Human Error in Process Safety

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Key Terms:

1. Human Error: Error resulting from an individuals or groups mistakes rather than error caused by the process.
2. Omission Unintentional: Error caused by a worker accidentally omitting steps in the procedures.
3. Omission Intentional: Error caused by a worker intentionally omitting steps in the procedures.
4. Commission Intentional: Error caused by intentionally altering the procedures or performing them incorrectly.
5. Commission Unintentional: Error caused by accidentally altering the procedures or performing them incorrectly.
6. Competency: The ability of a worker to perform a task correctly or to recognize dangerous situations.
7. Human Error Mitigation: Techniques that can be used to help prevent incidents caused by human error.

Abstract:
The objective of this report is to present a detailed insight on human error and its effects on process safety. In this report, human error will be broken down into 5 types of human error. These categories include omission (intentional), omission (unintentional), commission (intentional), commission (unintentional) and competency. The most beneficial human error mitigation techniques explored are to perform a task analysis and to perform a human error identification analysis. The human error identification analysis can be further broken down into Human Factor Analysis (HFACS) and Systematic Human Error Reduction and Prediction Approach (SHERPA). These mitigation techniques work by structurally breaking down incidents to expose the root causes. The two main incidents looked at for the purpose of this report are the Formosa incident and the BP Amoco incident. The reason these two incidents were chosen is because they are well documented and they are both caused by human error. After further research, it was determined that the Formosa incident should be classified as unintentional commission and the BP Amoco incident should be classified as unintentional commission.

Introduction

Human Error at the operational level is a primary contributing factor for many process incidents. Although the error occurs at the operational level, improper designs, poor procedures, and poor process safety are often the underlying causes of the error. The importance of planning for human error when designing the process or creating the procedures is vital when trying to mitigate error. The objective of this report is to explore error minimization techniques that can be applied to these different process levels.

Possible error mitigation techniques that can be applied include task analysis and human error identification techniques. These analyses are often used in the nuclear and aerospace industries, however, they have not been applied to many processes in the petrochemical, chemical or petroleum industries. Task analysis is useful to describe a process by breaking it down into smaller components. A task analysis can be applied to analytically evaluate a process and determine likely error scenarios.

Human error identification is another technique that can be applied to help prevent human error. This technique can be used to evaluate the likelihood that errors will occur in a given task. The two human error identification models focused on in this report are HFACS and SHERPA. Once these tools have been applied, the process can then be adjusted to minimize the possibilities of human error.

Results:

Table 1 below, shows the different types of human error which include intentional omission, unintentional omission, intentional commission, unintentional commission, and competency.

Table 1: Five Categories of Human Error

Types of Human Error	Definition
Intentional Omission	Error caused by people intentionally omitting steps in the procedures
Unintentional Omission	Error caused by people accidentally omitting steps in the procedures
Intentional Commission	Error caused by individuals/ groups intentionally altering the procedures or performing them incorrectly
Unintentional Commission	Error caused by individuals/ groups accidentally altering the procedures or performing them incorrectly
Competency	Error caused by individuals who aren't capable of performing a task or recognizing hazardous situations

For this report, seven different incidents were investigated and broken down into these categories of error. These incidents are shown in table 2 below:

Table 2: Incidents Caused by Human Error

Incident	Location/ Date	Type of Human Error
T2 Laboratories Explosion	Jacksonville, Fl, Dec 2007	Competency
Windscale Fire	UK, 1957	Competency
CH_3Cl Leak at Dupont	Belle W Virginia, 2010	Intentional Omission
Formosa	Pennsylvania, March 1979	Unintentional Commission
BP Amoco	Georgia, March 2001	Unintentional Commission
Danvers Explosion	Danvers Massachusetts, 2006	Unintentional Omission
Formosa Explosion	Illinois, April 2004	Unintentional Commission

T2 Laboratories Explosion

The first incident in the table is the T2 Laboratories explosion, which occurred in Jacksonville Florida on December 2007. The facility specialized in designing and producing specialty chemicals. They produced the chemicals in a 2500 L batch reactor with a cooling jacket to control the exothermic reaction. On December 19, 2007 the reaction overheated resulting in an explosion with a force of 1,400 lbs of TNT. The explosion resulted in 4 fatalities and 32 injured. Of the 32 injured only 4 worked at T2 Laboratories, the other 28 individuals worked at nearby facilities. The underlying cause of the incident is because of improper reactor scale-up. The system had no backup cooling system and the rupture disk was inadequate. This incident was categorized as 'Competency' because of the improper reactor scale-up and the failure to recognize hazardous situations.

Windscale Fire

The Windscale fire incident occurred in 1957 and is the largest nuclear incident for the UK. The root causes of the incident were improper reactor and casing designs. In a desperate attempt to match the United States and Soviet Union's nuclear power, the UK began to construction of the Windscale plant. The plant was constructed to produce small amounts of plutonium. However, political pressure resulted in an increased rate of plutonium being produced as well as tritium. Due to the high demand for plutonium and tritium needed, the uranium casings were reduced in size. This made the uranium much more likely to overheat and catch fire. On October 10, 1957, the operators noticed that channel 2053 was overheating. They turned the fans on to reduce the heat, however, what they didn't realize was that there was a fire in channel 2053. Immediately after turning the fans on the fire began to spread throughout the chimney. The fire continued for hours until the fans were finally turned back off. This incident was categorized as 'Competency' because of the operator's inability to recognize and deal with the hazards.

Methyl Chloride Leak at Dupont

The next incident is the methyl chloride leak at the Dupont plant in Belle West Virginia. This incident occurred in 2010 and resulted in over 2000 lbs of methyl chloride being leaked over a 5 day period. The leak occurred due to a burst rupture disk which sent an alarm to the control room. The operators ignored the alarm assuming it was a false alarm. This incident is a good example of 'Intentional Omission' because the operators chose to ignore the alarm rather than perform maintenance.

Formosa Nuclear Incident

The Formosa Incident occurred in Pennsylvania in March 1979 and became the largest nuclear incident in the history of the United States. The incident began around

4:00 am on March 28 when a malfunction allowed the reactor coolant to overheat. A release valve then automatically opened to allow enough heated coolant to escape to reduce pressure. The release valve was only meant to open for 10 seconds, however, the valve became stuck and remained open. This allowed most of the coolant to be released. The system then began to add new coolant to the reactor, but the engineers reduced the flow of coolant into the reactor. This caused the reactor to overheat leading to a partial meltdown. This incident was categorized as ‘unintentional commission’ because the engineers hindered the system’s safeguards by reducing the coolant flow.

BP Amoco

The BP Amoco thermal decomposition incident took place in March 2001. The operating unit was shut down for repair of equipment failure in the extruder prior to the incident. The level detector in the vessel was often reported as damaged or malfunctioning. On the day of the incident, the lead operator chose not to perform a number of tasks on the normal startup checklist. An attempt was made to start the production unit but after approximately 1 hour, the startup was aborted due to problems with the extruder downstream of the reactor–but not before an unusually large amount of partially reacted material had been sent to the polymer catch tank. The vessels were flushed and instructions were left for the night shift to empty the polymer catch tank and the reactor knockout pot of polymer that had accumulated during the aborted startup. Other than the nitrogen line, no connections to the polymer catch tank were locked or tagged.

The maintenance technician began removing bolts on the cover of the tank in order to empty it but the removal of each bolt gradually reduced the restraining capacity of the cover, resulting in an explosive release of pressure. This incident was categorized under ‘unintentional commission’.

Danvers Explosion

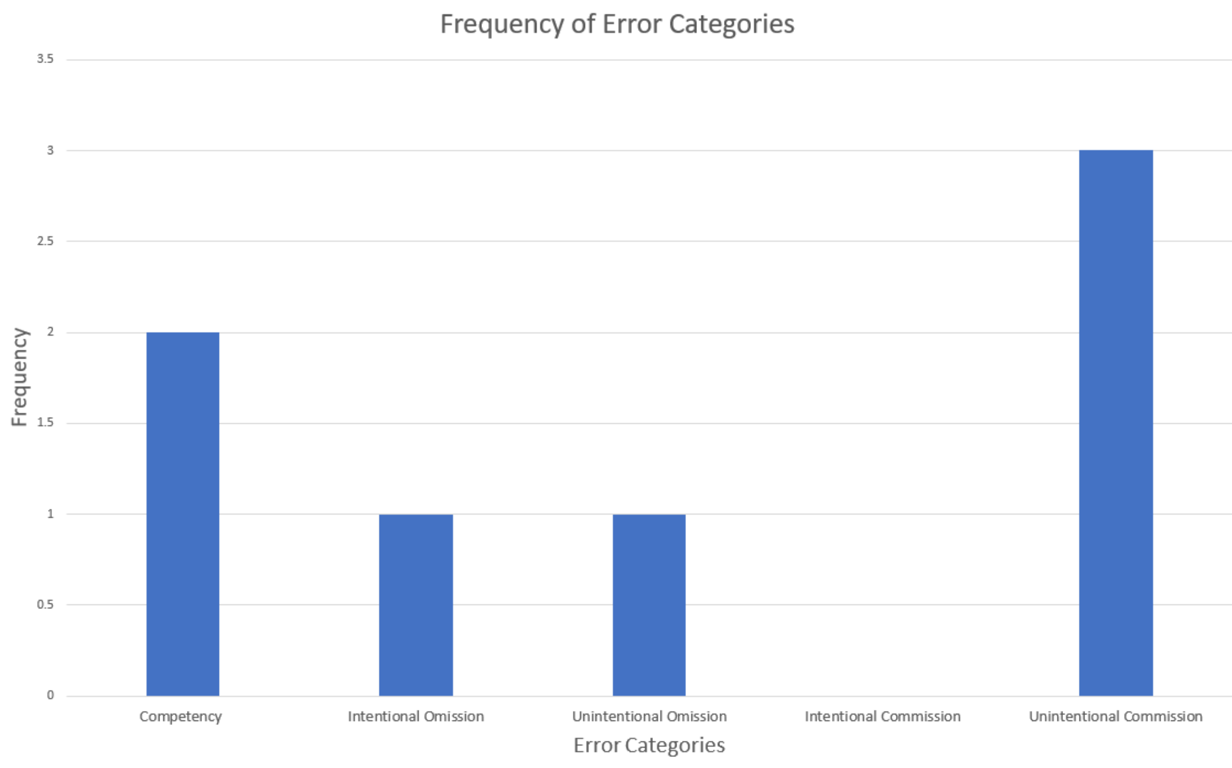
The CAI Inc. facility specialized in producing paints and inks. The process for producing these chemicals contained several flammable materials, such as heptane and propyl alcohol. In November of 2006, an operator forgot to turn off the heating steam to a 10,000 lb tank of flammable solvents. The solution in the tank began to overheat allowing flammable vapors to escape the tank and fill the unventilated building. The vapor then ignited and caused a massive explosion around 3:00 am. The force of the explosion resulted in the destruction of at least 16 nearby homes. This accident is categorized as ‘Unintentional Omission’ because the operator forgot to perform a routine step, which resulted in the explosion.

Formosa

In April 2004, an operator at the Formosa Plastic Vinyl Chloride Plant begin the cleaning cycle for reactor 306. After spraying the reactor with high pressured water, he walked to the lower level to drain the water out of reactor 306. The reactor turned the wrong direction and began trying to open the bottom valve and drain valve for reactor 308, which was under high pressure. The interlock system prevented the bottom valve from opening. Without checking that he was working on the correct reactor the operator bypassed the interlock system to open the bottom valve. The content in the reactor began to shoot out filling the plant with vapor. The operators then began trying to close the valves until a spark ignited the vapors causing an explosion. The explosion resulted in 5 deaths and a community-wide evacuation.

The graph below demonstrates the most likely type of error based on the incident samples taken. According to the table, the category with the highest number of incidents is unintentional commission. It can also be seen from the table that none of the incidents looked into were categorized as intentional commission

Figure 1: Graph showing the frequency of human error categories



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Mitigation Techniques

In this report, two major mitigation techniques were analyzed; Task Analysis and Human Error Identification.

Task Analysis is a technique that describes the structure and organization of different tasks required to meet the overall objective of the job [1]. In order to analytically evaluate a task and account for all possible error scenarios, a task analysis must be performed. There are multiple methods that can be employed when carrying out a task analysis, for example, Hierarchical Task Analysis (identifying the overall goal of the task, then the various sub-tasks and the conditions under which they should be carried out to achieve that goal), Flow or sequence diagrams (activities required to perform the task represented as a flow chart).

For the task analysis, various amounts of information are needed in order to fully understand the task at hand. The information is collected using methods aimed at providing qualitative and quantitative data to assess human performance [1]. Some of these methods include:

- Discussions and interviews with experts including workers, supervisors, trainers, safety specialists
- Observation of actual performance
- Critical incident technique: near-miss reports
- Documentation: operating and emergency procedures
- Activity analysis: analyzing the actual procedure sequentially
- Simulations and mock-ups

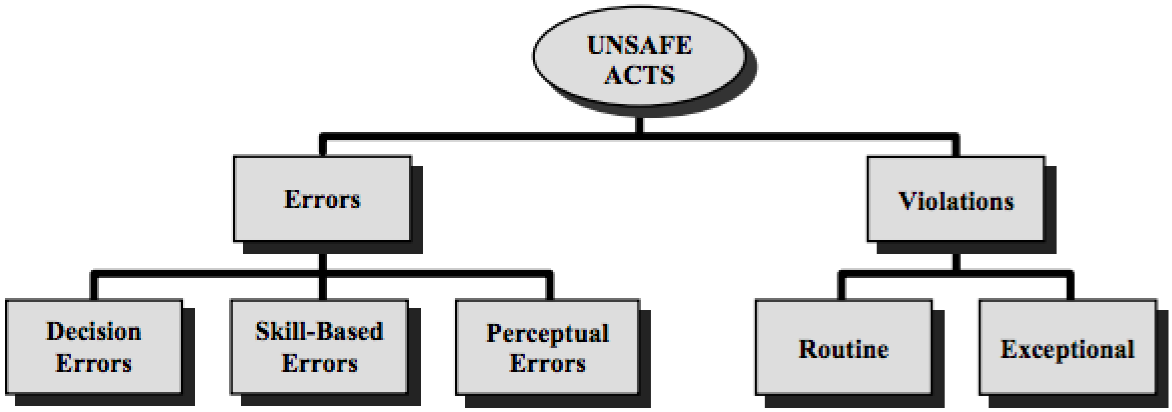
Once the task analysis has been performed, a number of error analysis techniques can be employed to assess the day-to-day operations and exhaustively identify any possible errors in the process. When the worker's role has been defined and their tasks properly laid out, the possible human failures and consequences can be identified for both normal working conditions and worst-case scenarios. A risk assessment can be performed and different error reduction strategies can be developed to reduce the potential errors.

Human Error Identification is a qualitative and quantitative approach to determine the likelihood of error for a certain task or process. There are a number of Human Error Identification models, in this report, we focused on HFACS and SHERPA.

Human Factor Analysis and Classification System (HFACS) is a human error framework that was originally used by the US Air Force to investigate and analyze human factors aspects of aviation. This method of identification is based on the Swiss Cheese model of error causation, it attempts to define what the "holes in the cheese" really are within the context of everyday operations. With regards to human error, one of the levels of failure is 'Unsafe acts' and can be divided into two categories; errors and violations - these categories are further divided into subcategories as seen in Fig. 2.

Errors are unintentional behaviors, while violations are a willful disregard of the rules and regulations

Figure 2: Hfacs framework for Unsafe acts



Systematic Human Error Reduction and Prediction Approach (SHERPA) is used to analyze and quantify errors in different processes [2].
To start with, the incident in question is analyzed and all the tasks/ steps that were potentially due to human error are identified.
Next, the tasks are classified by associating them with possible errors in Table 3 [2].
An investigation of each error is then undertaken using various analyses. The analyses include:

- Consequence Analysis: What is the consequence of the error?
- Recovery Analysis: Can the error be recovered and if so how?
- Probability Analysis: What is the probability that the error will occur (high, medium or low)?

The errors are ranked as High (H), Medium (M) or Low (L) for the 3 different analyses and each is assigned a value on a scale of 1 to 3 depending on their ranking. The High being 3 and Low 1, except for the recovery analysis where the scale is interchanged. Each task should have a Risk Index between 1 to 27.

Table 3: Possible error classifications

Error type	Code	Error Mode
Action Errors	A1	Operation too long/short
	A2	Operation mistimed
	A3	Operation in wrong direction
	A4	Operation too little/much
	A5	Misalign
	A6	Right operation on wrong object
	A7	Wrong operation on right object
	A8	Operation omitted
	A9	Operation incomplete
	A10	Wrong operation on wrong object
Checking Errors	C1	Check omitted
	C2	Check incomplete
	C3	Right check on wrong object
	C4	Wrong check on right object
	C5	Check mistimed
	C6	Wrong check on wrong object
Retrieval Errors	R1	Information not obtained
	R2	Wrong information obtained
	R3	Information retrieval incomplete
Communication Errors	I1	Information not communicated
	I2	Wrong information communicated
	I3	Information communication incomplete
Selection Errors	S1	Selection omitted
	S2	Wrong selection made

For this report, SHERPA was performed for two incidents; BP Amoco and Formosa. Below are the results;

BP Amoco

Task

1. During pre-startup checks, operators decided it wasn’t necessary to re-purge the extruder since it had been purged approx. 4 hrs earlier
2. The extruder was not prerun to verify operability
3. Extruder failed to start. Molten polymer continued to be directed to extruder while staff attempted to diagnose the problem

4. Startup aborted, flow of raw materials stopped, and flushing solvent injected to clean equipment. However, molten polymer continued to accumulate because extruder wasn't open
5. Unclear communication and instructions left for the night shift to empty polymer accumulated during failed startup
6. No connections to polymer catch tank were locked or tagged
7. Bolts removed on tank, resulting in an explosive release of pressure and ejection of molten liquid.

Table 4: SHERPA for BP Amoco incident

Task element	Error mode	Probability	Consequence	Recovery	Risk Index
1	C1	M - 2	M - 2	M - 2	8
2	C1	L - 1	M - 2	L - 3	6
3	A4	L - 1	M - 2	M - 2	4
4	A4	L - 1	M - 2 / H - 3	M - 2	4 / 6
5	I3	H - 3	M - 2 / H - 3	M - 2	12 / 18
6	A8	L - 1	H - 3	M - 2	6
7	C1	L - 1	H - 3	L - 3	9

From the analysis, it can be seen that Tasks 1, 5 and 7 were the most error-prone.

Formosa

Task

1. During the reactor cleaning process, an operator turned right towards reactor 308 rather than turning left toward reactor 306
2. The operator did not check to ensure that he was working on the correct reactor and began to open the bottom valve and the drain valve
3. The inner lock on the bottom valve prevented the valve from opening, but the reactor ignored this warning sign
4. The operator then bypassed the interlock which released PVC vapor into the plant
5. The operators chose to stay and stop the leak rather than evacuating

Table 5: SHERPA for Formosa incident

Task element	Error mode	Probability	Consequence	Recovery	Risk Index
1	A6	M - 2	M - 2	M - 2	8
2	C1	L - 1	M - 2	M - 2	4
3	C1	L - 1	M - 2	M - 2	4
4	A10	L - 1	M - 2 / H - 3	L - 3	6 / 9
5	A8	M - 2	M - 2 / H - 3	L - 3	12 / 18

From the analysis, it can be seen that Tasks 1, 4 and 5 were the most error-prone.

Expert Industry Input

Over the course of this project, we were able to interact with professional engineers, from two companies (aE Solutions and Phillips 66), whose daily tasks revolve around process safety in industry.

From aE Solutions, we were provided with a summary of safety principles and processes related to human error using a ‘mind map’ which can be found in the appendix of this report. A suggested error mitigation technique was the use of human reliability models. This method of analysis involves the use of Task Analysis and Human Error Identification to determine the probability of errors in certain tasks, using gathered information and evidence. The principles of developing human reliability models stems from the Bayes’ Rule, which is a formula that describes how to update the probabilities of hypotheses when given evidence. In order to develop the models, in depth analysis of previous incidents and tasks are performed taking into consideration various factors. With the new information, one can more accurately predict the cause of human error and take active steps towards mitigation.

When consulting with companies to mitigate human error, aE Solutions focuses on the following; competency, training, procedures and employee engagement. Addressing/ improving competency is the most pertinent solution they recommend. Competency was defined as an individual’s subject matter expertise and their ability to carry out certain tasks using intuition. This would come in handy during unexpected accidents, because the workers would be able to quickly react, trying to solve / mitigate the problem before any catastrophic consequences, i.e the probability of recovery would be significantly increased.

With Phillips 66, we were fortunate to interact with an engineer who is part of a Global Benchmarking committee tasked with improving process safety in industry. She mentioned that the biggest task and challenge surrounding understanding and improving safety in industry is the lack of 'good data'. Good data was defined as more detailed investigations of incidents and accidents that occur in industry, gathering as much information as possible from the relevant parties and focusing on the analysis of possible error precursors. The deeper investigation of the causes of incidents can help individuals better understand the "exact why's" of different situations, which would help perform better task analyses.

In a bid to improve workplace systems, Phillips 66 is currently focusing on reliability improvement. According to their investigations, it was determined that the majority of the errors involving human interactions were knowledge based errors.
In order to improve reliability, they are focusing on efficiently conveying information to each of the workers, therefore, they have been re-working their operating procedures and making them easier to understand.

To start, as much information as possible is obtained about the day to day operations in the plant and the different tasks carried out. Next, they look for error precursors in everyday critical tasks (currently they have identified approximately 65 critical tasks).

The tasks are then ranked by criticality using a template obtained from nuclear engineering procedures. Precise, short and generic procedures are then developed for each task. Multiple employees in different roles are then asked to walk through the task e.g. from subject matter experts to low level employees who might be asked to perform the task. They are asked to challenge the procedures for any unclear pieces of information and the procedures are refined accordingly, making sure to build-in the capacity for failure. The goal of modifying the procedures is to reduce the chance for human error and to make sure the people on the ground who work directly with the equipment can give feedback and actively participate in developing a model that provides them the highest chance of success.

Conclusions

In this report, we have studied different error analysis and prediction techniques and it can be concluded that the best way to reduce the occurrence of error is to improve the reliability of different tasks in a bid to try and error-proof processes. From research and statistics, it is suggested that most of the errors attributed to human interactions are knowledge-based errors, i.e. mistakes made due to lack of knowledge. A possible mitigation technique is to perform a thorough task analysis that should be performed for all tasks, i.e. for both normal operating conditions and worst-case scenarios. The tasks can then be ranked by criticality and error precursors identified for each of the everyday critical tasks.

From the incidents researched, the major causes of human error are unclear operating procedures and communication. Therefore, when the error precursors have been identified and as much information as possible has been gathered about the process, it is recommended to develop more clear operating procedures. It is important that the procedures be precise, short and generic. Simplifying the procedures is a good method to reduce the probability of errors. Once the procedures have been developed, it is important to screen and test them with different levels of personnel to ensure that everybody can easily follow them.

Another mitigation technique is to use different error prediction techniques to predict tasks with a high probability of human error. After identifying the most error prone tasks, additional exhaustive analyses can be applied to further study the task and identify specific pitfalls that lead to an increase in human error. Active error reduction strategies can then be developed in order to mitigate and avoid the repetition of the identified problem areas.

Recommendations

To provide a more in depth understanding of human error and the effect it has on process safety it is recommended that the task analyses presented in this report be further explored. These possible mitigation techniques could be further applied to other incidents mentioned in this report. Another recommendation to better understand human error, is to expand the number of incidents reported on. Of the seven incidents researched, none fell into the commission intentional category. Expanding the quantity of human error incidents researched could provide a better understanding of human error and allow more in depth patterns to be observed.

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Appendix

aE Solutions - Mind Mapping