International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-6, August 2013

Study on Cognitive Approach to Human Error and its Application to Reduce the Accidents at Workplace

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Abstract—The err is in built in human nature. There are no specific counter measures for error. Human cognition uses processes that allow us to be amazingly fast, to respond flexibly to new situation [1] and to juggle several tasks at once (Flower and Hayes 1980). Unfortunately, these processes inevitably produce occasional errors. It is now well understood that these errors are the product of limitations in human information processing coupled with design features that are ill matched to human abilities. This is especially true for highly automated environments in which robust perceptual-motor tasks have been largely replaced by more error-prone cognitive tasks. The emerging model of cognition provides at least partial model of cognitive mechanism to understand the way human thinking works. The most effective way to deal with error due to human behavior and unpredictable environment is by safety culture and favorable system design.

***Index Terms—* Cognition, Human error, Safety culture, System design**

I. INTRODUCTION

The err is in built in human nature. Error themselves are not intrinsically bad. Indeed they are often highly adoptive as in trial and error learning or the serendipitous discovery that can rise from error [1]. There are no specific counter measures for error. Routed as it is in the human condition, fallibility cannot be eliminated but its adverse consequences can be moderated through target error techniques [2]. It has been estimated that up to 90% of all workplace accidents have human error as a cause [3]. There are theories that show why human error is so universe and constant. The human cognitive functions make the person fast and flexible but the thinking process itself is prone to some inevitable error. Human cognition uses processes that allow us to be amazingly fast, to respond flexibly to new situation [1] and to juggle several tasks at once (Flower and Hayes 1980). Unfortunately these processes inevitably produce occasional errors. To study the cognitive function many broad spectrum researches were done. Out of these, emerging model of cognition was the most widely accepted from Reason's 1990 genetic error-modelling system and Baars 1992b global workspace theory. This model is for overall cognition not only for error. It is agreed now that correct performance and errors follow from the same underlying cognitive process [1].

Manuscript published on 30 August 2013.
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II. MATERIALS AND METHOD

The available literature was searched on this topic extensively. Articles were procured and several web sites were consulted. The material was scanned thoroughly and the views of different authors were analyzed. Moreover in depth analysis was done on cognitive functions as applicable to human error and its application in modifying human error.

III. CRITICAL ANALYSIS

The cognition function of human mind is very complex system. We still do not understand it fully. Many researches have been done in this field but the most accepted theory till present time is the emerging model of cognition from Reason's 1990 genetic error-modelling system and Baars 1992b global workspace theory. This model explains the interaction between the human mind and environment. Hence this model helps in understanding the occurrence of human error.

A. The Emerging Model

Figure 1: Emerging Model of Cognition

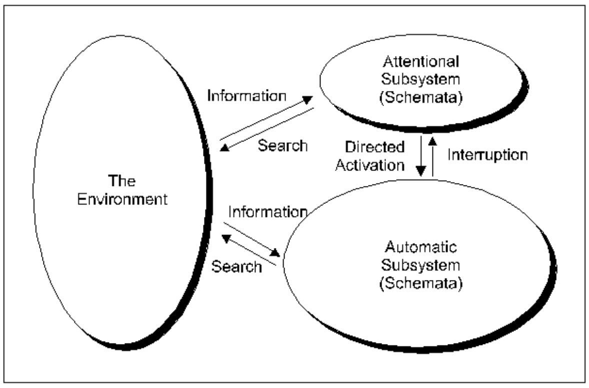

Figure 1, which illustrates the basic elements of this emerging model, is drawn from Reason's [1] Generic Error-Modelling System (GEMS) and Baars' [1992b] Global Workspace (GW) Theory.

Researchers now agree that both correct performance and errors follow from the same underlying cognitive processes [Reason, 1990, p. 36]. Human cognition uses processes that allow us to be amazingly fast [1], to respond flexibly to new situations [1], and to juggle several tasks at once [Flower & Hayes, 1980]. Unfortunately, these processes inevitably produce occasional errors.

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In most situations, the occasional errors produced by human cognitive processes rarely cause serious problems. In large spreadsheet models with thousands of cells, however, even a minuscule error rate can lead to disaster (Raymond R. Panko).

a. The Automatic Subsystem

Figure 1 shows that the model has three interacting subsystems. One is the automatic subsystem, which is characterized by cognition below the level of consciousness. A great deal of our everyday cognition occurs in the automatic subsystem.

The automatic subsystem is characterized by a great deal of parallel operation. For example, when we prepare to speak, we actually generate several competing plans [Baars, 1980]. We flesh them out in parallel with proper syntax, phonemics, and other aspects of speech. At some point during this process of development, we select a single utterance. Competition among competing plans is responsible for several types of errors that are incorrect in one or a few particulars but are highly lawful in other aspects of language. Because of parallelism, our automatic subsystem is extremely fast.

The automatic subsystem uses schemata [Bartlett, 1932; Neisser, 1976], which are organized collections of information and response patterns. When the proper conditions exist, a schema is activated. Each activated schema leads to specific response.

The automatic subsystem has an enormous pool of schemata to activate. There appear to be no known limits on schemata in long-term memory in terms of either their number or the duration of retention [1].

Reason [1] argues that there appear to be two core mechanisms for selecting schemata to be activated. The first is pattern matching. If the situation matches the activating criteria for a schema, that schema is activated. The second mechanism is frequency gambling [1]. This mechanism is required when there is no perfect match between the situation and a single schema or the normal process of selection between competing schemata is disrupted. In this case, the schema that has been activated the most frequently under similar conditions in the past will execute. Mostly, this frequency gambling will produce positive results but rarely will it result in errors. When frequency gambling fails, we get what Reason [1] called a strong but wrong error. We do something we have done many times before, rather than what we should do.

b. The Attentional Subsystem

The second subsystem in Figure 1 is the attentional subsystem [1]. The automatic subsystem is simple, relying largely on pattern recognition and frequency gambling. In contrast, the attentional system has powerful logical capabilities. Unfortunately, using the attentional mode is also "limited, sequential, slow, effortful, and difficult to sustain for more than brief periods [1]."

The resources of attentional subsystem are very limited. If we wish to memorize things, we can only remember about seven things [Miller, 1956]. If we are solving a logic problem, the resources we can allocate to memory are even more limited. These limitations can easily lead to errors in memory or logical analysis (Raymond Panko).

Even with logical attentional thinking, there appears to be schematic organization, just as there is in the automatic subsystem. In fact, it is likely that schemata in the attentional subsystem are really schemata from the automatic subsystem that rise to the attentional level [Baars, 1992b].

One aspect of schemata in the attentional subsystem is the reliance of people on "lay theories" (habitual informal theories) when they deal with technical areas such as physics [Furnham, 1988; Owen, 1986; Resnick, 1983]. Even after people receive training in specific areas, such as physics, they often revert to lay theories afterward [Resnick, 1983]. Lay theories are schemata that we have developed over many years. They are very likely to produce errors when we model situations.

c. The Environment

The third subsystem in Figure 1 is the environment. Human cognition is not merely internal. It is situated in the environment surrounding it. Neisser [1976] argued that schemata direct our exploration of the environment. Exploration samples specific aspects of the vast information surrounding us. This, in turn, modifies our schemata.

d. Interaction between subsystems and environment

The attentional subsystem holds goals. These goals influence the activation of automatic subsystem nodes and so at least partially control the automatic subsystem. If the attentional subsystem loses its goal, the entire cognitive system is likely to err. Baars [1992b] calls this aspect of the attentional subsystem the Global Workspace, after artificial intelligence theories.

The automatic subsystem can also take initiate action. If there is an error, for instance, the automatic subsystem can interrupt the attentional subsystem and demand attention [49]. In this way, a schema in the automatic subsystem can influence or even grab control of the Global Workspace, so that it can influence the activation of other schemata.

Sellen and Norman [1992] emphasize that the interaction with the environment takes place continuously as we plan and execute an action. First, we form a high-level intention. When we execute it, we constantly adjust our action through feedback with the environment. This adjustment takes place without burdening our limited attentional system in most cases.

e. Error Correction and Error Rates

The way human cognition operates, errors are inevitable. This makes the detection and correction of errors critical. Several studies have used protocol analysis to observe how people do cognitive work. In this technique, the subject voices what he or she is thinking during the process. Wood [37] used this technique to study statistical problem solving. Hayes and Flower [1980] used protocol analysis to study writing. Both studies found that as subjects worked, they frequently stopped to check for errors. In some cases, the error detection happened immediately after an error or the suspicion of an error. In other cases, it was done systematically. Kellog [1994] describes several studies that measured time spent in writing. These studies found that about a fifth of all writing time is spent in reviewing what we have already written.

Although the emerging model of human error is compelling and fits a broad spectrum of research in a qualitative fashion, it cannot, at this stage, predict error commission rates or error correction rates. Error rates are still a matter for empiricism.

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Most of the error rates are for mechanical errors. A good general figure for mechanical error rates appears to be about 0.5%.

f. Limitations of human behavior

The modern working environment is very different to the settings that humans have evolved to deal with. This exposes the limitations of humans to interact with the working environment. These limitations include:

Attention - the modern workplace can ‘overload’ human attention with enormous amounts of information, far in excess of that encountered in the natural world. The way in which we learn information can help reduce demands on our attention, but can sometimes create further problems (e.g. the Automatic Warning System on UK trains).

Perception - in order to interact safely with the world, we must correctly perceive it and the dangers it holds. Work environments often challenge human perception systems and information can be misinterpreted.

Memory - our capacity for remembering things and the methods we impose upon ourselves to access information often put undue pressure on us. Increasing knowledge about a subject or process allows us to retain more information relating to it.

Logical reasoning - failures in reasoning and decision making can have severe implications for complex systems such as chemical plants, and for tasks like maintenance and planning.

B. Classifying Human Failures

Two kinds of categorization are used: a classification by consequences, and a classification by psychological origins. In our study, psychological classification will be highlighted which focus upon the mental antecedents of the error. Three distinctions are important.

1) Slips and lapses versus mistakes
2) Errors versus violations
3) Active versus latent failures

1) Slips and lapses versus mistakes

All errors involve some kind of deviation. There are basically two ways in which this failure can occur:

The plan is adequate but the associated actions do not go as intended. These are failures of execution and are commonly termed slips and lapses. Slips relate to observable actions and are associated with attentional failures. Lapses are more internal events and relate to failures of memory.

The actions may go entirely as planned but the plan is inadequate to achieve its intended outcome. These are failures of intention, termed mistakes.

Slips and lapses:

In the case of slips, lapses, and fumbles, actions deviate from the current intention. Here, the failure occurs at the level of execution.

Slips and lapses occur during the largely automatic performance of some routine task, usually in familiar surroundings. They are almost invariably associated with some form of attentional capture, either distraction from the immediate surroundings or preoccupation. They are also provoked by change, either in the current plan of action or in the immediate surroundings [1].

Mistakes:

In the case of mistakes, the actions may go entirely as planned, but the plan itself deviates from some adequate path towards its intended goal. Here, the failure lies at a higher level: with the mental processes involved in planning, formulating intentions, judging and problem solving.

Mistakes can begin to occur once a problem has been detected. A problem is anything that requires a change or alteration of the plan. Mistakes can be further subdivided into two categories: rule-based mistakes and knowledge based mistakes.

Rule-based mistakes:

These occur in relation to familiar or trained-for problems. We are extremely good at making rapid and largely automatic assessments of complex situations based upon matching features of the world to patterns stored in long term memory. But this process can go wrong in two ways. We can misapply a good rule (i.e. one that is frequently applicable) because we fail to notice the contraindications or we can apply a bad rule that has remained uncorrected in our stored repertoire of problem solutions.

Knowledge-based mistakes:

These occur when the person encounters a novel situation that lies outside the range of his or her stock of pre-packaged problem solving routines. Under these conditions, persons are forced to resort to slow, effortful, online reasoning. This process is extremely error prone for several reasons. First, our capacity for conscious thought is highly resource limited; we can only attend to and manipulate one or two discrete items at any one time. Second, we have to rely upon a mental model (attentional subsystem) of the current situation that is nearly always incomplete and, in parts, incorrect. Third, we have a marked tendency in these circumstances to ‘‘fixate’’ upon a particular hunch or hypothesis and then select features of the world to support it, while neglecting contradictory evidence. This has been called ‘‘confirmation bias’’ or ‘‘cognitive lock-up’’ and has been frequently observed in nuclear power plant operators and others during attempts to recover from an emergency [37].

2) Errors versus violations

Violations are deviations from safe operating practices, procedures, standards or rules. Such deviations can either be deliberate or erroneous (e.g. speeding without being aware of either the speed or the restriction). However, we are mostly interested in deliberate violations, where the actions (though not the possible bad consequences) were intended. Deliberate violations differ from errors in a number of important ways.

Whereas errors arise primarily from informational problems (forgetting, inattention, incomplete knowledge, etc), violations are more generally associated with motivational problems (low morale, poor supervisory examples, perceived lack of concern, the failure to reward compliance and sanction non-compliance, etc).

Errors can be explained by what goes on in the mind of an individual, but violations occur in a regulated social context.

Errors can be reduced by improving the quality and delivery of the necessary information within the workplace. Violations generally require motivational and organisational remedies.

3) Active versus latent failures

Active failures are unsafe acts (errors and violations) committed by those at the ‘‘sharp end’’ of the system (e.g. anesthetists, surgeons, nurses). They are the people whose actions can have immediate adverse consequences.

Latent failures are created as the result of decisions taken at the higher echelons of the organization.

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Their damaging consequences may lie dormant for a long time, only becoming evident when they combine with active failures and local triggering factors to breach the system's many defences. This classification was given by The Human Factors Analysis and Classification System (HFACS).

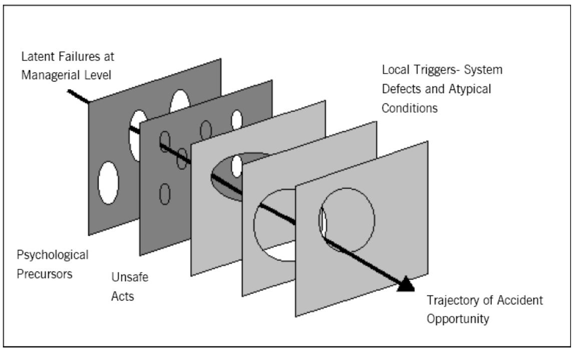
The Human Factors Analysis and Classification System (HFACS) was developed initially as a framework to understand "human error" as a cause of aviation accidents (Shappell and Wiegmann, 2000; Wiegmann and Shappell, 2003). It is based on James Reason's Swiss cheese model of human error in complex systems. HFACS distinguishes between the "active failures" of unsafe acts, and "latent failures" of preconditions for unsafe acts, unsafe supervision, and organizational influences.

Unsafe acts are performed by the human operator "on the front line" (e.g., the pilot, the air traffic controller, the driver). Unsafe acts can be either errors (in perception, decision making or skill-based performance) or violations (routine or exceptional). There are two types of preconditions for unsafe acts: those that relate to the human operator's internal state and those that relate to the human operator's practices or ways of working. Adverse internal states include those related to physiology (e.g., illness) and mental state (e.g., mentally fatigued, distracted). A third aspect of 'internal state' is really a mismatch between the operator's ability and the task demands; for example, the operator may be unable to make visual judgments or react quickly enough to support the task at hand. Poor operator practices are another type of precondition for unsafe acts.

Four types of unsafe supervision are: inadequate supervision; Planned inappropriate operations; Failure to correct a known problem; and Supervisory violations.

Organizational influences include those related to resources management (e.g., inadequate human or financial resources), organizational climate (structures, policies, and culture), and organizational processes (such as procedures, schedules, oversight).

The Swiss cheese model of accident causation



The figure shows a trajectory of accident opportunity and its penetration through several types of defensive system. The combined chances of an accident occurring are very small, as the holes in the various defence systems must all line up. Some are active failures of human or mechanical performance, and others are latent conditions, such as management factors or poor system design. However, it is clear that if steps are taken in each case to reduce the defensive gaps, the overall chance of accident will be greatly reduced [59].

C. Application of cognitive approach in accident/incident reduction at work environment

This is a part of error management, which is most difficult to implement. Changing the way of thinking of a person is not a single object exercise. So we cannot change the human condition, but we can change the conditions under which humans work.

In most safety-critical industries, a number of checks and controls are in place to minimise the chance of errors occurring. For a disaster to occur there must be a conjunction of oversights and errors across all the different levels within an organisation. From the Swiss Cheese Model it is clear that the chances of an accident occurring can be made smaller by narrowing the windows of accident opportunity at each stage of the process. Factors such as training and competence assurance, management of fatigue-induced errors and control of workload can eliminate some errors. But errors caused by human limitations and/or environmental unpredictability are best reduced through improving system interface design and safety culture. Hence safety culture and system design are the most important error management tools to combat human error and address cognition changes in humans.

D. Safety Culture

Attribution of accidents to human failures at the 'sharp end' of an industry may not provide a full picture of all the factors involved. The management of the organisation must also take responsibility for decisions, which affect the safe functioning of the organisation as a whole (Health and Safety Executive 1999). Unwise decisions at this level are more difficult to link directly to an accident, as they are often implemented well before an accident occurs, and they do not make their presence urgently felt. Good decisions at this level can create a culture of safety, which can remove the precursor conditions for accidents or ameliorate their consequences.

Safety Culture is a term that was first introduced after the Chernobyl disaster in 1986. The safety culture of an organization is the product of the individual and group that determine the style and proficiency of an organization's health and safety programmes. A positive safety culture is one in which shared perceptions of the importance of safety and confidence in preventative measures are experienced by all levels of an organization. According to the Health and Safety Executive (HSE, the statutory body that ensures that risks to health and safety from work activities are properly controlled), factors that create this positive culture include:

- leadership and the commitment of the chief executive;
- a good line management system for managing safety;
- the involvement of all employees;
- effective communication and understood/agreed goals;
- good organizational learning/responsiveness to change;
- manifest attention to workplace safety and health;
- a questioning attitude and rigorous and prudent approach by all individuals.

Trust is a key element of a reporting culture and this, in turn, requires the existence of a just culture—one possessing a collective understanding of where the line should be drawn between blameless and blameworthy actions.

E. System design

A good system should not allow people to make mistakes easily. The common system design is carried out in the absence of feedback from its potential users, which increases the chance that the users will not be able to interact correctly with the system.

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A set of design principles has been proposed [21] which can minimize the potential for error. These principles are as below:

a. Accurate mental models

There is often a discrepancy between the state of a system and the user's mental model of it. This common cause of erroneous behaviour arises because the user's model of the system and the system itself will differ to some extent, since the user is rarely the designer of the system. Designers need to exploit the natural mappings between the system and the expectations and intentions of the user.

b. Managing information

As our brains are easily distracted and can overlook necessary tasks, it makes sense to put information in the environment, which will help us, carry out complex tasks. When under time pressure, technicians are likely to forget to perform tasks such as replacing nuts and bolts. A very simple solution to this problem would be to require technicians to carry a hand-held computer with an interactive maintenance checklist, which specifically required the technician to acknowledge that certain stages of the job had been completed. It could also provide information on task specifications if necessary. This would also allow a reduction in paperwork and hence in time pressure.

c. Reducing complexity

Making the structure of tasks as simple as possible can avoid overloading the psychological processes outlined previously. The more complex the task specifications, the more chances are for human error.

d. Visibility

The user must be able to perceive what actions are possible in a system and furthermore, what actions are desirable. This reduces demands on mental resources in choosing between a range of possible actions. Perhaps even more important is good quality feedback, which allows users to judge how effective their actions have been and what new state the system is in as a result of those actions.

e. Constraining behavior

If a system could prevent a user from performing any action, which could be dangerous, then no accidents would occur. However, the real world offers too complex an environment for such a simplistic solution: in an industrial operation, a procedure, which could be beneficial at one stage in the process, may be disastrous at another. Nevertheless, it is possible to reduce human error by careful application of 'forcing functions' by setting one step after the other.

f. Design for errors

In safety-critical systems, such as nuclear power plants, numerous safety systems are in place which can mitigate accidents. One approach is 'defense in depth' (implementing many independent systems simultaneously); another is 'fail-to safe state' system design. However, designers must assume that mistakes will occur, and so any useful system must make provision for recovery from these errors. Another consideration is that the design should make it difficult to enact non-reversible actions. Although this is an underlying principle of design, it needs to be applied carefully.

g. Standardization

When systems are necessarily complex but have been made as accessible and easy to use as possible and errors are still being made, then standardization is sometimes used as an attempt to make the situation predictable.

One problem with standardization is that if any advances in design or usage are made, then it is a very costly process to re-implement standardization across all departments of an industry. Also, a standardized system may be ideal for one set of tasks, but very inefficient for another set. Such practical considerations have tended to limit the application of standardization as an approach for reducing human errors.

h. User-centered design

Another basic principal of design is that it should be centred around the user at all stages from initial conception, through evolution and testing, to implementation. In practice however, systems designers are often given a brief, create the system and impose it upon the users without appropriate feedback. This can result in unexpected system behavior and over-reliance on manuals which themselves have been written by the system designers from their own perspective. Systems designed in this way will be opaque to the end user, and this can hinder effective interaction.

IV. DISCUSSION

Human error is the causal or contributing factor in the majority of accidents. It is now well understood that these errors are the product of limitations in human information processing coupled with design features that are ill matched to human abilities. This is especially true for highly automated environments in which robust perceptual-motor tasks have been largely replaced by more error-prone cognitive tasks. Attempts to reduce human error by improved design have met with only partial success, in part because the complexity of human cognitive behaviour has proven an obstacle to a useful theory of how errors are generated.

The complexity of human cognition makes it difficult to measure and quantify important aspects of human behaviour because of the variability inherent in complex performance. Improved understanding of how limitations in cognitive processing contribute to human error would facilitate the design of error tolerant (or error resistant) systems. Instances of error often reflect failures of executive control that result from limitations in human information processing. Failures of executive control lead to identifiable classes of memory errors, such as failures to remember intended actions (prospective memory failures), and habit capture error. Failures of executive control are also associated with failures in routine monitoring, where observers will fixate an information source but not apply the executive control needed to process the information.

In current theories of human cognition, executive control is associated with limited-capacity attention-demanding mental processing. Common cognitive acts such as fetching items from memory, reading text, solving problems, etc., require executive control, in contrast to early perceptual processes and low-level motor behaviours whose processing is independent of executive control. A better understanding of the relationship between executive control and the more autonomous information gathering and motor behaviours would lead to significant advances in our understanding of human error.

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The cognitive variables of most interest are not directly observable. This has made it difficult to relate theory to complex applications domains where measurement techniques are too crude for the required inferences.

The emerging model of cognition provides at least partial model of cognitive mechanism to understand the way human thinking works. Human Error has been cited as a cause or contributing factor in many major disasters and accidents. It is also important to stress that "human error" mechanisms are the same as "human performance" mechanisms; performance later categorized as 'error' is done in hindsight (Reason, 1991; Woods, 1990). Human error is part of the ordinary spectrum of behavior. Recently, human error has been re-conceptualized as resiliency to emphasize the positive aspects that humans bring to the operation of technical systems [39] (Woods and Leveson, 2006).

The most effective way to deal with error due to human behaviour and unpredictable environment is by safety culture and favourable system design.

The definition of safety culture suggested by the Health and Safety Commission is: "The safety culture of an organization is the product of the individual and group values, attitudes, competencies and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety programmes. Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety, and by confidence in the efficacy of preventative measures."

A positive safety culture implies that the whole is more than the sum of the parts. The different aspects interact together to give added effect in a collective commitment. In a negative safety culture the opposite is the case, with the commitment of some individuals strangled by the cynicism of others. From various studies it is clear that certain factors appear to characterise organisations with a positive safety culture. These factors include:

- The importance of leadership and the commitment of the chief executive
- The executive safety role of line management
- The involvement of all employees
- Effective communications and commonly understood and agreed goals
- Good organisational learning and responsiveness to change
- Manifest attention to workplace safety and health
- A questioning attitude and a rigorous and prudent approach by all individuals

System design is also very effective in creating environment where chances of error are reduced. The factors taken are already explained in details above and are:

- Accurate mental models
- Managing information
- Reducing complexity
- Visibility
- Constraining behavior
- Design for errors
- Standardization
- User-centred design

Designing for human error is a major challenge for developers of safety-critical and mission-critical systems. Most approaches to error-tolerant design use either general design guidelines or treat humans as just another error-prone system component. Hence, cognition approach to human error highlights the need to recognize the human as a thinking individual than as an error-prone system component.

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