Poznan University of Technology

FACULTY OF MACHINES AND TRANSPORTATION

Methods used to model human error from the point of view of ergonomics

Under the supervision of

Dr. Inż. Marcin Butlewski

Student Name

Abdulmuttalib A. MUHSEN, M.Sc. (Eng.)

Poznan 2017

TABLE OF CONTENTS:

LIST OF FIGURES:

1 HUMAN ERROR

1.1 INTRODUCTION

Human error can simply be described as an error made by a human. But it gets a little more complicated than that. People make mistakes. But why they make mistakes is important. With that in mind, human error is when a person makes a mistake because that person made a mistake. As opposed to being confused or influenced by other factors of the design. It is also known as Operator Error.

Human error is an important concept in ergonomics, but it is mainly referred to in context.

It is a possible answer to the questions: "What caused the accident?" or "How did it break?" That does not mean that the vase broke because of human error. However, when you are evaluating a mishap from a piece of equipment or a system then the cause may be human error. It may also be incorrect installation or a manufacturing defect or a slew of other possibilities.

There is an old episode of I Love Lucy where Lucy gets a job working on an assembly line boxing candies. The line is moving too fast for her to keep up and madcap comic romps ensure. The breakdown in the system was not mechanical but human error.

Human error is typically called into being during an accident or mishap investigation such as a car crash, house fire or a problem with a consumer product leading to a recall. Usually, it is associated with a negative happening. In industrial operations, something called an unintended consequence may occur.

This may not necessarily be bad, just unexplained. In addition, investigation may conclude that the equipment or system design is fine but the human component messed up.

The legend of Ivory soap is an example of positive unintended consequences due to human error. Back in the late 1800's Proctor and Gamble were manufacturing their new White Soap with hope to compete in the fine soap market.

One day a line worker left the soap mixing machine on while he went to lunch. When he got back from lunch the soap was extra frothy having incorporated more air than normal into it. They sent the mixture down the line and turned it into bars of soap. Soon Proctor and Gamble were inundated with requests for the soap that floats. They investigated, found the human error, and incorporated it into their product Ivory soap which is still selling well over a century later. (Note-recent research by proctor and Gamble suggests that the soap was actually invented by one of their chemists, but the legendary example still illustrates the human error point)

From a design perspective, the engineer or designer produces a piece of equipment or a system with intentions to function in a certain way. When it doesn't function that way (it breaks, catches on fire, messes up its output or is befallen of some other mishap) they try to find the root cause.

Typically, the cause can be identified as a:

- design deficiency - when the mechanical, electrical or other components of the design have a problem that caused the mishap
- equipment malfunction - when the machine operated incorrectly
- manufacturing defect - when the material or assembly has an issue that causes it to fail
- environmental hazard - when an outside factor such as the weather causes the hazardous condition
- human error - when a person did something wrong

If we look at watching TV as a system, we can give examples for all of these types of errors that would lead to the TV not working. If there is not a power button on the set itself, it is a design deficiency. If the channel scanner can't pick up the channels because of a software glitch it is a malfunction. If the screen won't light up because of a short, it is a manufacturing defect. If the set gets struck by lightning it is an environmental hazard. If you lose the remote in the couch cushions it is human error.

"That's all well and good," you say, "But what constitutes human error?" I am glad you asked. To better analyse the mishap and better understand the human error we have to quantify it.

Human error is more specific than just making a mistake.

1.2 HUMAN ERROR INCLUDES:

- Failing to perform or omitting a task
- Performing the task incorrectly
- Performing an extra or non-required task
- Performing tasks out of sequence
- Failing to perform the task within the time limit associated with it
- Failing to respond adequately to a contingency

To continue with our TV example if you omit pressing the power button the TV will not come on and its human error. If you press power on the remote with it facing backwards you have performed the task incorrectly. Pressing the power button twice is an extra task and no TV. If you try to turn it on before you plug it in you are going out of sequence. If you have an old plasma TV and you move it laying down, if you turn it on without letting it sit upright for a while to redistribute the gasses you can actually blow it up by going out of sequence. If you do not pay your cable bill on time, you've failed to act within the allotted time and, again, no TV. Furthermore, if you do not tackle the cable guy when he comes to disconnect it you've failed to react adequately to a contingency.

Human error may be identified as the cause when the root cause is actually something else on the list. If a switch malfunctions when the operator uses it that is not human error, it is a malfunction. While there are some things that contribute to human error, design deficiencies are often misdiagnosed as human errors as well. There is an ongoing debate between ergonomically centered designers and engineering minded designers about human error and design deficiency. On one side is the belief that almost all human error is related to design deficiency because a good design should take into account human behaviour and design out those possibilities while on the other side they believe people make mistakes and no matter what you give them they will find a way to break them.

1.3 CLASSIFICATION OF HUMAN ERRORS

The term 'human error' is wide and can include a great variety of human behavior. Therefore, in attempting to define human error, different classification systems have been developed to describe their nature. Identifying why these errors occur will ultimately assist in reducing the likelihood of such errors occurring.

The distinction between the hands on 'operator' errors and those made by other aspects of the organization have been described by as 'active' and 'latent' failures.

Active Failures have an immediate consequence and are usually made by front-line people such as drivers, control room and machine operators. These immediately preceed, and are the direct cause, of the accident.

Latent failures are those aspects of the organization which can immediately predispose active failures. Common examples of latent failures include:

- Poor design of plant and equipment;
- Ineffective training;
- Inadequate supervision;
- Ineffective communications; and
- Uncertainties in roles and responsibilities.

Latent failures are crucially important to accident prevention for two reasons:

1. If they are not resolved, the probability of repeat (or similar) accidents remains high regardless of what other action is taken;

2. As one latent failure often influences several potential errors, removing latent failures can be a very cost-effective route to accident prevention.

1.3.1 Classifying Active Failures

In his classification of active failures distinguishes between intentional and unintentional error. Intentional errors are described as violations, whilst unintentional errors are classified as either slips/lapses or mistakes. These types of human failure are shown in the Fig.1.1 below:

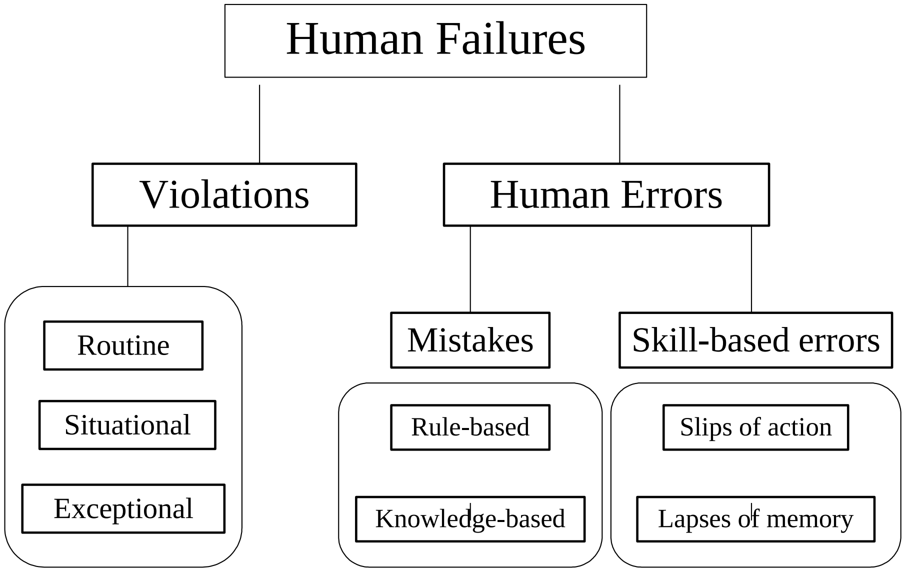


Fig.1.1-Human Failures

Slips and Lapses: These occur in routine tasks with operators who know the process well and are experienced in their work:

- They are action errors which occur whilst the task is being carried out;

- They often involved missing a step out of a sequence or getting steps in the wrong order and frequently arise from a lapse of attention;

- Operating the wrong control through a lapse in attention or accidentally selecting the wrong gear are typical examples.

Mistakes: These are inadvertent errors and occur when the elements of a task are being considered by the operator.

They are decisions that are subsequently found to be wrong, although at the time the operator would have believed them to be correct. There are two types of 'mistake', rule based and knowledge based:

- Rule based mistakes occur when the operation in hand is governed by a series of rules. The error occurs when an in appropriate action is tied to a particular event

- Knowledge based errors occur in entirely novel situations when you are beyond your skills, beyond the provision of the rules and you have to rely entirely on adapting your basic knowledge and experience to deal with a new problem.

Violations are any deliberate deviation from the rules, procedures, instructions and regulations, which are deemed necessary for the safe or efficient operation and maintenance of plant or equipment. Breaches in these rules could be accidental/unintentional or deliberate.

Violations occur for many reasons and are seldom willful acts of sabotage or vandalism. The majority stem from a genuine desire to perform work satisfactorily given the constraints and expectations that exist. Violations are divided into three categories: routine, situational and exceptional.

Routine Violations are ones where breaking the rule or procedure has become the normal way of working. The violating behavior is normally automatic and unconscious, but the violation is recognised as such, by the individual(s) if questioned. This can be due to cutting corners, saving time. or be due to a belief that the rules are no longer applicable.

Situational Violations occur because of limitations in the employee's immediate workspace or environment. These include the design and condition of the work area, time pressure, number of staff, supervision, equipment availability, and design and factors outside the organizations control, such as weather and time of day. These violations often occur when a rule is impossible or extremely difficult to work to in a situation.

Exceptional Violations are violations that are rare and happen only in particular circumstances, often when something goes wrong. They occur to a large extent at the knowledge-based level. The individual in attempting to solve a novel problem, violates a rule to achieve the desired goal.

Latent Failures

Latent failures are the factors or circumstances within an organization which increase the likelihood of active failures. Consider some examples of latent failures in relation to the example accidents given earlier.

Attitudes to Safety: The safety culture of an organisation is established, in part, by the attitudes to safety shown by management and supervisory staff. Unless managers lead by example and visibly demonstrate their commitment to safety, no amount of hard work in the preparation and establishment of rules and procedures and in providing training will have any lasting effect.

Rules & Procedures: Rules and procedures provide the framework upon which safety assurance is built and are claimed to be effective control measures. However, this is little more than an assumption rather than a proven reality. Studies have shown that safety rules and procedures are often:

- Written negatively, concentrating on should not be done rather than on what should be done;
- Impractical;
- In conflict with other rules

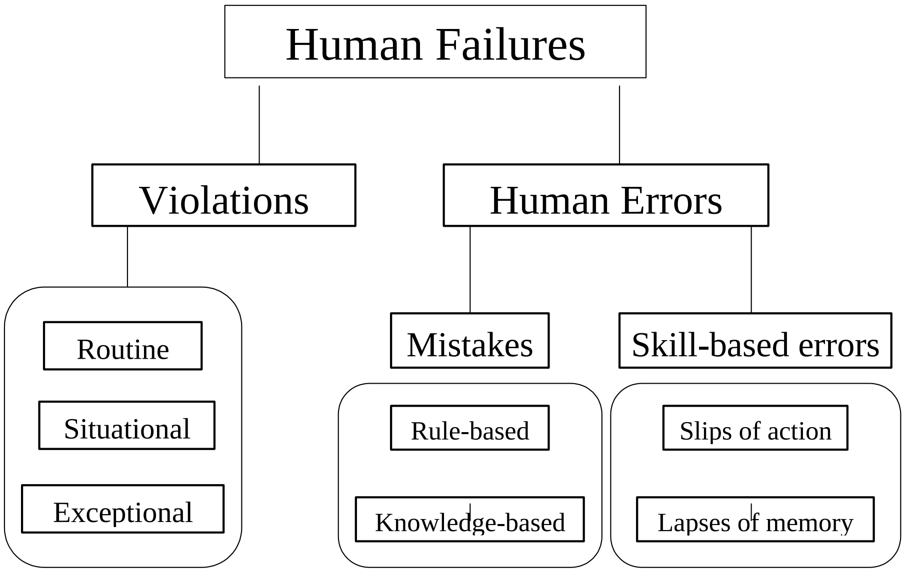
Training: Within training programmes, little consideration is given to evaluating its effectiveness. It cannot be assumed that by simply attending a training course means that one is adequately trained. Other common problems with training programmes include:

- Hazard awareness is often assumed rather than training;
- Training should concentrate on what is safe, rather than unsafe, what to do, rather than what not to do.
- Training is not always consistent with the rules and procedures.

Equipment design & Maintenance: limitations in the standard of ergonomics applied to the design of the equipment/plant increase the risk of human error. Whilst it is usual to associate design limitations with unintentional errors, i.e. slips & mistakes, poor designs also create a strong motivation for operators to violate safe working procedures.

1.4 STRATEGIES FOR REDUCING HUMAN ERROR

Reducing human error involves far more than taking disciplinary action against an individual. There are a range of measures which are more effective controls including the design of the equipment, job, procedures and training.



1.4.1 Actions for overcoming Active Failures

1.4.1.1 Slips and Lapses

Design improvement is the most effective route for eliminating the cause of this type of human error. For example, typical problems with controls and displays that cause this type of error include:

- Switches which are too close and can be inadvertently switched on or off;
- Displays which force the user to bend or stretch to read them properly;
- Critical displays not in the operators field of view;
- Poorly designed gauges;
- Displays which are cluttered with non-essential information and are difficult to read.

1.4.1.2 Mistakes

Training, for individuals and teams, is the most effective way for reducing mistake type human errors. The risk of this type of human error will be decreased if the trainee understands the need for and benefits from safe plans and actions rather than simply being able to recite the steps parrot fashion. Training should be based on defined training needs and objectives, and it should be evaluated to see if it has had the desired improvement in performance.

1.4.1.3 Violations

There is no single best avenue for reducing the potential for deliberate deviations from safe rules and procedures. The avenues for reducing the probability of violations should be considered in terms of those which reduce an individual's motivation to violate. These include:

- Under-estimation of the risk
- Real or perceived pressure from the boss t adopt poor work practices;
- Pressure from workmates to adopt their poor working practices;
- Cutting corners to save time and effort

1.4.1.4 Addressing Latent Failures

The organisation must create an environment which:

- reduces the benefit to an individual from violating rules.
- Reduces the risk of an operator making slips/lapses and mistakes.

This can be done by identifying and addressing latent failures.

Examples of latent failures include:

- Poor design of plant and equipment;
- Impractical procedures,
- Ineffective training;
- Inadequate supervision;
- Ineffective communications; and
- Uncertainties in roles and responsibilities.

2 HUMAN ERROR MODELS AND MANAGEMENT

The human error problem can be viewed in two ways: the person approach and the system approach. Each has its model of error causation and each model gives rise to quite different philosophies of error management. Understanding these differences has important practical implications for coping with the present risk of mishaps in clinical practice.

2.1 SUMMARY POINTS

- Two approaches to the problem of human fallibility exist: the person and the system approaches
- The person approach focuses on the errors of individuals, blaming them for forgetfulness, inattention, or moral weakness
- The system approach concentrates on the conditions under which individuals work and tries to build defences to avert errors or mitigate their effects
- High reliability organisations-which have less than their fair share of accidents-recognise that human variability is a force to harness in averting errors, but they work hard to focus that variability and are constantly preoccupied with the possibility of failure.

2.2 PERSON APPROACH

The longstanding and widespread tradition of the person approach focuses on the unsafe acts-errors and procedural violations-of people at the sharp end: nurses, physicians, surgeons, anaesthetists, pharmacists, and the like. It views these unsafe acts as arising primarily from aberrant mental processes such as forgetfulness, inattention, poor motivation, carelessness, negligence, and recklessness. Naturally enough, the associated countermeasures are directed mainly at reducing unwanted variability in human behavior. These methods include poster campaigns that appeal to people's sense of fear, writing another procedure (or adding to existing ones), disciplinary measures, threat of litigation, retraining, naming, blaming, and shaming. Followers of this approach tend to treat errors as moral issues, assuming that bad things happen to bad people-what psychologists have called the just world hypothesis.

2.3 SYSTEM APPROACH

The basic premise in the system approach is that humans are fallible and errors are to be expected, even in the best organisations. Errors are seen as consequences rather than causes, having their origins not so much in the perversity of human nature as in "upstream" systemic factors. These include recurrent error traps in the workplace and the organisational processes that give rise to them. Countermeasures are based on the assumption that though we cannot change the human condition, we can change the conditions under which humans work. A central idea is that of system defences. All hazardous technologies possess barriers and safeguards. When an adverse event occurs, the important issue is not who blundered, but how and why the defences failed.

2.4 EVALUATING THE PERSON APPROACH

The person approach remains the dominant tradition in medicine, as elsewhere. From some perspectives it has much to commend it. Blaming individuals is emotionally more satisfying than targeting institutions. People are viewed as free agents capable of choosing between safe and unsafe modes of behaviour. If something goes wrong, it seems obvious that an individual (or group of individuals) must have been responsible. Seeking as far as possible to uncouple a person's unsafe acts from any institutional responsibility is clearly in the interests of managers. It is also legally more convenient, at least in Britain.

Nevertheless, the person approach has serious shortcomings and is ill suited to the medical domain. Indeed, continued adherence to this approach is likely to thwart the development of safer healthcare institutions.

Although some unsafe acts in any sphere are egregious, the vast majority are not. In aviation maintenance-a hands-on activity similar to medical practice in many respects-some 90% of quality lapses were judged as blameless. Effective risk management depends crucially on establishing a reporting culture. Without a detailed analysis of mishaps, incidents, near misses, and “free lessons,” we have no way of uncovering recurrent error traps or of knowing where the “edge” is until we fall over it. The complete absence of such a reporting culture within the Soviet Union contributed crucially to the Chernobyl disaster. 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. Engineering a just culture is an essential early step in creating a safe culture.

Another serious weakness of the person approach is that by focusing on the individual origins of error it isolates unsafe acts from their system context. As a result, two important features of human error tend to be overlooked. Firstly, it is often the best people who make the worst mistakes-error is not the monopoly of an unfortunate few. Secondly, far from being random, mishaps tend to fall into recurrent patterns. The same set of circumstances can provoke similar errors, regardless of the people involved. The pursuit of greater safety is seriously impeded by an approach that does not seek out and remove the error provoking properties within the system at large.

2.5 ERROR MANAGEMENT

Over the past decade researchers into human factors have been increasingly concerned with developing the tools for managing unsafe acts. Error management has two components: limiting the incidence of dangerous errors and-since this will never be wholly effective-creating systems that are better able to tolerate the occurrence of errors and contain their damaging effects. Whereas followers of the person approach direct most of their management resources at trying to make individuals less fallible or wayward, adherents of the system approach strive for a comprehensive management programme aimed at several different targets: the person, the team, the task, the workplace, and the institution as a whole.

High reliability organisations-systems operating in hazardous conditions that have fewer than their fair share of adverse events-offer important models for what constitutes a resilient system. Such a system has intrinsic “safety health”; it is able to withstand its operational dangers and yet still achieve its objectives.

2.6 SOME PARADOXES OF HIGH RELIABILITY

Just as medicine understands more about disease than health, so the safety sciences know more about what causes adverse events than about how they can best be avoided. Over the past 15 years or so, a group of social scientists based mainly at Berkeley and the University of Michigan has sought to redress this imbalance by studying safety successes in organisations rather than their infrequent but more conspicuous failures. These success stories involved nuclear aircraft carriers, air traffic control systems, and nuclear power plants (box). Although such high reliability organisations may seem remote from clinical practice, some of their defining cultural characteristics could be imported into the medical domain.

Most managers of traditional systems attribute human unreliability to unwanted variability and strive to eliminate it as far as possible. In high reliability organisations, on the other hand, it is recognised that human variability in the shape of compensations and adaptations to changing events represents one of the system's most important safeguards. Reliability is “a dynamic non-event. “It is dynamic because safety is preserved by timely human adjustments; it is a non-event because successful outcomes rarely call attention to themselves.

High reliability organisations can reconfigure themselves to suit local circumstances. In their routine mode, they are controlled in the conventional hierarchical manner. But in high tempo or emergency situations, control shifts to the experts on the spot-as it often does in the medical domain. The organisation reverts seamlessly to the routine control mode once the crisis has passed. Paradoxically, this flexibility arises in part from a military tradition-even civilian high reliability organisations have a large proportion of ex-military staff. Military organisations tend to define their goals in an unambiguous way and, for these bursts of semiautonomous activity to be successful, it is essential that all the participants clearly understand and share these aspirations. Although high reliability organisations expect and encourage variability of human action, they also work very hard to maintain a consistent mind-set of intelligent wariness.

Blaming individuals is emotionally more satisfying than targeting institutions.

3.1 SWISS CHESE ACCIDENT MODELS

An excellent account of this work has been provided by Reason, which emphasises the concept of organisational safety and how defences (protection barriers such as material, human and procedures) may fail. In this approach the immediate or proximal cause of the accident is a failure of people at the "sharp end" who are directly involved in the regulation of the process or in the interaction with the technology . Reason defines accident as situations in which latent conditions (arising from management decision practices, or cultural influences) combine adversely with local triggering events (weather, location, etc.) and with active failures (errors and/or procedural violation) committed by individuals or teams at the sharp end of an organization, to produce the accident. The dynamics of accident causation are represented in the Swiss cheese model of defences (see figure 3.1), which shows an accident emerging due to holes (failures) in barriers and safeguards.

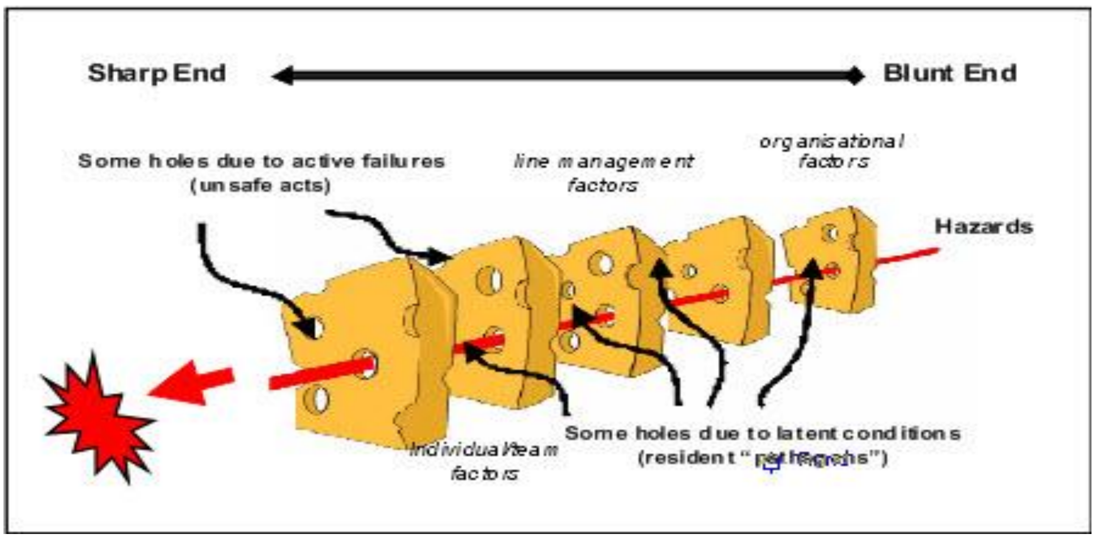


Fig.3.1- Reason's Swiss Cheese Model of Defences

The notion of latent factors supports the understanding of accident causation beyond the proximate causes, which is particularly advantageous in the analysis of complex systems that may present multiple-failure situations. Reason's model shows a static view of the organisation; whereas the defects are often transient i.e. the holes in the Swiss cheese are continuously moving. The whole socio-technical system is more dynamic than the model suggests.

The basic structural elements identified in the model are described as:

The Swiss cheese model is well suited to complex chemical process production systems, where a hierarchical organizational structure tends to exist (managers, front-line personnel, physical and operational barriers, etc.).

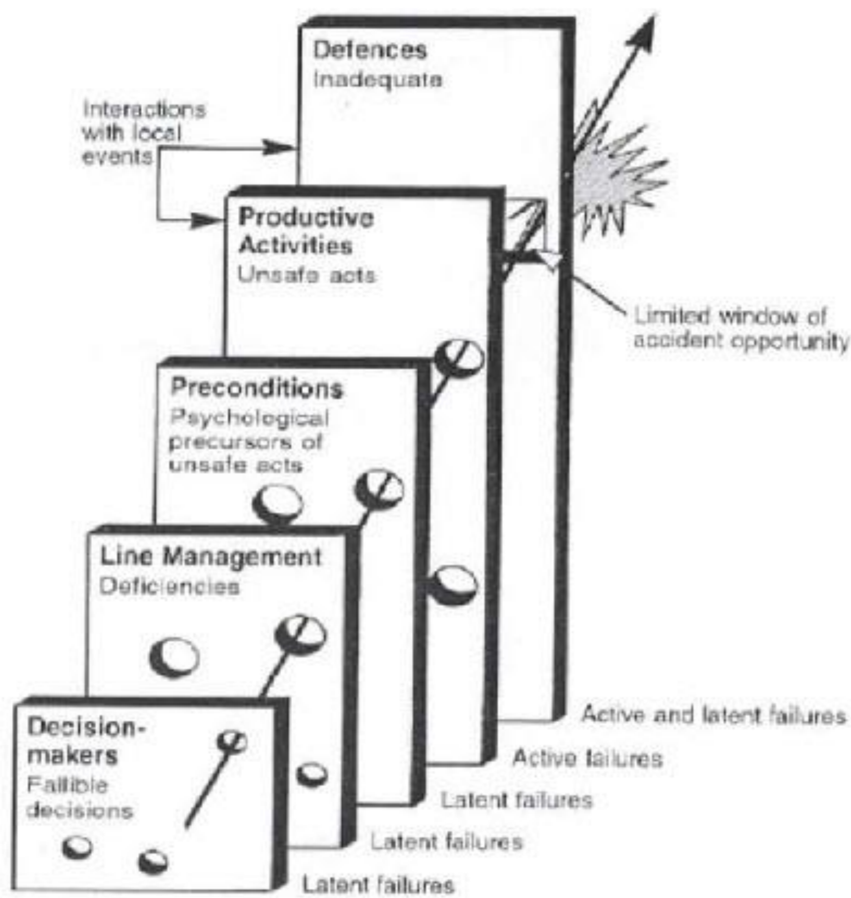


Fig.3.2- Structural elements

Decision makers: These include high-level managers, who set goals and manage strategy to maximize system performance (e.g. productivity and safety).

Line management: These include departmental managers, who implement the decision makers' goals and strategies within their areas of operation (e.g. training, sales, etc).

Preconditions: These refer to qualities possessed by people, machines and the environment at the operational level (e.g. a motivated workforce, reliable equipment, organizational culture, environmental conditions, etc.).

Productive activities: These refer to actual performance at operational levels.

Defenses: These refer to safeguards and other protections that deal with foreseeable negative outcomes, for example by preventing such outcomes, protecting the workforce and machines, etc.

Accidents occur because weaknesses or "windows of opportunity" open in all levels of the production system, allowing a chain of events to start at the upper echelons of the structure and move down, ultimately resulting in an accident if it is not stopped at any level. Said otherwise, most (if not all) accidents can be traced back to weaknesses in all levels of the system, including the decision makers level.

These weaknesses or "windows of opportunities" can be due to different factors, such as mechanical or technical failures, although, unfortunately, the human factor seems to be the most frequent or most traceable source of most accidents. These weaknesses, thus, map onto the normal structure, and, therefore, are particular to each organizational level. Human weaknesses in the system can be listed as follows:

- Fallible decisions at decision makers level.
- Line management deficiencies at line management levels.
- Psychological precursors of unsafe acts at precondition levels.
- Unsafe acts at production levels.
- Inadequate defenses at the defenses level.

3.2 THE DIRTY DOZEN

3.2.1 Introduction

Due to a spate of maintenance-related aviation incidents and accidents in the late 1980s and early 1990s, Transport Canada, together with the aviation industry identified 12 human factors, christened the "dirty dozen" which were human factors elements that degrade people's ability to perform effectively and safely which could lead to maintenance errors. In 1994, dirty dozen posters were developed which provided information and guidance to maintenance personnel all over the world to identify and prevent these dirty dozen factors. Safety nets were also introduced so that the appropriate mechanisms can be put into place to prevent human errors Fig.3.3.

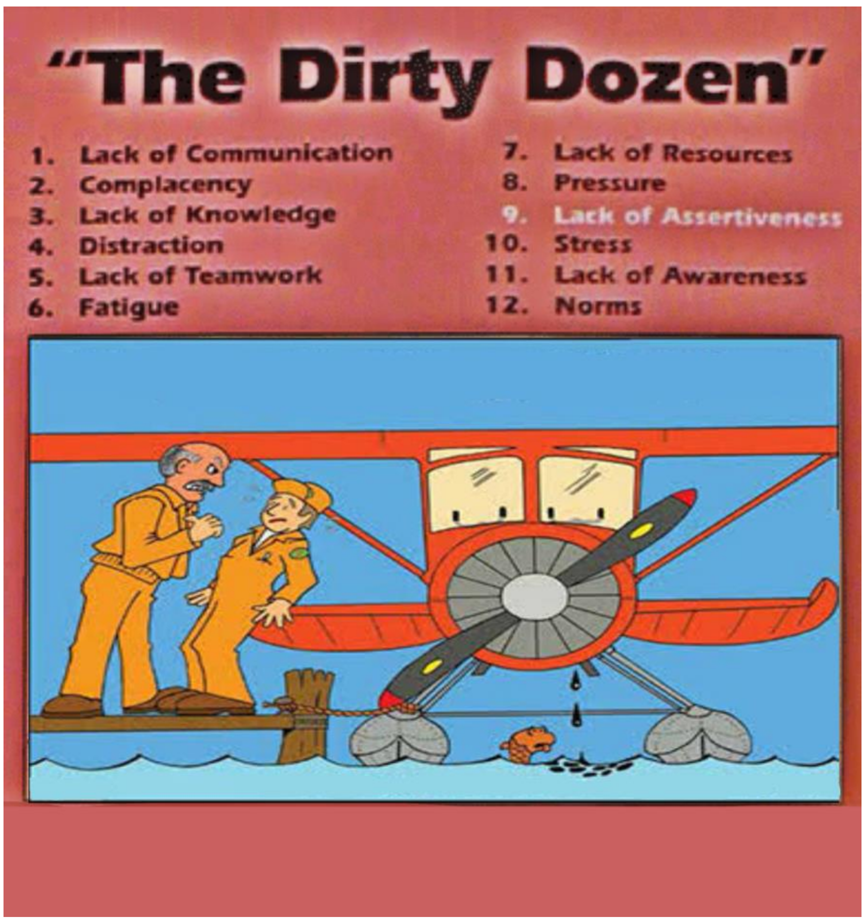


Fig.3.3-The Dirty Dozen

3.2.2 Lack of communication

In general, only 30% of verbal communication is received and understood by either side in a conversation.

People normally remember what was said first an last in an exchange; consequently it is important to put the most important part of your message first and then repeat it at the end.

Depending on the complexity of the message, it might be effective to provide some form of written instruction such as a checklist.

3.2.3 Lack of knowledge

Lack of knowledge can be defined as the lack of experience or training in the task at hand. Often one must ensure that their personnel have the required training before getting them to perform any task they are unfamiliar with.

3.2.4 Lack of teamwork

The lack of teamwork can be defined as the presence of a interdependent individuals who does not work together or communicate well with others to achieve a common set of goals.

3.2.5 Lack of resources

A lack of resources can interfere with one's ability to complete a task give because there is a lack of supply and support. Low quality products also affect one's ability to complete a task.

3.2.6 Complacency

Complacency can be defined as how one gets over-confident in his work. This is often a self-given satisfaction, one might think that since something has worked for you in the past, the same thing will work for you in the future. This is where the dangers of complacency would kick in.

Typically, complacency steps in after one has overcome a reasonably significant accomplishment. It's usually found in a person who has a lot of experience on the job or in one who has done a certain task multiple time.

3.2.7 Distraction

Distraction can be defined as anything that draws your attention away from the task at hand. Psychologists say distraction is the number one cause of forgetting things. We are always thinking ahead. Thus, we have a natural tendency, when we are distracted before returning to a job, to think we are further ahead than we actually are.

3.2.8 Norms

Norms are unwritten rules or behaviours, dictated and followed by most of a group. Norms can be positive and negative. A positive norm would be scanning the area inside the aircraft you have been working on prior to closing A negative norm would be pushing an aircraft into the hangar by yourself.

3.2.9 Pressure

Interestingly, people put the most pressure on themselves. Self-induced pressure are those occasions where one takes ownership of a situation, which was not of their doing. The 'monkey on you back' is yours because you accepted it. Being assertive and not accepting the 'monkey' will help.

Urgent demands, which influence our performance, include:

- Company
- Client
- Peer
- Self-induced

3.2.10 Fatigue

Studies have shown that, similar to being under the influence of alcohol, we tend to underestimate the problem and overestimate our ability to cope with it.

These studies have proven that after 17hours of wakefulness, you are functioning as if you had an equivalent blood alcohol level of 0.05%

After 24 hours the lever increases to 0.1%; a very sobering though. the more fatigued you are, the lower your IQ.
It is also noteworthy that the more fatigued you are, the more easily you are distracted.

3.2.11 Stress

There are two types of stress:

ACUTE

Acute stress relates to the demand placed on the body because of current issue. for examples, time constraints for converting the aircraft from passenger to cargo configuration. To handle acute stress, try to take a five minutes break and relax by deep breathing.

Chronic

Chronic stress results from long term demands placed on the body by both negative and positive major life events, such as divorce, or winning the lottery. Chronic stress can exaggerate the effects of acute stress. Dealing with chronic stress is more difficult and usually involves a lifestyle change.

3.2.12 Lack of awareness

The lack of awareness can be defined as the failure to be alert, vigilant or observative in the surrounding or in the job itself. Such incidents can lead to the failure to recognize the consequences of an action.

3.2.13 Lack of assertiveness

Lacking of assertiveness is defined as how one is aware that certain method of doing is wrong but is not confident enough to question or clarify. Thus leading to abnormal operating method which will nto be corrected leading to other faults that could've been solved at a much earlier stage.
Being "assertive" is the ability to express your feelings, opinions, beliefs and needs in a positive, productive manner. It is not the same as being aggressive

3.3 THE SHELL MODEL

3.3.1 Introduction

The SHELL model is a conceptual model of human factors that clarifies the scope of aviation human factors and assists in understanding the human factor relationships between aviation system resources/environment (the flying subsystem) and the human component in the aviation system.

The SHELL model was first developed by Edwards (1972) and later modified into a 'building block' structure by Hawkins (1984). The model is named after the initial letters of its components (software, hardware, environment, liveware) and places emphasis on the human being and human interfaces with other components of the aviation system.

The SHELL model adopts a systems perspective that suggests the human is rarely, if ever, the sole cause of an accident. The systems perspective considers a variety of contextual and task-related factors that interact with the human operator within the aviation system to affect operator performance. As a result, the SHELL model considers both active and latent failures in the aviation system.

3.3.2 The SHELL Model

Each component of the SHELL model (software, hardware, environment, liveware) represents a building block of human factors studies within aviation.

The human element or worker of interest is at the centre or hub of the SHELL model that represents the modern air transportation system. The human element is the most critical and flexible component in the system, interacting directly with other system components, namely software, hardware, environment and liveware.

However, the edges of the central human component block are varied, to represent human limitations and variations in performance. Therefore, the other system component blocks must be carefully adapted and matched to this central component to accommodate human limitations and avoid stress and breakdowns (incidents/accidents) in the aviation system. To accomplish this matching, the characteristics or general capabilities and limitations of this central human component must be understood.

3.3.3 Human Characteristics

3.3.3.1 Physical Size and Shape

In the design of aviation workplaces and equipment, body measurements and movement are a vital factor. Differences occur according to ethnicity, age and gender for example. Design decisions must take into account the human dimensions and population percentage that the design is intended to satisfy.

Human size and shape are relevant in the design and location of aircraft cabin equipment, emergency equipment, seats and furnishings as well as access and space requirements for cargo compartments.

3.3.3.2 Fuel Requirements

Humans require food, water and oxygen to function effectively and deficiencies can affect performance and well-being.

3.3.3.3 Input Characteristics

The human senses for collecting vital task and environment-related information are subject to limitations and degradation. Human senses cannot detect the whole range of sensory information available. For example, the human eye cannot see an object at night due to low light levels. This produces implications for pilot performance during night flying. In addition to sight, other senses include sound, smell, taste and touch (movement and temperature).

3.3.3.4 Information Processing

Humans have limitations in information processing capabilities (such as working memory capacity, time and retrieval considerations) that can also be influenced by other factors such as motivation and stress or high workload. Aircraft display, instrument and alerting/warning system design needs to take into account the capabilities and limitations of human information processing to prevent human error.

3.3.3.5 Output Characteristics

After sensing and processing information, the output involves decisions, muscular action and communication. Design considerations include aircraft control-display movement relationship, acceptable direction of movement of controls, control resistance and coding, acceptable human forces required to operate aircraft doors, hatches and cargo equipment and speech characteristics in the design of voice communication procedures.

3.3.3.6 Environmental Tolerances

People function effectively only within a narrow range of environmental conditions (tolerable for optimum human performance) and therefore their performance and well-being is affected by physical environmental factors such as temperature, vibration, noise, g-forces and time of day as well as time zone transitions, boring/stressful working environments, heights and enclosed spaces.

3.3.4 Components of the SHELL Model

3.3.4.1 Software

- Non-physical, intangible aspects of the aviation system that govern how the aviation system operates and how information within the system is organised.
- Software may be likened to the software that controls the operations of computer hardware.
- Software includes rules, instructions, regulations, policies, norms, laws, orders, safety procedures, standard operating procedures, customs, practices, conventions, habits, symbology, supervisor commands and computer programmes.
- Software can be included in a collection of documents such as the contents of charts, maps, publications, emergency operating manuals and procedural checklists.

3.3.4.2 Hardware

Physical elements of the aviation system such as aircraft (including controls, surfaces, displays, functional systems and seating), operator equipment, tools, materials, buildings, vehicles, computers, conveyor belts etc.

3.3.4.3 Environment

- The context in which aircraft and aviation system resources (software, hardware, liveware) operate, made up of physical, organizational, economic, regulatory, political and social variables that may impact on the worker/operator.
- Internal air transport environment relates to immediate work area and includes physical factors such as cabin/cockpit temperature, air pressure, humidity, noise, vibration and ambient light levels.
- External air transport environment includes the physical environment outside the immediate work area such as weather (visibility/turbulence), terrain, congested airspace and physical facilities and infrastructure including airports as well as broad organizational, economic, regulatory, political and social factors.

3.3.4.4 Liveware

- Human element or people in the aviation system. For example, flight crew personnel who operate aircraft, cabin crew, ground crew, management, and administration personnel.
- The liveware component considers human performance, capabilities and limitations.

The four components of the SHELL model or aviation system do not act in isolation but instead interact with the central human component to provide areas for human factors analysis and consideration. The SHELL model indicates relationships between people and other system components and therefore provides a framework for optimizing the relationship between people and their activities within the aviation system that is of primary concern to human factors. In fact, the International Civil Aviation Organization has described human factors as a concept of people in their living and working situations; their interactions with machines (hardware), procedures (software) and the environment about them; and their relationships with other people.

According to the SHELL model, a mismatch at the interface of the blocks/components where energy and information is interchanged can be a source of human error or system vulnerability that can lead to system failure in the form of an incident/accident. Aviation disasters tend to be characterized by mismatches at interfaces between system components, rather than catastrophic failures of individual components.

3.3.5 SHELL Model Interfaces

3.3.5.1 Liveware-Software (L-S)

- Interaction between human operator and non-physical supporting systems in the workplace
- Involves designing software to match the general characteristics of human users and ensuring that the software (e.g. rules/procedures) is capable of being implemented with ease
- During training, flight crew members incorporate much of the software (e.g. procedural information) associated with flying and emergency situations into their memory in the form of knowledge and skills. However, more information is obtained by referring to manuals, checklists, maps and charts. In a physical sense these documents are regarded as hardware however in the information design of these documents adequate attention has to be paid to numerous aspects of the L-S interface.

For instance, by referring to cognitive ergonomics principles, the designer must consider currency and accuracy of information; user-friendliness of format and vocabulary; clarity of information; subdivision and indexing to facilitate user retrieval of information; presentation of numerical data; use of abbreviations, symbolic codes and other language devices; presentation of instructions using diagrams and/or sentences etc. The solutions adopted after consideration of these informational design factors play a crucial role in effective human performance at the L-S interface.

- Mismatches at the L-S interface may occur through:
    - Insufficient/inappropriate procedures
    - Misinterpretation of confusing or ambiguous symbology/checklists
    - Confusing, misleading or cluttered documents, maps or charts
    - Irrational indexing of an operations manual
- A number of pilots have reported confusion in trying to maintain aircraft attitude through reference to the Head-Up-Display artificial horizon and 'pitch-ladder' symbology.

3.3.5.2 Liveware-Hardware (L-H)

- Interaction between human operator and machine
- Involves matching the physical features of the aircraft, cockpit or equipment with the general characteristics of human users while considering the task or job to be performed. Examples:
    - designing passenger and crew seats to fit the sitting characteristics of the human body
    - designing cockpit displays and controls to match the sensory, information processing and movement characteristics of human users while facilitating action sequencing, minimizing workload (through location/layout) and including safeguards for incorrect/inadvertent operation.
- Mismatches at the L-H interface may occur through:
    - poorly designed equipment
    - inappropriate or missing operational material
    - badly located or coded instruments and control devices

    - warning systems that fail in alerting, informational or guidance functions in abnormal situations etc.
- The old 3-pointer aircraft altimeter encouraged errors because it was very difficult for pilots to tell what information related to which pointer.

3.3.5.3 Liveware-Environment (L-E)

- Interaction between human operator and internal and external environments.
- Involves adapting the environment to match human requirements. Examples:
    - Engineering systems to protect crews and passengers from discomfort, damage, stress and distraction caused by the physical environment.
        - Air conditioning systems to control aircraft cabin temperature
        - Soundproofing to reduce noise
        - Pressurization systems to control cabin air pressure
        - Protective systems to combat ozone concentrations
    - Using black-out curtains to obtain sleep during daylight house as a result of trans meridian travel and shift work
    - Expanding infrastructure, passenger terminals and airport facilities to accommodate more people due to larger jets (e.g. Airbus A380) and the growth in air transport
- Examples of mismatches at the L-E interface include:
    - Reduced performance and errors resulting from disturbed biological rhythms (jet lag) as a result of long-range flying and irregular work-sleep patterns
    - Pilot perceptual errors induced by environmental conditions such as visual illusions during aircraft approach/landing at nighttime

- Flawed operator performance and errors because of management failure to properly address issues at the L-E interface including:
    - Operator stress due to changes in air transport demand and capacity during times of economic boom and economic recession.
    - Biased crew decision making and operator short-cuts as a consequence of economic pressure brought on by airline competition and cost-cutting measures linked with deregulation.
    - Inadequate or unhealthy organizational environment reflecting a flawed operating philosophy, poor employee morale or negative organizational culture.

3.3.5.4 Liveware-Liveware (L-L)

- Interaction between central human operator and any other person in the aviation system during performance of tasks.
- Involves interrelationships among individuals within and between groups including maintenance personnel, engineers, designers, ground crew, flight crew, cabin crew, operations personnel, air traffic controllers, passengers, instructors, students, managers, and supervisors.
- Human-human/group interactions can positively or negatively influence behavior and performance including the development and implementation of behavioral norms. Therefore, the L-L interface is largely concerned with:
    - interpersonal relations
    - leadership
    - crew cooperation, coordination, and communication
    - dynamics of social interactions
    - teamwork

  - cultural interactions
  - personality and attitude interactions.

- The importance of the L-L interface and the issues involved have contributed to the development of cockpit/crew resource management (CRM) programs in an attempt to reduce error at the interface between aviation professionals
- Examples of mismatches at the L-L interface include:
  - Communication errors due to misleading, ambiguous, inappropriate, or poorly constructed communication between individuals. Communication errors have resulted in aviation accidents such as the double Boeing 747 disaster at Tenerife Airport in 1977.
  - Reduced performance and error from an imbalanced authority relationship between aircraft captain and first officer. For instance, an autocratic captain and an overly submissive first officer may cause the first officer to fail to speak up when something is wrong, or alternatively the captain may fail to listen.

The SHELL Model does not consider interfaces that are outside the scope of human factors. For instance, the hardware-hardware, hardware-environment and hardware-software interfaces are not considered as these interfaces do not involve the liveware component.

3.3.6 Aviation System Stability

Any change within the aviation SHELL system can have far-reaching repercussions. For example, a minor equipment change (hardware) requires an assessment of the impact of the change on operations and maintenance personnel (Liveware-Hardware) and the possibility of the need for alterations to procedures/training programs (to optimize Liveware-Software interactions). Unless all potential effects of a change in the aviation system are properly addressed, it is possible that even a small system modification may produce undesirable consequences. Similarly, the aviation system must be continually reviewed to adjust for changes at the Liveware-Environment interface.

3.3.7 SHELL Model Uses

1. **Safety analysis tool**: The SHELL Model can be used as a framework for collecting data about human performance and contributory component mismatches during aviation incident/accident analysis or investigation as recommended by the International Civil Aviation Organization. Similarly, the SHELL Model can be used to understand systemic human factors relationships during operational audits with the aim of reducing error and enhancing safety. For example, LOSA (Line Operations Safety Audit) is founded on Threat and Error Management (TEM) that considers SHELL interfaces. For instance, aircraft handling errors involve liveware-hardware interactions, procedural errors involve liveware-software interactions and communication errors involve liveware-liveware interactions.

2. **Licencing tool**: The SHELL Model can be used to help clarify human performance needs, capabilities and limitations thereby enabling competencies to be defined from a safety management perspective.

3. **Training tool**: The SHELL Model can be used to help an aviation organization improve training interventions and the effectiveness of organization safeguards against error.

3.4 THE DOMINO THEORY

Heinrich's Domino Theory states that accidents result from a chain of sequential events, metaphorically like a line of dominoes falling over. When one of the dominoes falls, it triggers the next one, and the next... - but removing a key factor (such as an unsafe condition or an unsafe act) prevents the start of the chain reaction.

3.4.1 What are Unsafe Conditions and Acts?

According to Heinrich, all incidents directly relate to unsafe conditions and acts, which he defines as “unsafe performance of persons, such as standing under suspended loads ... horseplay, and removal of safeguards”; and “mechanical or physical hazards such as unguarded gears ... and insufficient light.”

3.4.2 The Dominoes

Heinrich posits five metaphorical dominoes labelled with accident causes. They are Social Environment and Ancestry, Fault of Person, Unsafe Act or Mechanical or Physical Hazard (unsafe condition), Accident, and Injury. Heinrich defines each of these "dominoes" explicitly, and gives advice on minimizing or eliminating their presence in the sequence.

3.4.3 Unsafe Act and/or Unsafe Condition:

The third domino deals with Heinrich's direct cause of incidents. As mentioned above, Heinrich defines these factors as things like "starting machinery without warning ... and absence of rail guards. " Heinrich felt that unsafe acts and unsafe conditions were the central factor in preventing incidents, and the easiest causation factor to remedy, a process which he likened to lifting one of the dominoes out of the line. These combining factors (1, 2, and 3) cause accidents.

Heinrich defines four reasons why people commit unsafe acts "improper attitude, lack of knowledge or skill, physical unsuitability, [and] improper mechanical or physical environment." He later goes on to subdivide these categories into "direct" and "underlying" causes. For example, he says, a worker who commits an unsafe act may do so because he or she is not convinced that the appropriate preventative measure is necessary, and because of inadequate supervision. The former he classifies as a direct cause, the latter as an underlying cause. This combination of multiple causes, he says, create a systematic chain of events leading to an accident.

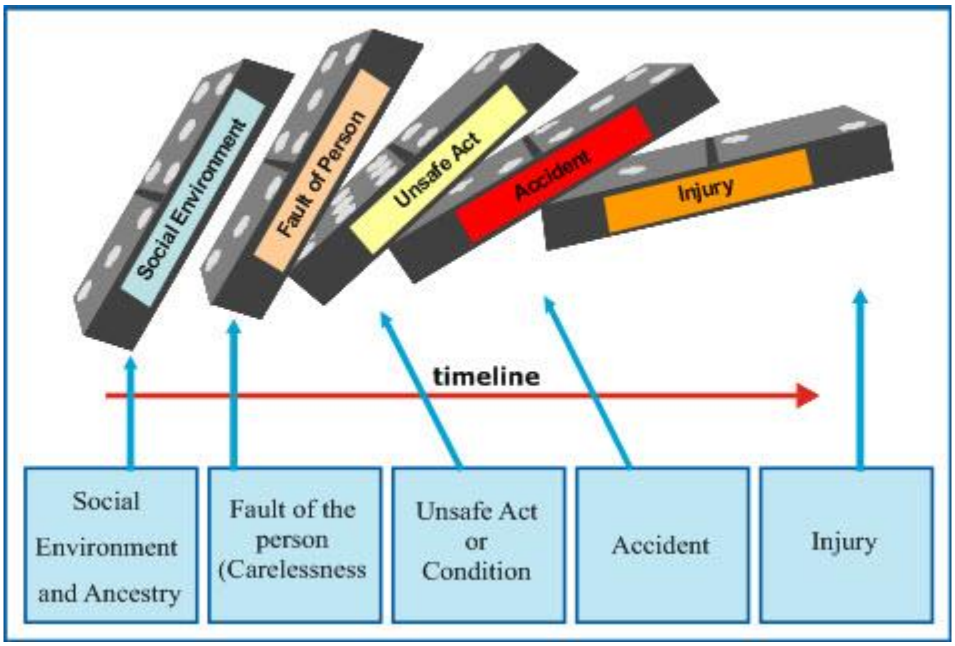


Fig.3.4- Heinrich's Domino Model of Accident Causation

4 CONCLUSIONS

Human error is inevitable. Reducing accidents and minimizing the consequences of accidents that do occur is best achieved by learning from errors, rather than by attributing blame. Feeding information from accidents, errors and near misses into design solutions and management systems can drastically reduce the chances of future accidents. Hence, studying human error can be a very powerful tool for preventing disaster.

Human Error is more than operator/pilot error. Everyone can make errors no matter how well trained and motivated they are. It is useful to distinguish between active and latent failures. Active failures are those hands on operator errors that immediately precede an accident. Latent failures are the factors or circumstances within an organisation which increase the likelihood of active failures. Latent failures lie hidden until they are triggered at some time in the future. In the domino theory or chain described earlier in the course active failures are analogous to the immediate cause and latent failures analogous to the underlying or root cause.

High reliability organisations are the prime examples of the system approach. They anticipate the worst and equip themselves to deal with it at all levels of the organisation It is hard, even unnatural, for individuals to remain chronically uneasy, so their organisational culture takes on a profound significance. Individuals may forget to be afraid, but the culture of a high reliability organisation provides them with both the reminders and the tools to help them remember. For these organisations, the pursuit of safety is not so much about preventing isolated failures, either human or technical, as about making the system as robust as is practicable in the face of its human and operational hazards. High reliability organisations are not immune to adverse events, but they have learnt the knack of converting these occasional setbacks into enhanced resilience of the system.

Accident causation models were originally developed in order to assist people who had to investigate occupational accidents, so that such accidents could be investigated effectively. Knowing how accidents are caused is also useful in a proactive sense in order to identify what types of failures or errors generally cause accidents, and so action can be taken to address these failures before they have the chance to occur.

5 REFERENCES

1. Lerner MJ. The desire for justice and reactions to victims. In: McCauley J, Berkowitz L, editors. Altruism and helping behavior. New York: Academic Press; 1970.

2. Marx D. Discipline: the role of rule violations. Ground Effects. 1997;2:1–4.

3. Reason J. Managing the risks of organizational accidents. Aldershot: Ashgate; 1997.

4. Medvedev G. The truth about Chernobyl. New York: Basic Books; 1991.

5. Marx D. Maintenance error causation. Washington, DC: Federal Aviation Authority Office of Aviation Medicine; 1999.

6. Reason J. Human error. New York: Cambridge University Press; 1990.

7. Weick KE. Organizational culture as a source of high reliability. Calif Management Rev. 1987;29:112–127.

8. Weick KE, Sutcliffe KM, Obstfeld D. Organizing for high reliability: processes of collective mindfulness. Res Organizational Behav. 1999;21:23–81.

9. Dupont, G. (1997). The dirty dozen errors in aviation maintenance. In Meeting Proceedings Eleventh Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection: Human error in aviation maintenance (pp. 45-49). Washington, DC: Federal Aviation Administration/Office of Aviation Medicine.

10. Cacciabue, P.C. (2004). *Guide to applying human factors methods: Human error and accident management in safety critical systems.* London: Springer-Verlag London Ltd, 2004.

11. Campbell, R.D., & Bagshaw, M. (2002). *Human performance and limitations in aviation* (3rd ed.). United Kingdom: Blackwell Science Ltd, 2002.

12. Edkins, G., & Pfister, P. (Eds.). (2003). *Innovation and consolidation in aviation: Selected contributions to the Australian aviation psychology symposium 2000.* England: Ashgate Publishing Ltd, 2003.

13. Hawkins, F.H., & Orlady, H.W. (Ed.). (1993). *Human factors in flight* (2nd ed.). England: Avebury Technical, 1993.

14. International Civil Aviation Organisation (1993). *Human factors digest no 7: Investigation of human factors in accidents and incidents.* Montreal: Author, 1993.

15. Johnston, N., McDonald, N., & Fuller, R. (Eds). (2001). *Aviation psychology in practice.* England: Ashgate Publishing Ltd, 2001.

16. Keightley, A. (2004). *190.216 human factors study guide.* Palmerston North: Massey University, 2004.

17. Maurino, D. (2005). *Threat and error management (TEM).* Retrieved August 17, 2009 from the World Wide Web: http://www.flightsafety.org/doc/tem/maurino.doc

18. Wiegmann, D.A., & Shappell, S.A. (2003). *A human error approach to aviation accident analysis: The human factors analysis and classification system.* England: Ashgate Publishing Ltd, 2003.

19. Wiener**,** E.L., & Nagel, D.C. (Eds). (1988). *Human factors in aviation.* California: Academic Press Inc, 1988.

Web site:

1. https://ar.wikipedia.org/wiki/%D8%A7%D9%84%D8%AE%D8%B7%D8%A3_%D8%A7%D9%84%D8%A8%D8%B4%D8%B1%D9%8A_%D8%A7%D9%84%D9%83%D8%A7%D9%85%D9%86
2. https://ar.wikipedia.org/wiki/%D8%AE%D8%B7%D8%A3_%D8%A8%D8%B4%D8%B1%D9%8A
3. http://www.hse.gov.uk/humanfactors/topics/humanfail.htm
4. https://oshwiki.eu/wiki/Human_error
5. https://en.wikipedia.org/wiki/Swiss_cheese_model
6. https://maankattan.com/2012/09/14/anesthesia-errors-%D8%A7%D9%84%D8%AA%D8%AE%D8%AF%D9%8A%D8%B1-%D8%A8%D9%8A%D9%86-%D8%A7%D9%84%D8%A3%D8%AE%D8%B7%D8%A7%D8%A1-%D8%A7%D9%84%D8%B7%D8%A8%D9%8A%D8%A9-%D9%88%D9%82%D8%B7%D8%B9-%D8%A7%D9%84/
7. http://www.flyingway.com/vb/showthread.php?t=161109
8. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1117770/
9. http://iteattachment.blogspot.com/2011/10/
10. http://www.hrdp-idrm.in/e5783/e17327/e24075/e27373/