

PETRONAS TECHNICAL STANDARDS
HEALTH, SAFETY AND ENVIRONMENT

TRIPOD-BETA – THE ANALYTICAL TOOL
(GUIDELINE)

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AMENDMENTS RECORD SHEET

Chap No.	Section No.	Description	Issue No.	Date	Rev No.	Date	Approve by: (initial)
All	All	PTS 60.0504 Tripod Beta – the investigation tool	1	June 2005	0	0	IGA

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1. **INTRODUCTION**

Tripod-BETA is a methodology for conducting the incident analysis in parallel with the investigation, supported by a PC-based tool. Interaction between these two processes - investigation and analysis - provides the investigators with confirmation of the relevance of their fact gathering and highlights avenues of investigation pointing to the identification of latent failures. The benefit to the analysis process is that logical anomalies can be highlighted and resolved while the investigation is still active.

The net result should be a deeper and more comprehensive investigation and a clearer understanding of the failures that must be addressed in order to make significant and lasting improvements in accident prevention.

Tripod-BETA builds upon previous Group accident investigation and hazard management advice:

- PTS 60.0401 Hazards and Effects Management Process.

The methodology is supported by TRIPOD BETA software that provides the means to collect and assemble the facts from the investigation and manipulate them on screen into a graphic representation of the event and its causes - an accident tree. The program tests the tree structure to ensure that it is logical in terms of the Hazards and Effects Management Process (HEMP) and the Tripod theory of accident causation, and that other 'rules' applying to the investigation have been followed. A draft accident report can be generated for final editing using a word processing package.

The software is issued with a Tripod-BETA Software Guide, which gives a detailed description of how to use the application.

This report describes the application of Tripod-BETA during an investigation, where the facts collected by the investigation team are the input to the analysis

2 **OVERVIEW**

2.1 **OBJECTIVES**

a) The objective of incident investigation and analysis is to identify: the active and

b) latent failures

in hazard management measures that caused or contributed to the incident.

The purpose of Tripod-BETA analysis is:

a) to provide an investigation team with a structure for the investigation derived from the core elements of the incident and,

b) by feeding back the results of the analysis as the investigation progresses, to identify leads and information gaps.

2.2 **METHOD**

The Tripod-BETA method uses investigation facts to construct a 'Tripod-BETA Tree', a conceptual model describing the hazard management aspects of the incident. The classification and linkage of tree elements represent the cause-effect logic of the tree diagram.

The tree reflects three phases in a typical incident investigation:

Typical investigation	Tripod-BETA analysis
The initial phase usually concentrates on the incident site and its immediate surroundings, gathering the facts concerning the event and its consequences.	The core model of a Tripod-BETA tree defines the incident mechanism in terms of hazards, targets and events.
The next phase of an investigation examines the circumstances of the incident to identify what hazard management measures failed. The scope of investigation may widen during this phase to include off-site activities.	Failed or missing hazard management measures (controls and defences) are added to the core model in the second phase of Tripod-BETA tree building.
The last phase of investigation aims to identify the underlying causes of the incident. Investigation scope may	The final phase of a Tripod-BETA tree is to plot Tripod causal paths for each failed or missing hazard management

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include organisational arrangements.

measure, leading from immediate failures to underlying causes.

The structure of the Tripod-BETA tree defines the scope of the investigation. It provides the means to verify the relevance of findings in terms of their contribution to the incident being investigated. The model highlights leads for further investigation to uncover latent failures (root causes).

2.3 RESOURCES

The main resource requirements for application of Tripod-BETA in an investigation are:

- a facilitator who is familiar with the rationale of the BETA incident model and the operation of the Tripod-BETA software
- a team with an understanding of the basic concepts of the incident model.

In most investigations many members of the investigation team will only have a basic working knowledge of the HEMP and Tripod models and their terminology. It is expected that the BETA facilitator will be familiar with the process and will be able to assist the team understanding the concepts, especially in the classification of tree elements and the resolution of logical links.

It is not necessary for the facilitator to be the leader of the investigation; in established Operating Units (OPUs) expertise in Tripod-BETA analysis will most likely be developed with HSE advisers, as part of their services to the line.

3 THE CORE DIAGRAM

3.1 DIAGRAM ELEMENTS

The core of a Tripod investigation tree is a representation of the incident mechanism, describing the main incident event and other significant events that occurred before or afterwards. The diagram comprises a number of linked 'trios', each containing three elements: an event, a hazard and a target.

Event

In incident investigation terms an event is a happening, a 'change of state', whereby a target is adversely affected (or threatened) by a hazard. In the Tripod-BETA model all events have potential injury, damage or loss 'penalties' and some have actual penalties.

Typical main events in Oil and Gas operations are associated with “loss of control” or “containment” or “with unexpected contact”, such as:

- hydrocarbon gas release
- oil spill
- contact with hot pipe
- contact with electric current
- explosion
- fall
- collision

Hazard

A hazard is an energy source, material, condition, etc. that causes or has the potential to cause injury, damage or loss.

Hazards that are an obvious energy source are relatively easy to identify, e.g.:

- sources of extreme heat
- electricity
- materials under pressure
- objects under tension or compression
- flammable materials, liquids or gases
- explosives
- radiation sources

Toxic material such as acids and caustic substances, poisonous chemicals and gases, notably H₂S, are also obvious hazards.

Less obvious hazards are:

- carcinogenic material (e.g. asbestos)
- extreme cold

- biological hazards (e.g. animals and insects or micro-organisms)
- toxic metals (e.g. mercury, lead) that may have a cumulative harmful effect

The following are recognisable as hazardous but it sometimes more difficult to describe the form of the hazard:

- differences in elevation (source of the potential energy released in a fall)
- conditions that are non-toxic but nevertheless life threatening e.g. such as lack of oxygen, smoke, fumes, water (as a drowning medium)
- ergonomic conditions (such as noise, light, heat, work station layout, etc.) that could lead to stress or physical strain injury
- moving equipment, including vehicles, aircraft, where the energy of movement (kinetic) can be released by impact or rapid deceleration
- Hand and power operated rotating machinery, cutting tools
- natural phenomena such as wind, rain, waves, earthquakes etc.

Further details on industrial hazards can be found in the Hazards and Effects Hierarchy and Checklist of Sources - Hazards - Effects in PTS 60.0401 Hazards and Effects Management Process.

Target

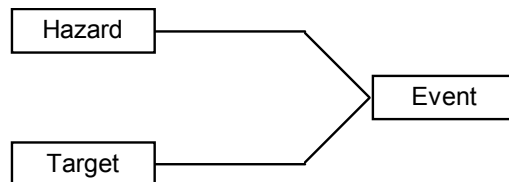
Hazard management measures can best be understood in the context of a target, victim or 'object of harm'. Hydrocarbon gas is a potential fire/explosion hazard but may also be an asphyxiant. Identification of the target focuses on the hazard management measures relevant to that incident. Four categories of target are considered:

Category	Potential harm
People	Injury or damage to health (employees or third parties)
Assets	Damage to plant or equipment - loss of material - disruption or shutdown of operation - damage to third party assets.
Environment	Damage or contamination - severe nuisance.
Reputation	Adverse media attention - public concern, protest - prosecution - business restriction - reactive legislation.

3.2 BUILDING THE CORE DIAGRAM

A typical core diagram starts with a main incident event, either the first or the most serious event of the incident. The hazard and target are placed to the left of the event, and joined by 'hazard trajectories' (see Figure 1).

Figure 1 Hazard - Event – Target

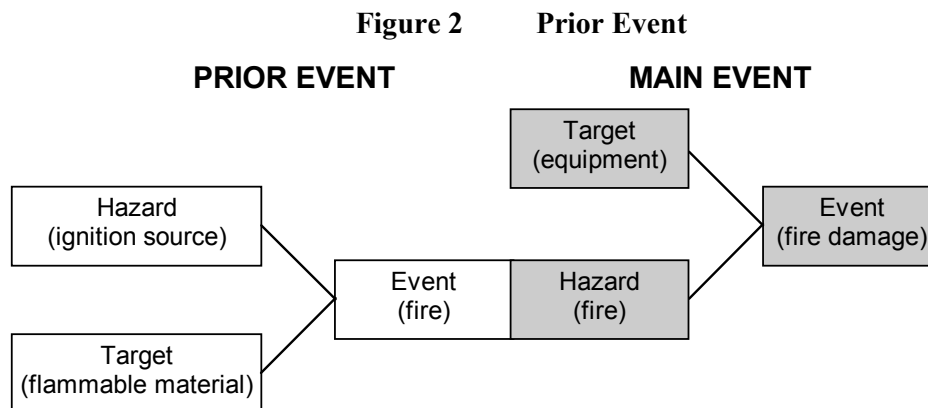


Hazard trajectories are conceptual pathways connecting the hazard and target to the event. Hazard management measures relevant to the incident will be located on these trajectories.

3.2.1 Prior Events

When the hazard or the target was the outcome of a prior event, another hazard and target combination needs to be included in the scope of the investigation. For example, if the main event was fire damage to equipment, the event causing the hazard (fire) needs to be accounted for. The core diagram would show two hazard - target - event constructions (see Figure 2)

If the presence of the flammable material was itself caused by another event (e.g. a pipe leak), a further hazard/target combination would need to be identified.



Designating the flammable material as a target is worth a mention. The normal convention is always to regard, say, hydrocarbon gas as a hazard. However, in the context of this model it is necessary to consider the 'fire' event. The fire was the result of a chemical reaction when heat (the ignition source) was applied to the flammable

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material. The flammable material suffered an adverse change of state (combustion), therefore in this specific context it was a 'target'.

It should also be noted that 'fire' features as both an event and a hazard. In the Tripod-BETA model this is represented by a combined 'event-hazard' node. Similarly, an event creating a target is represented as an 'event-target'. All hazard and target 'end nodes' should be examined for possible prior events. When no prior events are evident, the hazard or target end node represents a logical limit to the investigation scope.

As the core diagram is being constructed all hazard and target 'end nodes' should be examined for possible prior events. When no prior events are evident, the hazard or target end node represents a logical limit to the investigation scope.

3.2.2 Subsequent Events

The main event may not be the final event in an incident. Subsequent events may be added in a similar manner to prior events, to account for escalation or events during recovery. Different targets can be shown separately.

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Figure 3 Subsequent Event

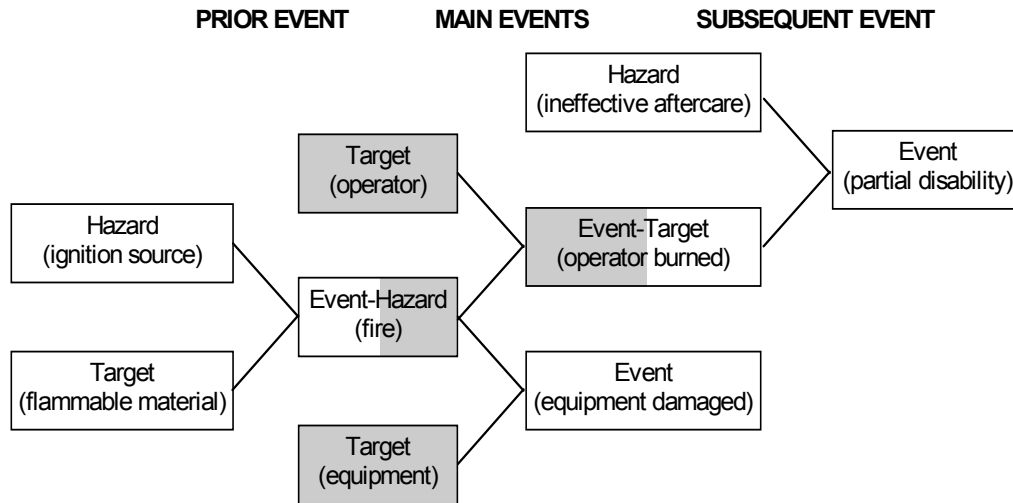


Figure 3 illustrates damage and injury resulting from a fire incident. Note that the burn victim becomes a 'target' for ineffective aftercare. This may seem a novel concept, but, particularly in field operations, recovery measures for injured persons may involve rescue, stabilisation at the incident scene and transportation to an appropriate medical centre, all of which involve additional risk. Rescue and recovery operations should always be considered as a potential investigation lead.

Construction of the core diagram is a **critical success factor** in an incident investigation. The diagram sets out the scope of the investigation, the hazard, target and event 'end nodes' indicating points where no further investigation is considered necessary. The different hazard trajectories indicate where effective hazard management measures would have prevented events or consequences.

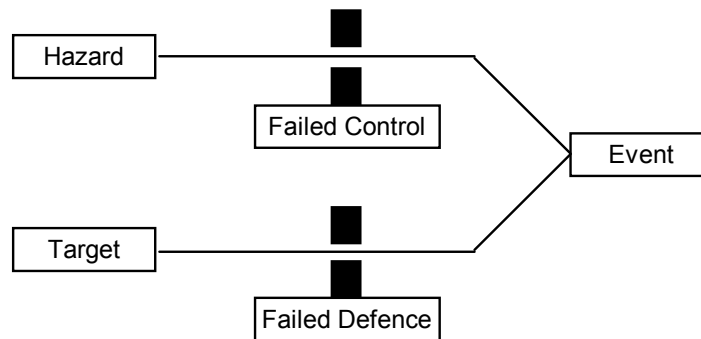
4 HAZARD MANAGEMENT MEASURES

A business must manage its hazards and protect potential objects of harm; an accident or incident means that there have been failures in hazard management and protective measures. When an incident occurs, the trigger event is the last control or defence to fail. In most cases there will have been other controls or defences that had failed before the last one. The investigation needs to identify all failures so that they can be addressed.

The Core Diagram defines the chain of events, with the implication that any hazard management measures relevant to a trajectory must have been ineffective. To complete the model of WHAT happened it is necessary to establish what measures were in place (but failed) and what should have been in place (but were missing). This requires a thorough examination of the operation, including design aspects where appropriate.

Hazard management measures relevant to a specific incident can be considered as being located on one or other of the hazard trajectories. For convenience, measures addressing hazards are called 'controls' and those addressing targets are called 'defences' (see Figure 4), but both terms should be taken as including all relevant aspects of hazard management as defined in the Hazard and Effects Management Process.

Figure 4 Hazard Management Measures



4.1 HEMP

The Hazards and Effects Management Process (HEMP) defines four aspects of hazard management:

- identify (the hazard)
- assess (the possible consequences of hazard release or exposure)
- control (the hazard)

- recover (from a failure to control the hazard)

Accidents and incidents are the result of failures in one or more of these aspects, most frequently in the last two. Failure to control a hazard results in an 'unplanned, unwanted event'. Failure to control a hazard combined with failure to recover results in an 'unplanned, unwanted event with unacceptable consequences'.

4.1.1 Identification and Assessment

The first stage in hazard management is identification and assessment of potential hazards. This activity is not confined to the design stage of a project, but should be reflected in all stages, e.g. in:

- facility and equipment design specification
- change control documentation
- operating and maintenance plans, procedures and practices
- ad hoc operational plans and contracts
- Permit to Work (PTW) controls

Missing or inadequate controls and defences may be the result of identification and assessment failures. The investigation should verify that specific hazards, and likewise the presence of targets, were recognised and that appropriate controls and defences were specified.

In this context, an investigation should also verify that a hazard could not have been avoided by different design, process or practices. Similarly, verification should be made that the presence or location of a target could not have been avoided, or exposure reduced, by different processes or procedures.

4.1.2 Control

Broadly speaking, controls include aspects of control and containment aimed at preventing release or exposure of a hazard. Controls can also be applied with the objective of segregating targets from hazards.

Controls and defences should be seen in the context of the hazard and its potential targets. A substance such as 'live' crude oil may present a number of potential hazards to different targets, e.g. fire and explosion as a threat to personnel and to facilities, asphyxiant gases as a threat to personnel, pollution as a threat to agriculture, fishing or tourism. The controls identified should be relevant to target in the core diagram.

For some hazards maintaining the hazard within process limits (process controls) will be the principal means for preventing inadvertent release or exposure. Containment and segregation from potential targets will be the principal aim for more static hazards.

It is not necessary to classify controls or defences in an investigation but investigators should identify all controls and defences and understand their functions.

Controls and defences can have more than one function and some, e.g. procedures, can even apply to both hazard and target.

Controls may be organisational and procedural as well as technical.

As a general rule, there should be at least one control measure for each identified hazard. High potential hazards will have multiple controls (defence-in-depth).

4.1.3 Recovery

Recovery measures address the consequences of release or exposure of a hazard with the aim of protection of targets, prevention of escalation or mitigation of damage effects. Measures include emergency response facilities, contingency procedures, relief systems and secondary containment.

The examples of hazard management measures in Table 1 are not comprehensive, but are presented to illustrate the range of measures that may be built into operations with a function either of preventing the release of a hazard or of preventing or mitigating the adverse consequences of hazard release. Function descriptions are given to prompt recognition of various controls and defences in the context of hazards and potential consequences.

Table 1 Hazard Management Measures

HAZARD IDENTIFICATION AND ASSESSMENT				
Environment Impact Assessment (EIA)	prediction of the physical, chemical, biological and socio-economic effects of an activity			
Hazard Identification (HAZID)	identification of hazards to new ventures or at major modifications			
Hazard and Operability Study (HAZOP)	examination of process and engineering to assess the potential for, and possible effects of, malfunction or maloperation			
Health Risk Assessment	identification of health hazards and evaluation of risk to health in the work place			
Job Safety Analysis (JSA)	application of hazard management and effects process at task level			
QRA study	quantitative evaluation of the risk imposed by a system design			
HAZARD MGT MEASURES	FUNCTION			
	Controlling:- directing or regulating a process or action so as to maintain a hazard or potential target within required limits of operation			
		Containing:- maintaining a hazard or potential target within defined physical limits		
			Protecting:- intervening between a hazard and a potential target or between two hazards so as to prevent contact.	
			Mitigating:- acting after the release of a hazard to lessen the potential harm	
CONTROL				
Coatings			x	intervene between the object coated and corrosive material
Corrosion allowance			x	material additional to the functional thickness requirement that can be 'sacrificed' to corrosion
Detection and alarm systems	x			alert operators to deviations from acceptable operating parameters
Handrails/fencing		x		keep operators/third parties within 'safe' areas or outside hazardous areas
Heat or electrical insulation		x	x	prevent contact between hazard and potential victim/target
HSE meetings/briefings	x			reinforce correct work practices and awareness of hazard controls
Labelling & colour coding	x			indicate presence/nature of hazard
Machinery guards			x	intervene between moving machinery and potential victims
Operator training	x			provide operators with skills and judgement criteria

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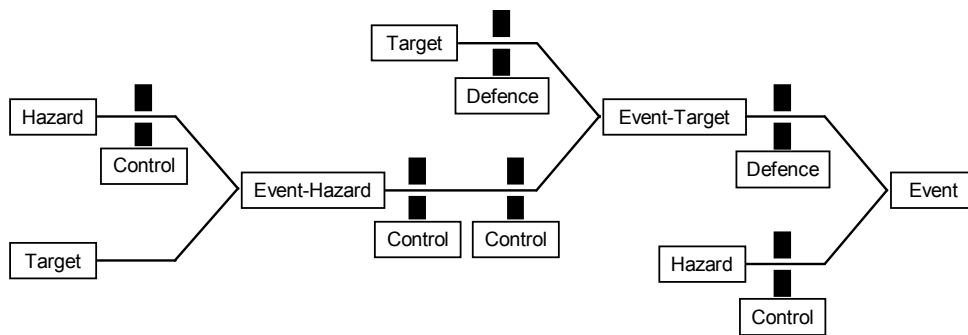
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Permit to Work (PTW)	x			written system to control potentially hazardous work
Plans and instructions	x			direct an operation - addressing specific aspects
Procedures	x			regulate an operation - define operating methods/limits etc.
Process/ machinery controls	x			automatically or manually regulate a process or machine to keep within design limits for efficient & safe operation
Restricted or controlled access			x	keep hazards, e.g. flammable in storage separated from potential targets (personnel)
Safe driving distance			x	keep one hazard (moving vehicle) outside the control envelope (stopping distance) of another
Signs and notices	x			indicate presence of hazard or control instructions
Storage facilities		x		establish boundaries for hazardous materials e.g. tanks, warehouses
Storage quantity limits			x	keep hazards e.g., flammable or toxic chemicals, within control capabilities
Supervision	x			ensure that hazard management is practised
RECOVERY				
Contingency plans			x	reduce the effect of a hazardous event by controlling the hazard and evacuating/ protecting potential targets
Emergency response facilities			x	provide the means to control a hazardous event and evacuate/protect potential targets
Emergency response procedures			x	define organisation and equipment for responding to a hazardous event
Fire walls, fire doors			x	limit the propagation of fire to adjacent areas
Life saving appliances			x	effect escape from the vicinity of a released hazard and
Personal protective equipment			x	prevent or limit the harm to personnel of a released hazard
Relief valves			x	avert escalation of an incident due to build up of hazard properties
Tank bunds			x	secondary containment of a released hazard

Figure 5 illustrates the first part of an accident 'model' with hazard management measures located on appropriate trajectories in the core diagram. It is a representation of WHAT happened in an incident and WHAT failed.

Figure 5 Failure Mechanism

Knowing WHAT happened is only part of the investigation. Even if the failed and missing controls and defences are reinstated, the underlying causes of failure will remain. To make more effective recommendations to avoid similar incidents, we need to find out WHY the various failures occurred

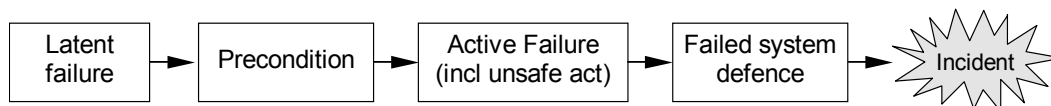
5 TRIPOD CAUSATION PATHS

5.1 TRIPOD BASICS

The Tripod theory is based on the premise that accidents are nearly always events that have a number of causes. Active failures, e.g. unsafe acts, do not occur in isolation but are influenced by external factors - the preconditions. These factors themselves originate from failures elsewhere in the business - latent failures. Latent failures often originate in decisions or actions taken by planners, designers or managers remote in time and location from the front line of operations, where most accidents occur.

This is not an entirely new concept; other accident causation theories have identified 'immediate causes' and 'underlying causes' as accident elements. What Tripod does is to connect these causes to show that latent failures can actually encourage active failures as well as magnify their consequences. A brief summary of the development of the Tripod Theory is presented in [Appendix 1](#).

Figure 6 illustrates a Tripod causation path leading to a failed defence. Each failed control or defence will have its own causation path.

Figure 6 Tripod causation model

All identified failures should be addressed, but addressing the active failures may only have a localised effect. Latent failures have a more widespread influence on the

safety of an operation. Measures to prevent latent failures are likely to have the greatest beneficial impact in accident prevention.

In a Tripod-BETA investigation a Tripod causation path is traced back in time from each failed or missing control or defence to its latent failure. It should be noted that whereas the core diagram and control/defence element links represent direct cause and effect, Tripod element links can represent influences as well as direct cause. An active failure may be the result of more than one precondition.

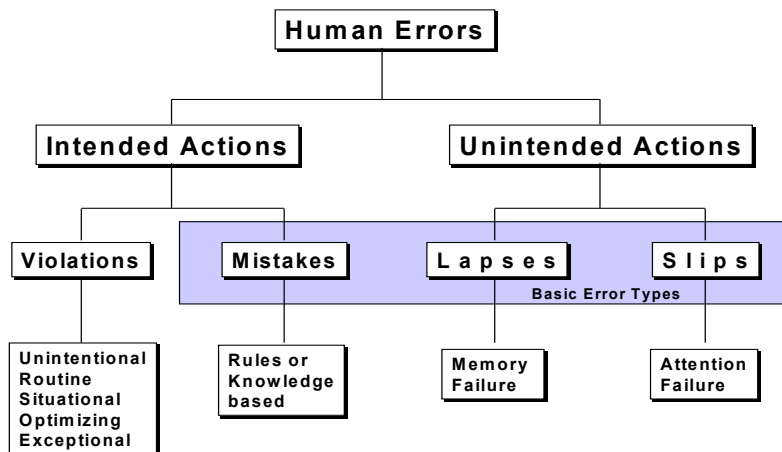
5.1.1 Active Failures (Unsafe acts and Technical failures)

Active failures are the failures close to the accident event that defeat the controls and defences on the hazard trajectory. In many cases these are the actions of people - categorised as unsafe acts in Tripod terminology. Human errors are implicated in four out of five active failures, but human error is a broad term that includes a number of different sources of error.

Not all active failures are human actions. Physical failure of controls/defences also occur due to conditions such as over stress, corrosion or metal fatigue. Human actions are often implicated as contributory causes to these active failures but they are not, in themselves, unsafe acts.

The conditions that lead to routine violation of procedures differ from those that cause attention failures. Knowing the form of human error helps in the identification of preconditions (see Figure 7).

Figure 7 Sources of human error



5.1.2 Preconditions

Preconditions are the environmental, situational or psychological 'system states' or 'states of mind' that promote or directly cause active failures. Table 2 illustrates the connection between unsafe acts and typical preconditions.

Table 2 Errors and preconditions

Error type	Description	Possible Causes	Pre-conditions
Slips	Unintended deviation from a correct plan of action	Attention Failure Mis-timing	Distraction from task Pre-occupation with other tasks
Lapses	Omission / repetition of a planned action	Memory failure	Change in the nature of task Change in the task environment
Mistake (rule based)	Intended action not appropriate for the circumstances	Sound rule incorrectly applied Application of unsound rule	Failure to recognize correct area of application Failure to appreciate rules deficiencies
Mistake (knowledge based)	Error in judgment not covered by the rule	Insufficient knowledge or experience - maturity Time / emotional pressure	Organizational deficiency inadequate training
Unintentional violation	Lack of awareness and understanding	Do not know about Not correct or understood	Not available Not update / trained to
Routine violation	Habitual deviation from required practice	Natural human tendency to take path of least effort	Indifferent environment (no penalty nor reward for compliance)
Situational violation	None ideal operating environment / resource constraint	Compliance instead of safe behavior Overlooked / ignored until !!	Work pressure Non conducive working environment
Optimizing violation	Conflict between job and personal goals	Incentives to violate Restrictive rules Overloaded with procedures	Absence of ownership / responsibility Flexibility
Exceptional violation	Ad hoc infringement of regulated practice	Wide variety - dictated by local conditions	Particular tasks or circumstances not planned for
Sabotage	Deliberate violation for malicious reasons - outside the scope of most accident scenario		