driver adjusts his speed to avoid or be able to manage sliding. This definition also recognizes that hazards can lead to injury at different rates. For example, circular saws have guards that snap closed quickly when the saw is pulled from the wood. This guard is required because the worker cannot detect and respond to the situation quickly enough to avoid injury when a circular saw kicks back. Other hazards such as falls lead to an irreversible loss of control and so steps must be taken to prevent the propagation through loss of control to injury. Fall protection and nets provide just this service.

This definition of hazard is richer than the current working definition and can be applied in pre-task planning, where different strategies are appropriate depending on the nature of the hazards. Two examples illustrate the issue.

Boundaries where hazards may be released are not absolute: For example, driving at or below highway speed limits does not assure safe passage and people break these rules because they do not accept their validity (especially when late for dinner.) The situation is similar in construction. Ladders slip or fall for a variety of reasons. Use rules may help if people accept their validity. A ladder fall simulator could demonstrate just how easy it is to release the hazard and how quickly it propagates. Some companies do teach people to drive in a variety of conditions on training tracks. These courses teach people how to recognize the situation determined boundaries to regain control when lost. Are there other situations where simulators could be developed for construction? This approach will certainly raise concern among many that people will take greater risks once they better

understand the boundary conditions. This will be discussed in a section devoted to adaptation below.

Boundaries are difficult to detect and sharp. Once crossed, recovery of control is impossible and limiting propagation cannot be assured. Current practice requires that electrical systems be locked out for just these reasons. Fall hazards such as the open holes in decks are similar but firm lockout policies requiring work to cease when the condition occurs do not appear to be the norm. (It would be interesting to see the data on how many electrical accidents are due to failed lockouts and compare that with falls through openings.) Where else might firm lockout procedures be applied? This approach will raise objections related to the boundary of economic failure. Should all work be suspended on a large deck because of an unprotected hole at the far end well away from the crew? If yes, who should have the firm authority to stop work?

Other ideas come to mind. Structural engineers design structures to hold loads. Good practice requires them to identify the likely failure mode of the structure if loads are exceeded and depending on the circumstance adjust the design to assure the failure is safe. The same principle could be applied to pre-task planning. We have long proposed the practice of carefully designing operations with First Run Studies and that this process should include careful consideration of the hazards involved. Could current practice and First Run Studies both be improved by asking the crew, “Where will accidents be likely to occur if people try to either improve productivity or reduce their effort?” Or, “How can we improve performance, reduce effort, and work in such a way that hazards can be eliminated?” In effect, “How can we expand the safe zone?”

ADAPTATION

At this point, we hope to have legitimized ‘working near the edge’. A Rasmussen-based approach suggests that improved safety and organizational performance can be achieved by learning to work close to the loss of control boundary. This approach contradicts current practice with its emphasis on eliminating hazards and following rules to stay well back from the boundary. Some safety professionals find the idea of increasing the individual’s ability to cope near the edge or to recover when a hazard is released unsettling. This fear is not groundless as it is well established that people adjust their behavior when new technology is developed to reduce risk. The effect is for people to compensate in ways which keep the level of risk as they perceive it about constant. This compensating behavior can have ugly consequences when either the risks actually are increased due to overcompensation or when the resulting failures are worse.

Fear of compensation was a central issue in the debate over the use of nets to protect workers on building the Golden Gate⁶. Management feared that reducing the consequence would increase risk taking behavior. We come down on the side of teaching people to use their judgment rather than expecting them to blindly follow rules. Rules cannot be structured for all contingencies. Further, the very real pressures of work should not be ignored. Improving judgment and developing skills for working near the edge are the only alternatives to rules and enforcement.

⁶ The Golden Gate is considered to be the first modern project to use nets and hard hats. When Brunelleschi constructed the dome of Santa Maria del Fiore in Florence in the 15th century he employed safety nets for the masons. Only one fatality was recorded on that project.

A RESEARCH PROGRAM

Rasmussen proposes a different cause and effect model for the way incidents are caused and propagate to injury. We propose to test this model to see the extent to which it explains incidents in construction and then to develop ways to apply First Run Studies in operations design; ways to help workers better detect where hazards may be released, better cope near the edge, and recover if control is lost; and finally to minimize the effects if loss of control is irreversible.

The model proposed by Rasmussen appears to offer new and important leverage on safety, but it will require significant adjustments to current thinking and practice. We propose to first confirm that the model does in fact provide a sound theory for the way accidents occur in construction. We suspect that currently applied root cause analysis data will not provide definitive answers because the new model was not used to identify causes. New data will be required and a collection protocol established. We will structure a post incident evaluation procedure to determine what the employee understood about the loss of control boundary and the extent to which they were influenced by the pressure for production or desire to reduce effort. We hope to determine if there are ways to either reduce the pressure or establish lockout situations, if there are ways boundaries could be made more visible, and finally if there are ways to help people regain control when a hazard is released. This first work will establish the extent to which further work can be expected to produce positive results.

Additional work will be required to complete the three level strategy:

IN THE SAFE ZONE: Enlarge the safe zone through planning the operation using First Run Studies. Identify the various boundaries and how to work in relation to them, then check the actual method against the plan. Working further upstream, the concept of boundaries and the coping behavior required near them should better inform designers how to reduce accidents through product design.

AT THE EDGE: a) Make visible the boundary beyond which work is no longer safe (a hazard can be released) and teach people how to recognize the boundary. b) Teach people how to detect and recover from errors at the edge of control.

OVER THE EDGE: Design ways to limit the effect once control is lost.

CONCLUSION

'Self inflicted wounds' are a type of accident that is resistant to current theory and practice, even best practice. The new strategy offered here recognizes that organizational and individual pressures push people to work 'near the edge'. Standardizing procedures and enforcing work rules in dynamic work situations is impossible in the face of these pressures. Adopting a new definition of hazard and applying better planning can expand the zone of safety and increase the extent to which tasks are fail-safe. But hazards will remain and so workers need to be trained so they can always answer these questions.

Where are you—in what zone?

What is the risk or hazard you now face?

What can be done to prevent releasing the hazard?

What can be done to reduce harm should the hazard be released?

We must also adjust the post incident analysis to consider the design of the work system in relation to these concepts. Safety performance and productivity will improve as we learn from accidents how to extend the safe zone.

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