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Why Bad Things Happen to Good People

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Accidents in the process industries are extensively investigated to determine root causes, for lessons learned, and many times in search of the "guilty". Accidents are seldom simple and most accidents have human elements that led to or facilitated the accident. Many times the people involved in these accidents, when considered individually on their merit, would be considered "good" people yet "bad things" (accidents) still occur.

We certainly have improved our approach to process safety in the US process industries since the federal regulation 29 CFR 1910.119, "Process safety management of highly hazardous chemicals" was implemented in 1992 and ANSI/ISA-S84.01, "Application of Safety Instrumented Systems for the Process Industries" in 1996. However, accidents are still occurring and there may not be an overall decline in process safety events [2]. One only has to keep an eye out in the news or go to the Chemical Safety Board web site www.csb.gov and look at the investigations going on or look at the rotating billboard, "CHEMICAL ACCIDENTS IN THE NEWS," to confirm this.

The origins of this paper are from the author's wondering about why accidents happen in environments of seemly competent people with apparent procedures and practices in place to prevent accidents. Why seeming competent people acting in concert in a group do not always reduce the likelihood that an accident would occur but just the opposite? And, why do a number of events, conditions, and factors seem to come together and line up at the exact time and place to cause an accident?

The Human Factor

"Errare humanum est" - To err is human.

In evaluating causes of accident, human contributions stand out. In fact it is supposed by some that all accidents can be traced back to human errors of some sort if you look long and hard enough. The "*Human Performance Handbook*", Department of Energy, DOE-HDBK-1028- 2009, gives the human error percentage at 80% as shown in Figure 1, with it further broken down into 30% individual and 70% organizational errors [3]. Other studies give the number for refineries as 47% (19% random, 81% human factors) [1], for boiler incidents 83% [5], for chemical incidents 1987-1996 63% [17], and in a range of 45-90% [6]. In any case, it is clear that humans contribute significantly to the occurrence of accidents.

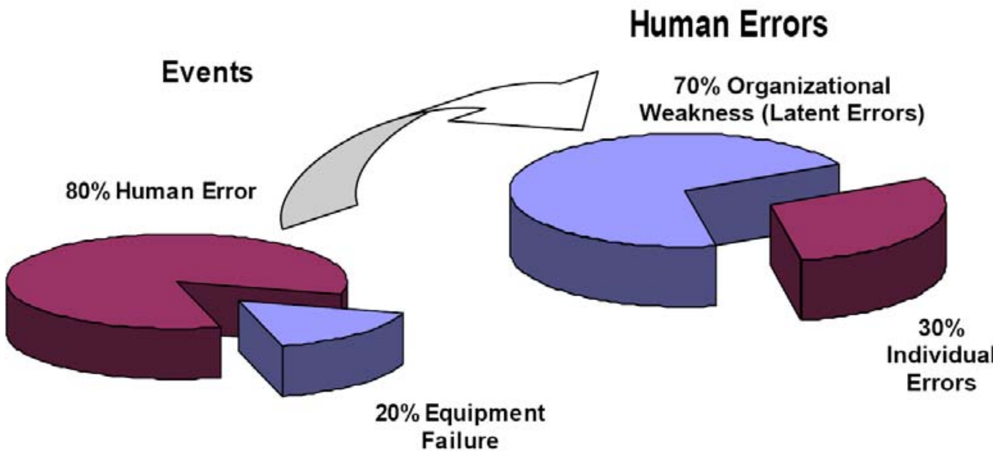

Figure 1 – Error Characterization [3]

Equipment failure aspects of accidents shown in Figure 1 as 20% are not part of the topic of this paper, even though there are commonly human elements involved in equipment failures.

Now and Then

Looking back over 30 something years in the process industry, some things have changed, some things have stayed the same, and some things have repeated themselves. Having started out in the pneumatic/mechanical instrumentation era, a number of things strike me as different over the years that potentially affect human factors and the potential causes of accidents.

One of the first things that strikes me is the quantity and density of information available to the operator. This is not a new issue but it puts increasing requirements on the operator to separate the wheat from the chaff and affect operator competency issues, in particular under abnormal conditions. It also seems that increasing the amount of available information without consideration of the effect on the average operator is an easy thing to do on the small scale. This informational gap between information (wheat and chaff) and useful data (wheat) is illustrated in Figure 2. The modern control systems can concentrate tremendous amount of information and function for the operator but it seems that we have about the same number of operators or in some cases less.

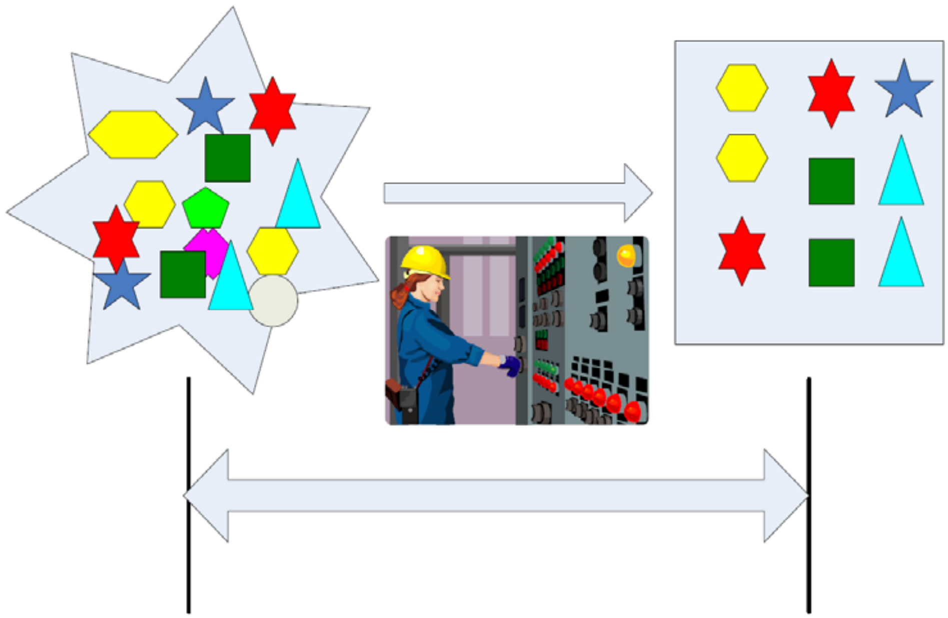

Figure 2 – Informational Gap

The second thing is the increased level of abstraction. Abstraction is a way to deal with complexity. We've moved from field instruments, boards full of instruments, and full graphic displays to consoles full of digital monitors, table top computer displays, and in some cases larger wall mounted displays. We've also moved the board and some of the field operator functions to more centralized control rooms and in some cases to remote control rooms. Our instrumentation has moved from mechanical□pneumatic ➔ analog ➔digital ➔smart ➔??, each of which represents an increase in layers of abstraction to the point where we know the function of our systems but not always the workings of them. Due to human limitations, more information usually translates into greater need for abstraction. To understand the forest we must abstract the trees but this process is not always reversible. This leads to more brainwork and less direct physical and sensory input to maintain a worldview of our operating surroundings which leads to more potential for errors (faulty manipulation is easier in the abstraction than in the physical).

When board instrumentation was actually mounted on a board, there were limitations to how far the control room could be from the process and board operators actually went out into the process area on occasion and sometimes talked with the outside operators in person rather than by radio. With DCS systems, this distance limitation goes away and some board operators may never even get close to the process they control, their only communication with the outside operator is by radio, which leads to more abstraction and operators find that their work has substantial similarity with video games rather than controlling a dangerous process.

The third thing is that the quality of management looking up from the bottom does not seem to have changed much over the years. Some of the complaints heard 30 years ago are the same as heard today. Poor communication is a good example. Today, there is more information available but there are still communication path issues (both ways) and much can be lost in the translation that can defeat the advantage of the availability of more information. Some of this appears to be human behavior but some is certainly environmentally based (nature vs. nurture). You would have thought that we would have learned better management techniques leading to a better understanding of safer ways to do things but it doesn't always seem so. Trevor Kletz's observation in his book "*Lessons from Disaster: How Organizations Have No Memory and Accidents Recur*" regarding lack of corporate memory (each generation having to learn anew) obviously has some broader merit. Another example is not having a punitive environment which was another refrain I heard before over the years (first time I think was in the early 90's but it still comes up). Improvement in management implies a structural solution which can be an enabler of people to improve safety, however, it should be remembered that no structure can fully compensate for the shortcoming of the people operating within the structure. On the converse, the author has observed that competent people can many times make up for a poor management structure.

The fourth thing involves technology. The last thirty years has brought substantial changes in technology in our industry and society. While technology can be pointed to as providing improvements, technology has brought complexity and its own bag of troubles and unintended consequences. We have more information but sometimes less understanding of the information or suffer from garbage in – garbage out syndrome, or worse garbage in – gospel out. In engineering, we now have CAD and CAE systems, computer databases, and computer tools but some of the same errors are being made (incorrect drawings, wrong materials, things won't fit up, etc.). We also have new errors such as copy and paste, data input errors, wrong models, etc. to contend with. We can put out more engineering faster but the quality appears in some cases to be no better than years past. With technology typically come complexity and invisibility and the more complexity and less understanding comes more potential for accidents. Some of the problem maybe that implementation of technology has in many cases been viewed as an isolated event like adding on an accessory rather than from a systemic viewpoint which considers complex interactions with complex environments.

The fifth thing is potential for degrading of the safety infrastructure. All facilities have an underlying, invisible infrastructure that consists of safety margins that help protect the facility. Some of these are engineering safety margins, operational margins, functional redundancies, and items normally taken care of by people as a matter of good practice. The reduction of personnel for economic reasons and the resulting loss of work capacity and experience leads to more work for the remaining personnel which can lead to potential errors and things that are a matter of good practice not being done due to resource limitations. All these can chip away at the safety infrastructure until a latent condition is created waiting for the right conditions to occur for an accident.

Situational Awareness (SA)

Ignoring random error, why do we make mistakes that can lead to an accident? One common issue that seems to apply across the board to individuals, groups, and organizations is situational awareness. If we don't have the correct situation awareness, we can make bad decisions potentially leading to an accident.

This is not a new issue but the introduction of digital systems and DCS systems have complicated things by squeezing down the window to the process and increasing the informational level. Since the mid-1990, considerable work has been done by the Abnormal Situation Management Consortium (www.asmconsortium.net) in regards to situational awareness particularly in HMI and control room design. They have a number of papers available at their website. There has been considerable research into situational awareness in aviation and the military. Endsley has written or co-authored a number of papers on the subject, some of which are listed in the references. [4,11,12,13]

Situational awareness can be considered as the sum of the operator's perception and comprehension of the process information and the ability to make projections of the system states (near future) on this basis [13]. While not always obvious, situational awareness also involves an awareness of the risk of the current state and the evaluation of the risk of the future states. Many times we can have the correct situational information (pressures, temperatures, levels, etc) from our control systems but translating that into risk involved is not always easy.

The author was once told a story by an operator at a LOPA where the relief to the atmosphere by an atmospheric relief valve was being discussed and in particular, the dispersion model at low flow rates and potential radiation levels if the relief ignited did not bode well for anyone in the vicinity of the relief valve when it went off. This operator said that they had had a spurious opening of the relief valve and he had gone up there and closed off a valve at the suction of the relief valve. He stated very vehemently that he would never do that again. He understood the situation but not the risk.

The SA concept can be extended to the team environment when a team is involved in determining the projections of the near future systems states such as can occur during a escalating process event [13]. A generic model of situational awareness is given in Figure 3.

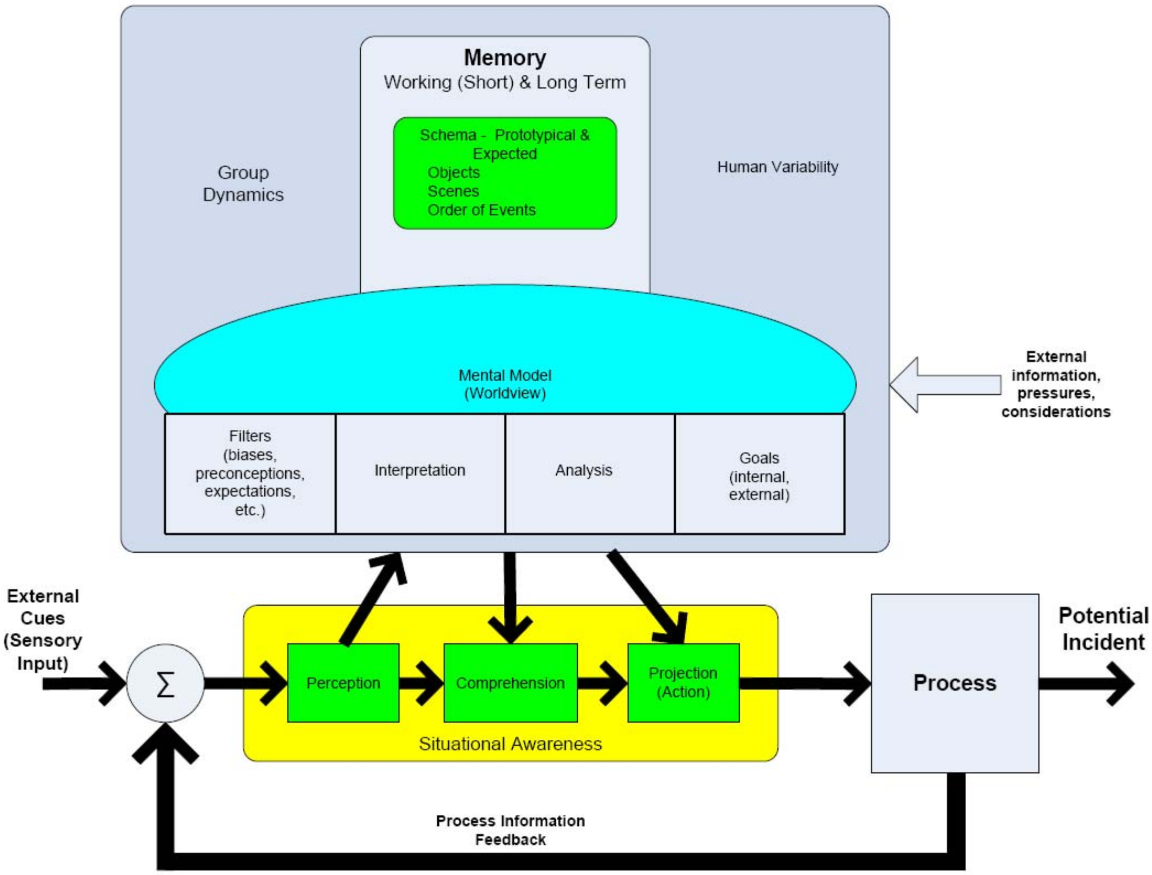

Figure 3 – Situational Awareness Generic Model

Situational awareness not only involves the fidelity of the information received by the operator but the operator's willingness to accept the fidelity of the information and act on it. This requires updating of the operator's worldview or in the case of a group, the group's worldview. A funny thing that happens on the way to the worldview is that the information is filtered by biases, preconceptions, expectations, interpretations, and in the best case critical and valid analysis, in the worst case none at all (See Figure 3). This filtering, even with the best of information, can sometimes lead to a distorted or incorrect worldview leading to an accident.

Other factors can influence (and distort) an operator's worldview such as past experiences and historical information. The use of experience in dealing with a particular situation tends to operate on case based or schema reasoning where in response to a situation, the operator calls up from memory previous cases or schema for the same or similar situation to reason (but does not necessarily analyze) about the current situation. Sometimes the reasoning behind the called up case is really folklore (incorrect original reasoning or information passed down as truth but which is not) or based on historical information that may suffer distortion due to translation effects or time distortion (a legend). In other cases, the cases may appear to be correct but the case is mismatched.

Another interesting effect related to information and problem solving that can lead to errors is one of focus. Humans have a limited number of items that they can focus on at one time. In a flood of information, it is sometimes easy to focus on understood information or information that makes “sense” to the exclusion of other truthful information or the acceptance of only confirming information. This can lead to a case of not seeing the forest for the trees or vice versa and to a breakdown of situational awareness. This is one area where a group can sometimes be beneficial (though not always – see the Trip to Abilene paradox [10]) or when a third party enters the arena.

From observations of operators, there appears to be in some cases a natural conservatism to change or revision of the operator’s worldview and the first response to information indicating a change can be suspicion. The author remembers long ago, when he was an instrument tech before he became an engineer, the first response by an operator to a deviation seemed to be to blame the measuring instrument. Not too long ago, when talking to a senior operator about troubleshooting process problems, the operator was asked what the first thing he did was. He stated that he checked to see if his instruments were lying to him. The author has heard this refrain before in other cases in different words over the years. This can result from a general distrust in instrumentation due to poor reliability or maintenance, distrust of a particular instrument (commonly for historical reasons), or from a conservation of worldview (current worldview is working – don’t change it). In an example, a 16” reactor agitator shaft for a 50’ long, 12’ in diameter plastics reactor was twisted off at a girth weld. This resulted because the operators/process had managed to create a solid piece of plastic 12’ in diameter, 50’ long (first time for everything) which went into a bind that resulted in the twist off of the shaft (locked rotor for the agitator motor and it did its best to do its job). The operators did not believe the amp meters on the variable speed drive which indicated high amps was reflective of what was happening in the process. To top it off, the operators/process later managed to again create a large chunk of plastic but did not twist off the shaft (different time and shift), where the author had the honor (and it was an honor for an I&E engineer moonlighting as a mechanical engineer) to inspect the girth weld on the night shift in a fresh air mask to approve it for startup. A reflection of this pattern can be seen in a common operational bias against making any change to a perfectly running process.

Groups come into play in the front lines because escalating abnormal events tend to draw people like flies to molasses. In the control room, the shift foreman and supervisors show up attracted by alarms or operator notifications; heck the author has even seen a plant manager show up. On the outside, operators move toward the troubled area looking to help. These ad hoc groups act in concert to solve the problem. While small groups can many times work with synergy (leadership, increased competence levels, knowledge, capabilities, etc.), groups can be subject situational awareness problems (e.g. failure of group to integrate similar and disparate worldviews) and to psycho-social effects leading to group think [9] such as dominance, pecking order, personalities, politics, vested interests, Trip to Abilene syndrome [10], etc. [13]. Consideration of group interactions/dynamics involved in accidents in the process industry seem to be an area of some neglect.

While a lot has been written about frontline situational awareness, organizations have a similar form in how various levels of management and supervision perceives the levels above and below them. This is complicated by how communication flow up and downhill. There is a saying about how crap flows downhill while the smell of roses rises uphill. On the downhill slope, there is a tendency to minimize the perceived negative effects of changes while getting any perceived positive benefit from the change. On the uphill slope, there is a tendency to spin the good to better, while spinning the bad to less bad. Obviously, the more punitive the environment, the more likely for bad news to be hidden. This is conducive neither of accurate communications nor of situational awareness in either direction. If the only communication is through official management chains, it is unlikely that the perceptions at the top are what the reality is at the bottom, nor is the perceptions at the bottom what intended from the top. One would think that this problem would have been fixed along ago. However, it seems that corporate management memory can be short and new generations of executives seem many times to have to be trained anew. If you stay around long enough in the process industries, you will probably notice that many things tend to repeat themselves but do not necessarily improve themselves.

Another cause can be related to complexity of change in complex systems and how sometimes the law of unintended consequences can come into play. If decisions are not looked at closely, unintended negative consequences may result. You may fix something here but just transfer the hazard elsewhere or change the hazard to have a different favor but just as risky or more. An example of this is the addition of more automation of protection systems, which most people would agree is a good thing. An unintended consequence is that in some cases the units under protection are operated closer to their limits, or shortcuts are taken because there are automated protections in place to provide protection, thus increasing the risk of exceeding normal conditions.

Non-supervisory groups can also have issues with situational awareness. These groups can be focus group, various team arrangements, ad hoc meetings, process hazard analysis teams, risk assessment teams, etc. These groups can act in synergy, do an adequate, if not, in some cases mediocre job (known commonly as muddling your way through), or can be subject to the same issues with situational awareness and group think issues as the frontline groups, though typically not in the same timeframe.

Individual Errors Leading to Accidents

Individual errors can occur due to various reasons such as slips, mistakes, capture errors, misidentification, and various psycho-sociological reasons. [3,4,6,20]. These classifications do not fully explain why apparently experienced, competent people make errors that lead to accidents. For example, there was an accident where an experienced, long term electrician employee made a decision to work on a 277VAC lightning circuit live, alone at night, and without following procedures for working on live on circuits of that voltage level leading to a fatal electrocution. The electrician knew better and was aware of the procedures yet chose to take actions that led to his death.

Another example, was where two experienced contract electricians were installing a conduit on an energized 480VAC motor control center (MCC) when after taking off the end of the MCC, one of the electricians stuck his hand up into the MCC to attach one end of a Greenlee hole punch. This electrician's arm contacted the 480VAC bus which resulted in one of the electricians being killed and the other seriously injured. The electricians were certainly aware of the hazard and they were aware of site work policies involving live work over 150V to ground but accident still happened. It is interesting to note these accidents occurred over the space of 20 something years and at two different sites.

In a third case, a man-lift was operated close inside a structure to set some structural steel and somehow got stuck in the upward direction crushing an experienced man-lift operator to death. Later investigation showed that the dead man switch was defeated by duct tape. These cases, in retrospect, leave one wondering how these experienced personnel could have made these mistakes. Figure 4 is illustrative that experience alone is not always sufficient to protect you and to prevent accidents. These deviations from accepted safety practices (which I do not believe are unique in the industry) appear to involve personal underestimation of risk and/or an overestimation of one's ability to control the risk [3]. It should be remembered that no matter what our experience, knowledge, or abilities are, we are never too old to learn to do something stupid [15].

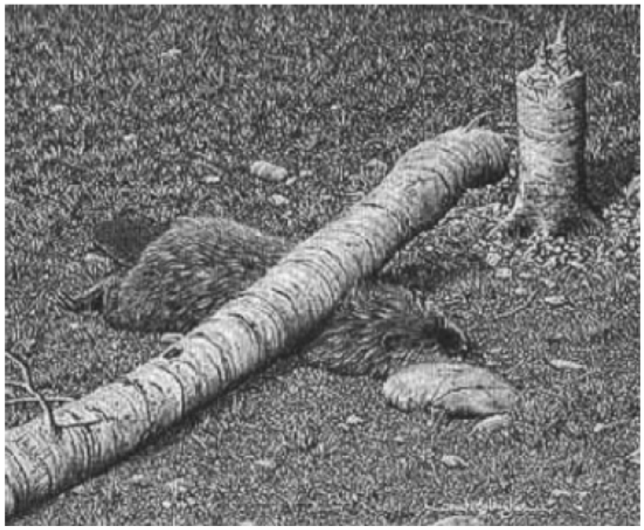

Figure 4 – Even the experienced can be wrong [18]

Invulnerability vs. Vulnerability

There is also a natural human failing for people to believe that bad things cannot happen to them. This may just be a natural extrapolation from past experience that nothing bad has happened so far or an inherent personality trait to overestimate our ability to control risk. We tend to be confident in our abilities to accomplish our work safely. This can be reinforced by personal history and successful deviations in the past. This can lead to a belief in our own personal invulnerability to accidents. While we believe theoretically that an accident can happen to us, we really don't believe it will happen. This overconfidence in achieving a successful deviation can be the cause of accidents. It is interesting that talking to people after an accident to someone else, the accident doesn't necessarily change the attitudes of people as the accident is brushed off as bad luck or an unfortunate event that won't happen to them (typically a function of distance from the accident). The safety effects of an accident or incident tend to decay with time unless reinforced.

A group form of invulnerability is the "Can't happen here" syndrome. I wonder how many times this refrain is heard or thought in process hazard analyses (PHA). Probably a lot as one of the common citations is incomplete or incorrect PHA. This may be historical based (complacency or even a bit of arrogance) or simply a failure of imagination, i.e. they can't imagine that bad things will happen to them.

On the other hand, vulnerability is the assumption that even though the situation seems the same, there is always the risk of harm when performing risky work or working in a risky environment. Both individuals and organization must have this vulnerability to the potential risk of work they perform or the risk of the process they work around to help insure safety in what they do.

Failure to Follow Procedures

Many accidents are the result of not following existing safety procedures. This is not an uncommon result from an accident investigation and many times the company refrain is if they had only followed the procedures none of this would have happened.

Some of this can be laid on individual propensity for risky behavior or to assume that rules do not apply to them. In hindsight, maybe the rationality we attribute naturally to people didn't actually exist at the time of the violation. In any case, it seems clear that from an individual perspective, there is some perceived benefit to the person doing the violation (excluding ignorance and stupidity), either in the positive or in relief of a negative. Looking from a benefit perspective may give insight into why procedural violations occur.

The other doorstep that this can be laid on is an organizational weakness of normalization of deviation; again there are benefits lurking somewhere. Failure to follow procedures as an organizational weakness may be explained if the safety culture has allowed deviation in the past (normalization) due to internal or external pressures, because it is convenient, a temporary benefit, or just plain sloppiness. Normalization of deviation can be an insidious weakness in that it doesn't typically happen overnight but rather over a period of time where the underlying implications may not be clear to everyone involved.

A Series of Seemingly Unfortunate Events

Accidents are seldom simple and most accidents have a number of elements that led to or facilitated the accident. When looking at individual elements probabilistically, multiplying probabilities together, it is hard to see how an accident could have occurred. A common refrain "That's double jeopardy and we don't have to consider that" is essential a qualitative probabilistic analysis. Yet we have cases of triple, quadruple, n-jeopardy occurring to cause accidents.

The author came to the conclusion some years back that many accidents were a combination of immediate events and unrecognized background conditions or enabling factors that were laying in wait that added up to an accident when combined. This is simply a matter of superimposition, i.e. events, factors, and conditions line up, which are added up to exceed a threshold which leads to an accident. This conceptual model is presented in Figure 5.

In Figure 5, the state of normal operation varies with operational demand and when you are operating closer to the normal operating limit, the more likely that you will exceed those limits. Human error is modeled as a combination of a pseudo-random human error potential and latent biases that make or facilitate a human to make an error. Latent organizational weaknesses are modeled as a pseudo random variation (local management and supervisory decisions) and a constant bias value for latent weaknesses that are lurking in the background waiting to come to bear. For example, a flaw in a procedure that could lead to an accident is a constant value whenever the procedure comes into play, however, the potential for human error and the state of the process in relation to the risk of the procedure flaw may vary. If there is a combination of events indicated in the model that can cause an accident, there is a statistical likelihood that that event will occur. The likelihood of an accident is a function of organizational weaknesses, individual and group performance levels and variances, and the level of operational risk. The more or stronger the organizational weaknesses, the poorer individual and group performance, and the more operational risk, the more likely that an accident will occur. In many cases, many of the factors that lead to an accident are already in place just waiting for an initiating cause and subsequent propagating events leading to an accident. So it is not a case of the stars and the moon lining up but rather conditions are lined up just waiting for one or more events to line up.

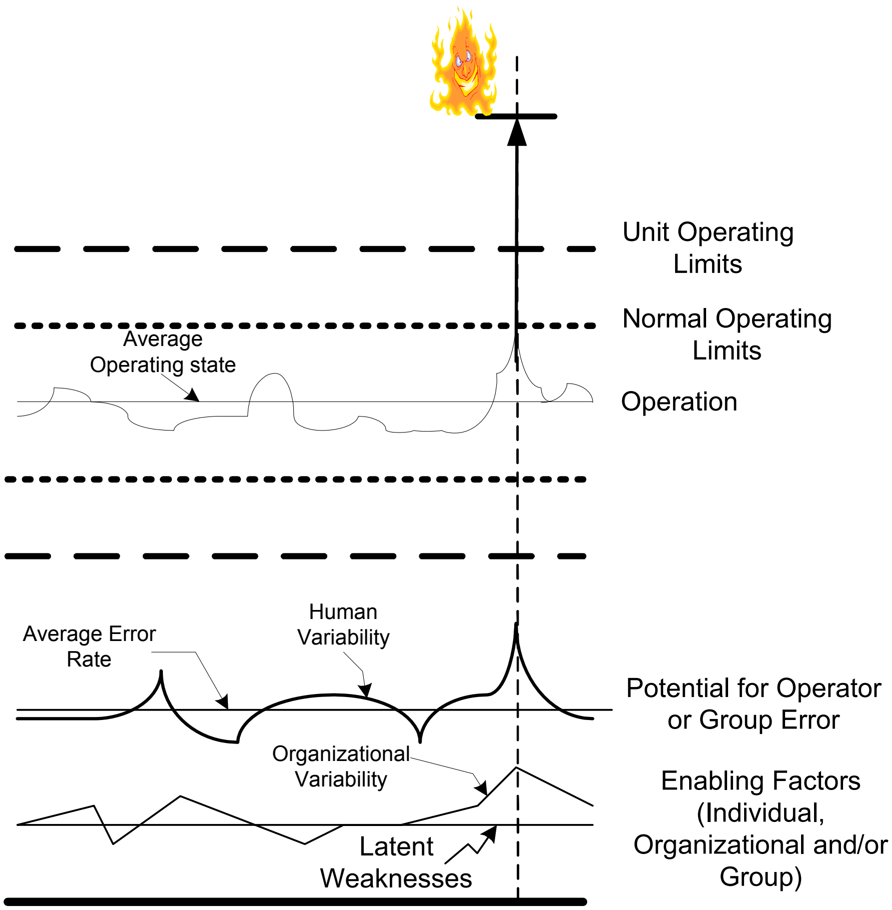

Figure 5 – Latent Organizational Weaknesses Chart

In looking at the model, it can be noted that there are some constant lines and variance around the lines. A constant line has in effect a probability of 1 to occur while the variance has some pseudo-randomness associated with it. From a probabilistic perspective, the failure to consider if the events are truly independent (needed for the multiplication work), i.e. suffer from a common underlying cause or element, or are latent where the probability is 1 when the latency is invoked can lead to an incorrect conclusion based on apparent probability. Latency can be insidious because we do not fear what we do not know.

Hollnagel proposed a similar concept called the functional resonance accident model and applied it to an aircraft navigation system [16]. He likened this issue to stochastic resonance of signal but without true randomness. In his model, normal is modeled as a varying signal (normal operation), while the environment (all that affects normal operation) was modeled as noise (many varying signals), which sometimes lined up as a natural system emergent property which led to a resonance condition (an accident). He goes on to propose an analysis method that analyzes functional entities and their coupling to reduce their “noise effect.”

These models lead to conclusion that to understand why an accident occurs, we must not only look at the sequential cause and effect and epidemiological (active and latent causes) accident models but to view accidents as phenomena that can happen in the context of a system. The author’s purpose was to conceptually model how multiple causes can line up to cause an accident and what useful information can be derived from the model. It seems clear that recognizing and reducing latent biases (organizational weaknesses) can improve safety but need to be viewed in the context of the whole rather than separated pieces. Reducing human and operational variability or improving system tolerance to variability also provides opportunities for improvement.

Conclusions

Concrete conclusion regarding the human element of accidents is hard to come by simply because we are placing complex human beings into increasing complex environments which in many cases require more performance from them than in times past. Since the days of Freud, psychologists have been trying to figure the innards of human beings with limited success. Yet within our operating environments, human beings represent a key to improving safety, not to place the blame on individuals but to look at the role human action in accidents, individually, in groups, in organizations, and in systems leading to improved safety for all.

It seems the more things change, the more things seem to stay the same. Technology has played a big part in the changes, but wherever technological “improvements” have been made, it seems like the problems solved just leads to new problems created by the solutions. While our cultural demographics have changed somewhat, the common elements are people and the artificial structures we create to manage our increasing complex affairs. Unfortunately, while people have memories (imperfect though they may be), the structures we create appear many times to be limited by the temporal memories of the people in the structures leading to less improvement than we would like.

The conceptual model in Figure 5 provides an explanation for the question of why things can line up to cause an accident. While some of the conclusions regarding the individual and organizational causes are not really new, it provides a graphical basis to discuss and to help attack the problem.

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