A Training Perspective on Abnormal Situation Management: Establishing an Enhanced Learning Environment

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Abstract

A persistent paradox in the domain of supervisory control is that as automation technology advances in complexity and sophistication, operations professionals are faced with increasingly complex decisions in managing abnormal situations. An Abnormal Situation Management (ASM) R&D Consortium has been established to address problems currently facing industrial plant operations during abnormal conditions. We have observed and interviewed a broad range of personnel at several plants in the U.S., Canada and Europe. Several critical areas were identified as important to the improvement of operations practices and the safety of operations under abnormal situations. In this paper, we focus specifically on the area of training personnel to manage abnormal situations. We discuss the need for a paradigmatic shift in the process industry's approach to the issues of training. Specifically, a paradigmatic shift of attention from training to learning is required, in which the emphasis is placed on practices and technical solutions that create a work environment that is itself an enhanced learning environment.

I. Introduction

The largest economic disaster in U.S. history (not due to natural causes) was a $1.6 billion explosion at a petrochemical plant in 1989. This accident, due in part to ineffective human intervention, represents an extreme case in a continuum of minor to major process disruptions, collectively referred to as abnormal situations in this paper. Most abnormal situations do not result in explosions and fires but are costly nevertheless, resulting in poor product quality, schedule delays, equipment damage, and other significant costs. The combined ability of the automated control system and plant operations personnel to effectively manage abnormal situations has an estimated economic impact of at least $20 billion annually in the petrochemical industry alone.

Most oil refineries and petrochemical plants use distributed control systems (DCS) to simultaneously control thousands of process variables, such as temperature, flow, level and pressure. The major human role in this control scheme is to supervise these highly automated systems. This supervisory activity requires: monitoring plant status; adjusting control parameters; performing planned operations activities; and detecting, diagnosing, compensating, and correcting for abnormal situations. Increased demands for higher efficiency and productivity in these industries are resulting in tremendous increases in the sophistication of process control systems through the development of advanced sensor and control technologies. However, these sensor and control technologies have not eliminated abnormal situations and will not in the future. Consequently, operations personnel continue to intervene to correct deviant process conditions.

A persistent paradox in the domain of supervisory control is that as automation technology increases in complexity and sophistication, operations professionals are faced with increasingly complex decisions in managing abnormal situations. A contributing factor to this phenomenon is that the sophistication of operations training and user interface technologies has not kept pace with the task demands imposed by abnormal situations.

Past research on the supervisory control task has focused on the operator. In developing an understanding of the current limitations in managing abnormal plant situations, we have expanded our scope of investigation to the broader operations team of supervisors, technicians, engineers, and operators.

Current efforts in applying new technologies tend to focus on improving the alarm management problem through better presentation, better information filtering, and better access to data. These efforts are exploring solutions within the current alarm management paradigm. However, we believe the process control industry needs more long-term solutions that address the more general problem of abnormal situation management. We need to develop the next generation solutions to dramatically improve the operations team's ability to prevent and respond to abnormal operations that may escalate to catastrophic events and affect overall process productivity.

In this paper, we present the results of our study in terms of implications for operations personnel training. In the first section, we define abnormal situation management activities in the context of industrial plant operations. The next section identifies specific findings from plant studies pertaining to current training practices. Finally, we present a solution vision that represents a paradigmatic shift in the approach to training operations personnel to handle abnormal situations.

II. Abnormal Situation Management

As part of the knowledge acquisition phase of understanding abnormal situation management in plant operations, the we visited several plants in the U.S., Canada, and Europe. The team observed and interviewed a wide range of operations, engineering and management personnel at these plants.

The goal of a plant's automated control system, typically a distributed control system, is to maintain the plant's normal operating state to meet product quality and throughput requirements. Inevitably, the process occasionally deviates from normal operating conditions. When the control system cannot cope with these unforeseen disturbances to the process, unplanned human intervention to restore the plant to its normal state is required. We define these situations as *abnormal situations*. Abnormal situations vary on a continuum ranging from a small deviation from normal operations to a catastrophic event. Abnormal situation management refers to the proactive or reactive intervention activities of members of the operations team. We describe sources of abnormal situations and the nature of human intervention activities below.

Sources of Problems

Three types of causal factors and the average percentages as initiating causes, based on 1992 plant incident reports from six sites, are shown in Figure 1. One or more of these factors may contribute to the onset and escalation of an abnormal state.

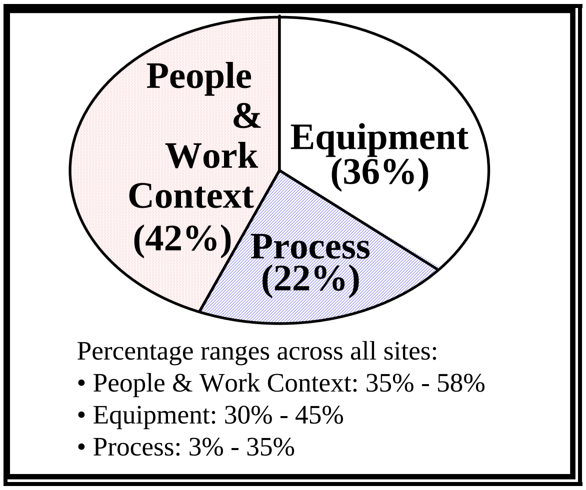

Figure 1. Initiating Causes from 1992 Plant Incident Reports

Data from the incident reports should be interpreted with some caution, since the findings are biased in a number of ways. First, individuals at some sites indicated a reluctance to identify people as the source of an incident. Second, these data were based on a small number of sites and thus reflect idiosyncrasies of the sites sampled. Despite these biases, we did find these averages to be consistent with the literature that has summarized the sources or root causes of a large number of incidents (Lorenzo, 1990).

For People and Work Context causes, the following types of explanations were given:

- Inadequate or no procedure (27%)
- Inadequate or incorrect action (22%)
- Fail to follow procedure/instruction (22%)
- Inadequate work practices (17%)
- Defective installation (6%)
- Fail to recognize problem (6%)

Establishing new procedures or conducting training were typical recommendations for these kinds of initiating causes.

Operations Interventions

Operating a plant is a complex task of coordinated activities between various people in an operations team. The members of the team include console (DCS) operators, field operators, instrument and controls technicians, shift supervisors, process engineers, and control engineers. As part of routine operations, there has to be a significant amount of communication between: (a) personnel sharing DCS consoles used to monitor a unit of the plant, (b) field personnel and those who remotely monitor the unit, and (c) personnel working on different but interacting units of a plant.

Especially during abnormal situations, supervisors, console operators and field operators communicate with one another as they diagnose, verify and adjust the state of the process. Thus, appropriate and timely intervention requires coordinated actions between individuals who are in the same vicinity as well as in remote locations.

Three basic activities of human intervention in managing abnormal situations are orienting, evaluating, and acting as shown in Figure 2 (For more discussion, see Chu, Bullemer, Harp, Ramanathan & Spoor, 1994). In this simplified model of operations activities, several points in the sequence of intervention activities can lead to success or failure in abnormal situation management. Moreover, success depends not only on the accuracy of an individual activity, but also on the timeliness of its completion.

Failures in orienting activities are frequently due to too much information, inappropriate level of detail, or excessive workload. Failures in evaluating are commonly attributed to inconsistent information, inaccurate information, and inappropriate detail. Failures in acting are often a result of inadequate procedures/instructions, complex procedures, and failure to comply with procedures or instructions. All activities are influenced by lack of time, lack of training or insufficient knowledge, too few people, and ineffective communications.

In terms of the explanations given for human intervention failures in the reported incidents, the documentation indicates that most problems occur during the execution of a compensatory or corrective response (Acting). However, subjective reports of operations personnel indicate more difficulty with the orienting and evaluating activities.

III. Training Issues

The findings on plant training are discussed in the context of three important components of an effective training program (Goldstein, 1986):

- Needs assessment
- Practices
- Evaluation

Training Needs Assessment

Assessment of training needs is the first stage of developing an effective training program. Two important findings related to the issues of abnormal situation management were identified:

- Formal methods for training needs assessment are NOT in use.
- Understanding of the sources of abnormal situation management problems is inadequate.

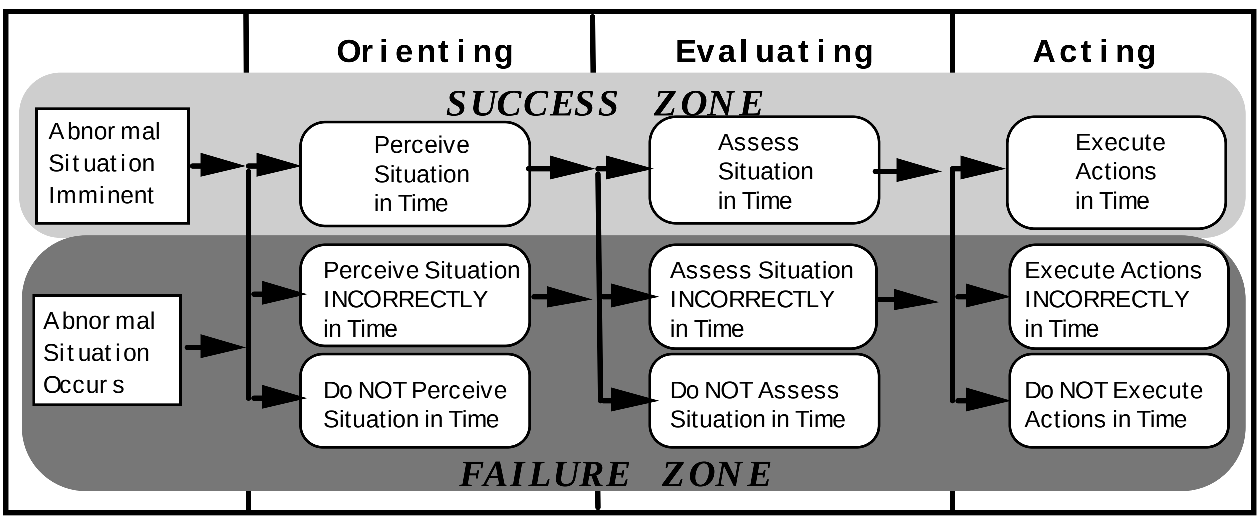

Figure 2. Operation Interventions Activities and Failure Sources[1]

Individual perceptions of the nature and causes of abnormal situation management varied at all plants. The varied opinions reflected a general lack of industry-wide understanding of the sources of abnormal situations and their impact on plant productivity. In fact, there was a tendency to attribute problems to sources other than people and work context.

[1] Based on failure tree diagram created by Ken Emigholz of Exxon Research and Engineering.

As mentioned above, when an incident occurred that was attributed to the failure of people to respond appropriately, a common reaction was to issue some instructional information to every current staff member as a short-term training action. However, these bulletins were often soon forgotten and not used as input to assessment of training needs.

A significant related finding was the lack of formal methods for assessing the nature of abnormal situations and the demand for specific knowledge and skill. In most cases, plant training specialists were former operational staff members. Although prior experience is valuable for understanding training needs. These personnel were often not familiar with formal methods for assessing training needs. Consequently, training programs tended to be narrowly focused, unintegrated, and based on traditional practices.

Training Practices

Current training practices were a ubiquitous concern among all plant personnel. Some key findings regarding current training practices were:

- Emphasis on informal "hands-on" and "on-the-job" apprenticeship training
- Strong initial training for field operators, moderate training for console operators, and weak training for all other operations staff
- Difficult organizational obstacles to effective training execution or on-the-job learning

The apprenticeship system has strengths and weaknesses. A strength of current training practice was the emphasis on "hands-on" training. Historically, journeyman-apprentice relationships have existed in the industrial process control environment. The novice accompanied the expert around the plant, observing and mimicking the skillful actions of the expert. The expert mentored the novice in the context of performing the job.

However, these apprentice ship systems have limitations, particularly in the context of learning to interact with complex systems:

- It takes a long time to train on all the operating conditions, when many occur infrequently,
- The quality of the training depends on the expertise and the mentoring skills of the journeyman.
- Rapidly changing technology reduces the ability of experienced staff to mentor younger staff more familiar with advanced technology.

The finding of differing levels of training depending on job class and time with the organization tends to accentuate the impact of the weaknesses of the apprenticeship system. A common practice we observed was an emphasis on the initial training of field and board operators with no formal continuation or refresher training for any operations personnel, The apprenticeship system was typically used to train individuals in field operations. In most cases, a formal evaluation was used to certify that individuals were competent. With board operations, a training period was typically established in which an operator would receive mentoring from a skilled board operator. The period was typically shorter than allowed for field operations and rarely involved a formal evaluation to certify competence. Other operations staff positions such as chief operator or shift supervisor had little to no training of any kind.

Several organizational obstacles to effective on-the-job learning were identified:

- Operations crew organizations
- Shift rotations
- Management response to human error

Many crew organizations placed most of the monitoring and decision-making responsibilities in the console operator position. In general, members of the operations staff desired more knowledge about the functions of the DCS and training on how to make effective use of its existing capabilities. Because of low situation awareness and lack of knowledge about how to interact with the process, supervisors and field operators were limited in their ability to effectively share responsibility and support the console operator in abnormal situations.

Some plants crosstrained and rotated staff through crew jobs to improve overall crew knowledge and skills. However, shift rotations reduced the impact of this strategy because of limited experience at any one position. For example, a person may work as the console operator only every four to six weeks.

The final organizational obstacle to effective learning was the response of plant staff and outside agencies to human error. Human error is inevitable. Understanding the sources of human error is a necessary step toward minimizing its occurrence and impact. The current climate did not invite candor in identifying contributing factors (as mentioned above). Consequently, effective learning could not take place.

Training Evaluation

The evaluation of training effectiveness is the final stage of developing an effective training program. Findings related to evaluation were similar to those of needs assessment:

- Formal methods for training evaluation are NOT in use.
- Evaluation , if it occurs, tends to focus narrowly on short term effects of training.

The limited training evaluation that was observed, tended to focus on short term effects of the hands-on training. In general, training specialists did not know the impact of their training programs on effectiveness of plant operations.

IV. Enhanced Learning Environment

The human performance demands of abnormal situations in the industrial process control environment challenge current training strategies and methods. A new paradigm is needed that closely couples training and job activities situated in the everyday work environment.

Quite by accident, the best training is on the job training, sporadic and informal and unmeasured as it may be. The interactions between people, plant equipment, processes and organizational entities that occur within the everyday work environment have a stronger impact on the operations team performance than any existing training program. The work environment is the primary learning environment. Plant personnel typically do not perceive the work environment as the learning environment.

The key to success is to build on this existing culture, introducing fixes for the problems that we see--much more likely to succeed than the introduction of some new comprehensive alien training bureaucracy. To improve the effectiveness of learning that takes place within the plant during on-the-job activities, plant developers and managers should design the work environment as an effective learning environment. For improving abnormal situation management performance, specific consideration should be given to aspects of the learning environment that will foster appropriate knowledge and skill development.

Simplisticly, the distinction between knowledge and skill development is used in this context to emphasize two general types of learning that are beneficial in the operations task environment[2]. Knowledge development refers to the acquisition of facts about the plant and its operation. For example, knowledge about how the plant functions, how the processes behave, specific job responsibilities, and operating goals under normal and abnormal situations. Skill development refers to the acquisition of the ability to respond in an automated manner to plant conditions, i.e., acting quickly and appropriately to plant situations without conscious deliberation over what to do.

Knowledge Development

The most significant issue confronting knowledge development is access to accurate information about abnormal situations and the impact of human interventions on preventing, alleviating or escalating them. From the perspective of training the operations team as a whole, one should consider the collective, distributive cognition of the entire team.

In designing for knowledge development, the work environment should:

- Provide adequate mechanisms to track performance and its impact on plant operations.
- Create an environment in which all individuals are motivated to provide and use feedback to improve overall plant performance.

[2]Theories of skill acquisition often characterize the development as a transitioning from the acquisition of factual, conscious knowledge about the relations between conditions and actions to the automated execution of the actions without deliberate, conscious thought (Anderson, 1982; Fitts, 1964).

- Create an environment in which collaboration is encouraged and supported through task rotation and distributed decision making.

Skill Development

Operations personnel often have only a few minutes in which to react. These time constraints require quick, appropriate responses. In many situations, people do not have time to think about what steps to take or search for information. In designing for skill development, the work environment should:

- Create an environment in which individuals can practice managing realistic abnormal situations, including collaborative activities.
- Provide individualized assessments on appropriate values for critical learning parameters, such as time intervals between practice scenarios.

V. Conclusions

In responding to today's training needs in industrial process control environments, we can benefit from advanced technologies in a few key areas such as simulation, artificial intelligence, communications and multimedia. For successful application of these technologies, training developers will need to understand and address the critical issues presented by ASM activities (See also Cochran and Bullemer, 1996).

Improvement in training methods to support abnormal situation management activities for all plant personnel can have a significant impact on plant profitability.

The importance of situated learning in informal contexts (out-of-school learning) is beginning to receive recognition as an example of successful learning (Brown, 1990). Brown claims the challenge is to "construct environments that reflect the nature of the practicum and that support the process of enculturation." Enculturation is the process of entering into the community of practice.

In the past, the introduction of new technology has had a negative impact on the situated learning that occurs during on-the-job performance (Norman, 1993). For example, replacement of the large control panels with the VDT displays of the DCS system has reduced the level of shared cognition and learning among members of the operations team. We need to ensure that new technologies facilitate the acquisition and maintenance of knowledge and skill rather than hindering it.

We believe a new paradigm in training is needed to make a significant improvement in abnormal situation management practices. Ironically, this “new paradigm” is likely to prove successful precisely because it captures the best aspects of existing practice and builds upon them.

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