

CHE 59700

**Research Report on Human Error in Process Safety
Incidents**

Team B

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Executive Summary

After a process safety incident occurs, root cause analysis is performed to determine what led to the incident and what preventative measures can be used in the future to prevent recurrence of similar incidents. Human error is a very common root error and is used to cover everything from insufficient training to inadequate operating procedures. This wide variety of errors makes it difficult to pinpoint exactly what led to the incident, meaning that further analysis is required to determine why human error occurred. There are five subcategories within human error: intentional commission, accidental commission, intentional omission, accidental omission, and competency.

This paper reviews seven incidents where human error was a key factor and then analyzes them in order to determine which subcategories are more frequent and pose the highest risk. One of the incidents was then analyzed further through the use of two mitigative techniques: Systematic Human Error Reduction and Prediction Approach (SHERPA) and Human Factors Analysis and Classification System (HFACS). These two techniques are used to determine which specific steps in the process were responsible for the incident. This paper then suggests some recommendations that would help prevent future incidents.

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Introduction

After a process safety incident occurs, it is imperative that root cause analysis is performed in order to determine preventative actions for mitigating similar incidents in the future. The analysis for many process safety incidents traces the root cause back to human error. Human error is used to summarize a variety of reasons, including insufficient training, incompetence, and lack of operations, policies, and procedures.

Human error is the general root cause, but it is possible to delve further into the issue to determine the reason human error occurred. There are five types of human error: intentional commission, accidental commission, intentional omission, accidental omission, and competency. The definitions of the five types of human error are provided below.

- Intentional commission refers to incidents where an individual purposefully alters the procedure or incorrectly executes them.
- Accidental commission refers to incidents where an individual unintentionally alters the procedure or incorrectly executes them.
- Intentional omission refers to incidents where an individual purposefully omits steps in the procedure.
- Accidental omission refers to incidents where an individual unintentionally omits steps in the procedure.
- Competency refers to incidents where an individual is completing assignments that they are unqualified to work on.

This research paper reviews various incidents where human error was a key factor and analyzes them in order to determine the subcategory within human error that was responsible for the incident. The types of human error are then analyzed in order to determine which subcategories pose the highest risk. This paper then analyzes one of the incidents by employing two of the more accessible and user-friendly mitigative techniques: Systematic Human Error Reduction and Prediction Approach (SHERPA) and Human Factors Analysis and Classification System (HFACS). This paper aids in understanding the impact human error has on process safety and suggests various methods to minimize the risk of these incidents occurring.

Objective

The objective of this research project is to analyze incidents that were caused by human error and determine the subcategories of human error that were responsible for each incident. The subcategories are then to be analyzed and used to determine which subcategories are the most common and pose the highest risk to process safety. The goal of this root cause analysis is to develop a better understanding of the role human error has on process safety and how to mitigate the risk of recurrence for similar incidents.

Review of Incidents

This section of the paper conducts brief literature reviews on each of the incidents and an explanation of which subcategory within human error was responsible for the incident.

LyondellBasell La Porte Fatal Chemical Release

On July 27, 2021, three contract workers from Turn2 Specialty Company were working at LyondellBasell's Complex in La Porte, Texas ("Fatal Release of Acetic Acid"). The contract workers were working to remove a plug valve actuator in order to use it as an energy isolation tool for repairing the piping spool. The workers accidentally removed the pressure-retaining component of the plug valve, causing about 164,000 pounds of acetic mixture to escape from the open equipment and spray the three contractor workers. Two of the workers were sprayed a fatal amount and the third worker was seriously injured.

This is not the first incident where workers accidentally removed the pressure-retaining components from the valve while trying to remove the actuator ("Fatal Release of Acetic Acid"). The CSB identified four previous incidents in which this type of incident has occurred. The CSB discovered that LyondellBasell and Turn2 Specialty Company thought this was an easy task and neither company properly assessed the risks.

The root cause for this incident is categorized as accidental commission as the contract workers knew the proper procedure but accidentally performed it incorrectly by removing the pressure-blocking component, causing the leak.

Sunoco Logistics Partners Flash Fire

Sunoco hired L-Con, Inc to perform the required piping modifications for the installation of their new aboveground storage tanks ("Flash Fire and Explosion at Sunoco"). L-Con, Inc subcontracted CARBER to assist with executing piping work, such as cutting and isolating. The contract between Sunoco and L-Con, Inc stated that the work area would not be completely free of crude oil. On August 11, 2016, CARBER cut and isolated a portion of the piping section that contained residual crude oil. On August 12, 2016, workers from L-Con, Inc performed the welding process to insert a spool piece between the isolation parts ("Flash Fire and Explosion at Sunoco"). The welding work was being conducted outside when the temperature was 84°F, which is above the flashpoint of the crude oil (73.4°F). The inside the pipe was filled with a mixture of crude oil vapor and air, which led to a flash fire and explosion when exposed to the sparks from welding. Sunoco approved L-Con, Inc to perform hot work on equipment containing flammable fluid, which is in violation of OSHA regulation.

Sunoco included an "Overview of Work Permits" procedure that pipes exposed to flammable liquid should be thoroughly cleaned and approved prior to executing hot work; however, the company did not explain how to clean the pipes, nor did they state that hot work on previously contaminated materials is an OSHA violation ("Flash Fire and Explosion at Sunoco"). L-Con, Inc also did not follow procedures, nor did they adequately train their employees for welding in the presence of hazardous materials.

The root cause for this incident is considered to be competency. The workers performed the job to the best of their ability; however, the workers were unable to clean the pipes correctly due to there not being an adequate operating procedure.

Loy Lange Box Company Pressure Vessel Explosion

In November 2012, engineers at Loy-Lange Box noticed water leaking from the bottom head semi-closed receiver (SCR) and decided to have Kickham Boiler and Engineering Inc repair it ("Pressure Vessel Explosion"). Approximately five and a

half years later on March 31, 2017, some engineers found a leak from below the SCR and contacted local welders to assess and repair the vessel; however, the welders were unable to go to the facility until three days later. The company continued running the vessel for the rest of the workday and then shut it down for the weekend ("Pressure Vessel Explosion"). On April 3, 2017, an engineer followed standard startup procedures when the SCR failed approximately an hour and twenty minutes later. The SCR failure caused a boiling liquid expanding vapor explosion (BLEVE), which resulted in the SCR being launched into the air for approximately ten seconds before crashing through the roof of a building 520 feet away.

The CSB discovered that the vessel was very corroded, which resulted in the bottom of the vessel thinning until it could no longer withstand the pressure ("Pressure Vessel Explosion"). Loy-Lange's startup and operating procedures for the vessel encouraged corrosion within the vessel due to the daily use of oxygenated water. The company also knew about the corrosion; however, they did not have an inspection program and they were not in compliance with the required inspections.

The root cause for this incident is considered to be intentional commission.

Thiokol-Woodbine Explosion

In 1971, Thiokol-Woodbine was responsible for producing large amounts of the components required for the large flamethrower that was utilized by the armored M132. They created two different pellets: an ignition pellet that would combust, generating high temperatures and an illuminant pellet that would produce the bright white light. During the process of creating the ignition pellet, an ignition chemical was manually mixed with other chemicals before being compacted to form ignition pellets. Prior to the incident, small fires had frequently occurred during this process (Corley). The company and workers did not consider there to be any risk due to all the fires self-extinguishing.

On February 3, 1971, the workers waited outside the building for the fires to go out; however, unlike previous fires, this fire spread along the conveyor belt to other parts of the production line. There were two small explosions before the fire spread to the storage room, which resulted in the biggest explosion(Dennis). This incident resulted in 29 fatalities and an additional 50 serious injuries ranging from

burns and severed limbs. The company had claimed that explosions were impossible, despite knowing that the components were highly flammable and stored in large quantities(Dennis). The company did not have adequate safety procedures in place and encouraged employees to ignore fires rather than using appropriate preventative and mitigative measures.

The root cause for this incident is considered to be competency due to the improper process operations and safety strategies.

HF Leakage

The hydrofluoric acid leakage of 8 tons of the chemical occurred from the Hube Global plant in Gumi, South Korea on September 27, 2012 at 15:45. At this plant hydrofluoric acid was used in the production of pharmaceutical precursors. This release occurred while two workers were attempting to transfer the HF from the delivery tanker into the holding tanks via a hose. During this process the two workers neglected to properly follow the safety protocol as they were videoed on a surveillance camera not wearing any safety gear/equipment (Jung 11216). Furthermore as they didn't have the hose properly secured when one of the workers fell from the tanker he disconnected the hose releasing the highly pressurized HF. This incident resulted in the deaths of 5 workers and another 18 injured along with affecting 12,243 residents as they were forced to leave their homes for 6 weeks. It also severely damaged 212 hectares of agricultural land along with killing 3,000+ animals (Lim 1284). During the few hours directly after release more damage than necessary was caused as first responders weren't fully equipped/briefed of the dangers with HF resulting in them having inadequate protective equipment and the HF being further dispersed after firefighters tried to put out the fires with water(Lim 1283).

The root cause for this incident is considered to be intentional omission due to the workers intentionally not wearing safety equipment while unloading the tanker and not following the procedure in the interest of saving time.

Hickson & Welch Limited Fire

The Hickson & Welch limited fire occurred on September 21, 1992 at Castleford, England. This facility was mainly responsible for the production of dyes, pesticides, and timber preservatives with the source of this incident being a batch still that retained residues of nitrotoluenes("Castleford"). This batch still was installed in 1961 and had never been cleaned resulting in a thick gritty sludge of 14 inches in depth coating the walls of the still. The engineers decided to pass steam through the still to soften the sludge. They did not analyze the composition of the sludge or determine the flammability of the gasses inside. The only safety measure they established was to keep the temperature below 90°C("Health"). The workers then used metal rakes to dislodge the sludge from the walls of the still. The rake created a static spark, which ignited the flammable vapors and resulted in a jet of fire erupting both horizontally and vertically for 1 minute. The eruption resulted in the ignition of numerous small fires and ultimately required over 100 firefighters to extinguish them. The resulting fire and blast killed 5 workers and injured 200 people, as well as caused over 3.5 million pounds in damages("Castleford").

The root cause for this incident is considered to be competency due to the inadequate safety protocols as they were unaware of all the dangers and risks associated with cleaning the still.

Georgia Poultry Plant Accident

The Georgia poultry plant accident occurred on January 28, 2021 in Gainesville, Georgia. In this plant large amounts of liquid nitrogen were used to freeze the chicken after it had been processed in order to safely store them for long periods of time. On the day of the incident workers entered the freezer area where the leak originated without any knowledge of the danger as all they could see was just a white fog that they thought was water vapor. As there were no gas sensors to detect the presence of nitrogen in the air, it was only when workers found themselves unable to breath that they knew that they needed to evacuate from the facility(Sharpe). This leak continued to spread until a maintenance manager was able to shut off an external isolation valve to the liquid nitrogen line finally stopping

the leak. After investigation it was discovered that this leak was most likely from improperly installed equipment that was done 4-6 weeks before the leak(Sharpe.

This incident resulted in the deaths of 6 people by asphyxiation with at least 10 others with significant injuries. This disaster could've been prevented if there were proper safety equipment in place like nitrogen gas sensors, lock-out/tag-out process for maintenance, and proper training on the risks and dangers of liquid nitrogen as most workers were not aware that it was used in the process. However while there were several system level failures that lead to this incident as the plant had a history of 4 OSHA (Reeds) violations in the past 10 years with other injuries like two finger amputations in 2017 the main cause of this incident was a "Competency" problem as the workers were unaware and untrained of the risks of a nitrogen leak and the signs, like the white fog, that could have served as a warning to evacuate.

Analysis

The following table summarizes all the incidents that were introduced in the previous section in order to organize the information for further analysis.

Table 1. Summary of Incidents with a Human Error Root Cause

Incident	Location	Date	Subcategories
LyondellBasell La Porte Fatal Chemical Release	La Porte, Texas	July 27, 2021	Accidental Commission
Sunoco Logistics Partners Flash Fire	Nederland, Texas	August 12, 2016	Competency
Loy-Lange Box Company Pressure Vessel Explosion	St. Louis, Missouri	April 3, 2017	Intentional Commission
Thiokol-Woodbine explosion	Woodbine, Georgia	February 3, 1971	Competency
HF Leakage	Gumi, South Korea	September 27, 2012	Intentional Omission
Hickson & Welch Limited Fire	Castleford, England	September 21, 1992	Competency
Georgia Poultry Plant Accident	Gainesville, Georgia	January 28, 2021	Competency

The table above was then used in order to analyze the various root causes and determine which human error root causes are the most common. The incidents analyzed in this paper are summarized in the figure below.

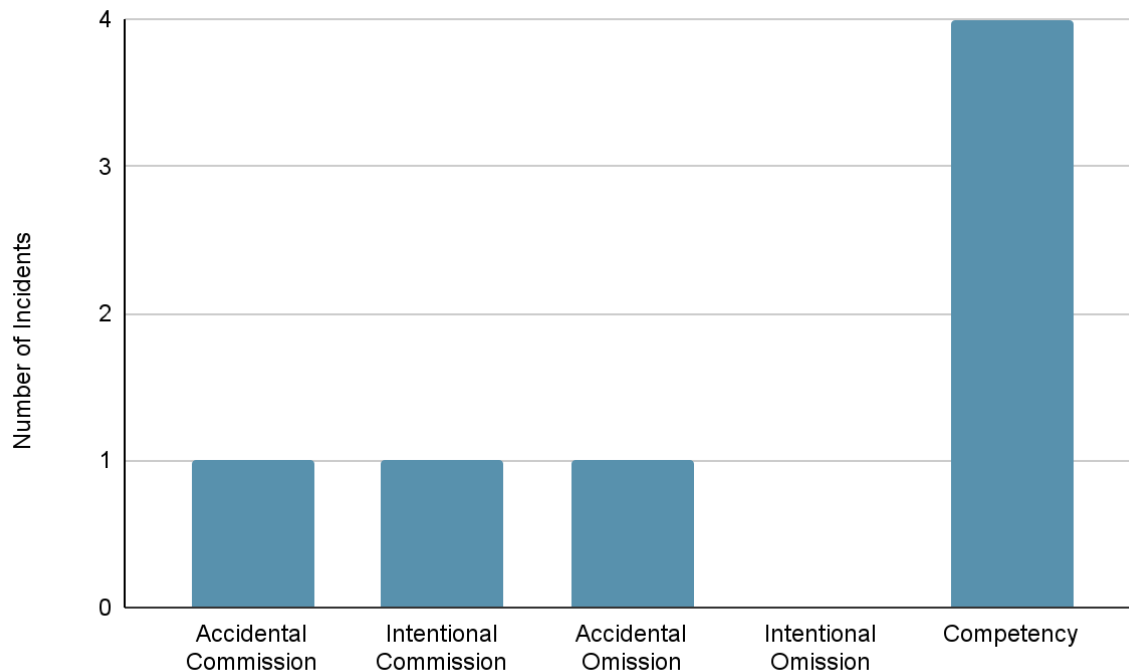


Figure 1. Summary of Incidents with Human Error Root Cause

Four out of the seven analyzed incidents were caused by errors regarding competency. Despite competency being the main root cause, these incidents were caused more by improper process operations and safety strategies than incompetent workers. Improper process operations and safety strategies cannot be classified under any other subcategory since the workers need to violate the procedures in order to qualify. If there are no procedures, then the root cause ultimately leads to competency.

There are three foundational problems that lead to incidents: competency of the workers, lack of proper process safety management, and absence of safety goals (Pasman). All four incidents shared the three foundational issues and it is highly likely that all four incidents could have been prevented had the workers and companies prioritized safety culture and adequate training of the proper procedures.

It is extremely difficult to anticipate all potential errors, however there are ways to mitigate some of the risks. There are two common methods to mitigate the risks associated with human error: human error identification techniques and task

analysis. These two methods will be analyzed in the following subsection of this paper and applied to one of the incidents in order to determine how it could have mitigated the risks of human error.

Human Error Identification and Task Analysis

The first step of identifying potential human error is to determine the level of risk that needs to be analyzed. It is important to analyze the scenario and assess the probability of various human errors in order to determine how unlikely the incident needs to be before it is beyond the scope of the analysis. The next step is to determine how the operations should proceed by using task analysis. According to Barry Kirwan, there are three elements that constitute an error:

- External Error Mode (EEM) is the external manifestation of the error.
- Performance Shaping Factors (PSF) influences the likelihood of the error occurring
- Psychological Error Mechanism (PEM) is the internal manifestation of the error

After identifying the errors, the consequences of the identified errors can then be analyzed (Kirwan). The probability of the errors is analyzed using Human Error Identification (HEI) techniques as a part of the Human Reliability Assessment (HRA) and the mitigation of these errors occurring is analyzed as a part of the Error Reduction Analysis (ERA).

There are various methods that may be employed for task analysis; however, the two most common methods are cognitive task analysis (CTA) and hierarchical task analysis (HTA) (Coursera). The CTA approach examines the thought processes required to complete a task, while the HTA approach examines the overall task by breaking it down and simplifying it into smaller subtasks. This paper utilizes the hierarchical task analysis since it is a better fit for this incident analysis.

The types of errors that contribute to these incidents are identified and included in the Human Error Identification (HEI) techniques (Kirwan). The list of HEI techniques has been continuously growing, which makes it a little difficult to determine the validity of many of the techniques as there is limited literature. Refer to Appendix A for the list of HEI techniques. There are five categories for the general

structure of the HEI techniques: taxonomies, psychologically based tools, cognitive modeling tools, cognitive simulations, and reliability-oriented tools (Kirwan). Some of these methods can get very complex and go beyond the scope of this paper; however, they are very useful tools when analyzing human error and it is important to keep them in mind. This paper utilizes two of the more accessible and user-friendly techniques: Systematic Human Error Reduction and Prediction Approach (SHERPA) and Human Factors Analysis and Classification System (HFACS). This paper initially researched Failure Mode and Effect Analysis (FMEA) and intended on using FMEA technique for analysis, however, it was much more difficult to employ than anticipated.

The Systematic Human Error Reduction and Prediction Approach (SHERPA) technique utilizes HTA and error taxonomy to identify potential human errors (Egham). This technique is used to identify each task step as one of the five following behavior types: action, retrieval, check, selection, and information communication. The utilization of the SHERPA provides an extensive analysis of potential human errors for an incident.

The Failure Mode and Effect Analysis (FMEA) is used to prevent process or system failure by exploring all potential failures and enhancing the design until all feasible errors are accounted for and no longer pose a risk to the operation (Sharma and Srivastava). This method was initially going to be included in the report, however, after further research, the HFACS technique was found to be much simpler and replaced FMEA in the analysis.

The Human Factors Analysis and Classification System (HFACS) analyzes historical data and breaks down the analysis to unsafe acts ("Human Factors Analysis and Classification System"). Unsafe acts consist of errors, which are unintentional, and violations, which are intentional.

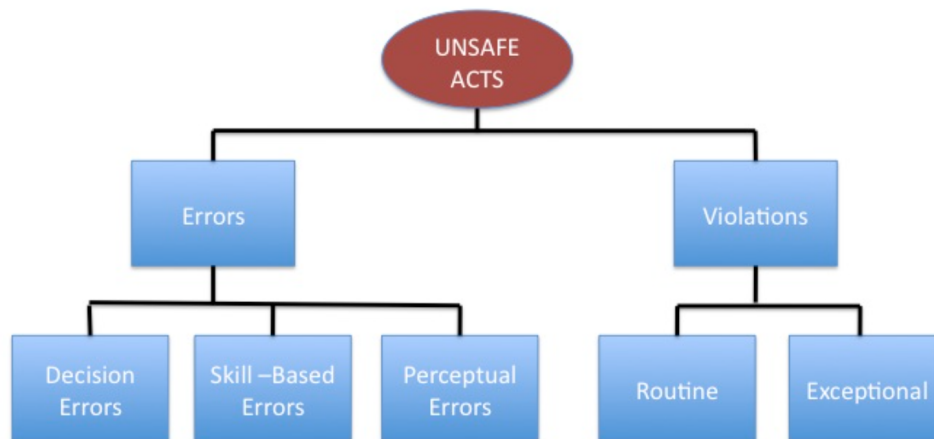


Figure 2. Human Factors Analysis and Classification System Unsafe Acts

Source: "Human Factors Analysis and Classification System (HFACS)." SKYbrary Aviation Safety, skybrary.aero/articles/human-factors-analysis-and-classification-system-hfacs#:~:text=HFACS%20provides%20a%20structure%20to,associated%20with%20an%20unsafe%20act.

SHERPA & HFACS Applied to Incident LyondellBasell Fatal Chemical Release Incident

The LyondellBasell fatal chemical release incident was analyzed in this section using both SHERPA and HFACS methods. The HFACS method was then employed and the errors from this incident were identified:

- Decision errors - Removing pressure based bolt nuts and a valve cover
- Skill-based errors - Inadvertently removing the final valve cover and plug when prying loose the stuck coupler from the plug
- Perceptual errors - Decided to go ahead with prying loose the stuck coupler even though it was attached to the plug, the only thing holding back the pressurized liquid

The violations were identified as:

- Routine - Sadly plug valve problems are not uncommon as 4 other serious incidents have occurred from the 1970s in North America alone. It is seemingly not uncommon for workers to be under-trained and unaware of the risks to ensure that the pressure-retaining bolts aren't removed and that the plug is left alone.

- Exceptional - Attempting to remove the stuck coupler is classified as an exceptional violation as this action should never have been performed and is not part of the standard procedure.

The SHERPA method was then employed and the task elements were written below:

1. Halted production so that the piping can be removed and repaired.
2. Used the upstream control valve equipped with manual hand jacks to stop the flow.
3. Removed the actuator from the plug valve to install a pipe tee over the valve stem.
4. Used a chain and padlock to lock the pipe tee to ensure that it is locked and unable to accidentally move.
5. Removed the insulation and the bracket mounting bolts.
6. Removed pressure-retaining nuts.
7. Removed actuator.
8. Removed the coupler from the valve cover. The force resulted in the plug ejecting from the plug body and acetic acid being quickly released, exposing the workers.

Table 2. SHERPA Analysis of LyondellBasell Fatal Chemical Release Incident

Task Element	Likelihood of Failure	Severity of Consequences	Likelihood of Recovery	Risk Index
1	M - 2	M - 2	M - 2	8
2	L - 1	M - 2	M - 2	4
3	M - 2	M - 2	M - 2	8
4	M - 2	M - 2	M - 2	8
5	M - 2	M - 2	M - 2	8
6	M - 2	M - 2	M - 2	8
7	H - 3	H - 3	H - 3	27
8	H - 3	H - 3	H - 3	27

H - High - 3; M - Medium - 2; L - Low - 1

This analysis illustrates that task elements 7 and 8 pose the greatest risks.

Conclusions

This research paper reviewed seven incidents where human error was a key factor and analyzed them in order to determine the subcategory within human error that was responsible for the incident. The types of human error were then analyzed in order to determine which subcategories pose the highest risk. It was determined through the analysis of this paper that the competency subcategory poses the highest risk. It was found that despite competency being the main root cause, the incidents were caused more by improper process operations and safety strategies than incompetent workers. Companies put themselves at higher risk with incidents due to their lack of adequate training and safety procedures as they make their employees incompetent. Majority, if not all, of the incidents could have been prevented had the companies provided adequate training, detailed operating procedures, and prioritized safety culture in the workplace.

This paper then employed two useful mitigation techniques, human error identification and task analysis, in order to analyze the LyondellBasell fatal chemical release incident. The incident was analyzed using two techniques: Systematic Human Error Reduction and Prediction Approach (SHERPA) and Human Factors Analysis and Classification System (HFACS). Ideally, additional mitigative techniques would be also employed in order to obtain a comprehensive list of the potential human errors. This would assist with further enhancing the design until all major errors are accounted for and no longer pose a risk to the operation.

Recommendations

In order to mitigate the risks of future incidents, companies should prioritize safety culture, provide adequate training for their workers, and develop detailed standard operating procedures for their workers to follow. Companies should also have workers understand the role that human error plays in incidents and employ various mitigation techniques in order to anticipate any potential errors prior to work being done.

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Appendix A

The following table identifies 38 various techniques:

Table 3. Human Error Analysis Techniques Reviewed

HAZOP*	HAZard and Operability Study technique (Kletz, 1974)
SRK*	Skill, Rule and Knowledge-based behaviour model (Rasmussen <i>et al.</i> 1981)
CMA*	Confusion Matrix Analysis (Potash <i>et al.</i> 1981)
Murphy Diagrams*	(Pew <i>et al.</i> 1981)
THERP*	Technique for Human Error Rate Prediction (Swain and Guttman, 1983)
DYLAM	DYnamic Logical Analysing Methodology (Amendola <i>et al.</i> 1985)
SHERPA*	Systematic Human Error Reduction and Prediction Approach (Embrey, 1986a)
IMAS*	Influence Modelling and Assessment System (Embrey, 1986b)
GEMS*	Generic Error Modelling System (Reason, 1987b; 1990)
PHECA*	Potential Human Error Causes Analysis (Whalley, 1988)
CADA*	Critical Action and Decision Approach (Gall, 1988)
TALENT	Task Analysis-Linked Evaluation Technique (Ryan, 1988)
HEMECA	Human Error Mode, Effect and Criticality Analysis (Whittingham and Reed, 1989)
HRMS*	Human Reliability Management System (Kirwan, 1990)
CES*	Cognitive Environment Simulation (Woods <i>et al.</i> 1990)
INTENT	[not an acronym] (Gertman, 1991)
SNEAK	[not an acronym] (Hahn and de Vries, 1991)
COMET	COMmission Event Trees (Blackman, 1991)
INTEROPS	INTEgrated Reactor OPERator System (Schryver, 1991)
TOPPE	Team Operations Performance and Procedure Evaluation (Beith <i>et al.</i> 1991)
TAFEI	Task Analysis For Error Identification (Baber and Stanton, 1991)
COSIMO	Cognitive Simulation Model (Cacciabue <i>et al.</i> 1992)
PREDICT	PRocEDURE to Review and Evaluate Dependency In Complex Technologies (Williams and Munley, 1992)
SCHEMA	Systematic Critical Human Error Management Approach (Livingston, <i>et al.</i> 1992)
PHEA	Predictive Human Error Analysis technique (Embrey, 1993)
TEACHER/SIERRA	Technique for Evaluating and Assessing the Contribution of Human Error to Risk [which uses the] Systems Induced Error Approach (Embrey, 1993)
COGENT	COGnitive EveNt Tree (Gertman, 1993)
CREWSIM	CREW SIMulation (Dang <i>et al.</i> 1993)
ADSA†	Accident Dynamic Sequence Analysis (Hsueh <i>et al.</i> 1994)
PRMA†	Procedure Response Matrix Approach (Parry, 1994)
CREAM	Cognitive Reliability and Error Analysis Method (Hollnagel and Embrey, 1994)
CAMEO/TAT	Cognitive Action Modelling of Erring Operator/Task Analysis Tool (Fujita <i>et al.</i> 1994)
CREWPRO†	CREW PROblem solving simulation (Shen <i>et al.</i> 1994)
SRS-HRA	Savannah River Site HRA (Vail <i>et al.</i> 1994)
EOCA	Error of Commission Analysis (Kirwan <i>et al.</i> 1995)
SYBORG	System for the Behaviour of the Operating Group (Takano, <i>et al.</i> 1996)
SEAMAID	Simulation-based Evaluation and Analysis support system for MAN- machine Interface Design (Nakagawa <i>et al.</i> 1996)
ATHEANA	A Technique for Human Error ANalysis (Cooper <i>et al.</i> 1996)

Note: Acronyms marked with an '*' were reviewed in Kirwan (1992a, b), those marked † are this author's acronyms for the techniques, since the authors did not supply one in the original reference reviewed.

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