

RESEARCH REPORT

TOPIC

“Human error is an all too common root cause of process safety incidents. Develop a list of serious process safety incidents where human error was determined to be a key factor.”

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EXECUTIVE SUMMARY:

Humans are involved at every stage of the life cycle. Human errors can happen in any situation because of different people and different mindsets. However, since many industrial safeguards are there to help on technology or mechanical failure, processes are not effectively protected from human errors. Human errors are the reason for almost 90% of industrial accidents around the world. Few such incidents are Vinyl chloride monomer explosion at Formosa facility in the year 2004, Propylene explosion at Formosa facility in the year 2006, BP Texas city incident in 2005, CAI/Arnel Chemical Plant Explosion in 2006 and recently MGPI Processing, Inc. Toxic Chemical Release in 2016. Apart from these incidents there are many more incidents that have happened because of human errors.

All these accidents began with small human errors like negligence at work, lack of proper communication, poor supervision, bypassing safety measures, not being attentive on duty, bad safety culture at work, poor safety knowledge and deviating from the PSM elements. Such small human errors can result in fatalities for employees working in the facilities and billions of dollars loss for companies. These human errors happen either unintentionally or because the employee thinks their method is superior. Typically, intentional mistakes are regarded as errors of judgment. Some claim that these mistakes are the result of a lack of risk awareness, but, the worker who makes an intentional mistake is well aware of the risk. Instead, some think they have a superior solution or that there are currently too many levels of security in place. It is expected that all the industries conduct process hazard analysis (PHA) regularly and be ready for worst case scenarios, but it's also shocking that many small industries don't even know that something called PHA exists.

These Human errors can be minimized by conducting process hazard analysis (PHA) at the industries and follow strict standard operating procedures with making logbook entry mandatory for both operator and supervisor for any kind of human involved operation at potential accidental risk. Companies might use human error identification analysis like SHERPA and THERP to know the potential risk at their facility and prepare their mitigating measures.

CSB always recommends all the companies to follow OSHA, PSM latest standards and make sure that chemical procedures are created to reduce the effects of human mistake and suggest companies to thoroughly investigate their high-risk hazards in the facilities by considering all near miss incidents consequences.

INTRODUCTION:

At any type of industries which involves manufacturing processes Human error is the major reason for the many industrial process accidents. Even though the mistake happens at the process level it generally has improper designs, inferior processes, and bad safety training as its underlying causes. Because of important occurrences where human error played a large role, awareness of human factors and reliability has grown dramatically during the past few years. All these disasters, as well as others, have revealed various human faults and mistakes, some of which were not widely known before the tragedy. Chemical industries incidents happening mostly due to human error while operation and organizational factors. In this report we will see how we can prevent such human errors from happening in the industries.

Here is the list of few such disastrous incidents happened due to human error:

1. Vinyl chloride monomer explosion at Formosa, Illiopolis, IL - 2004
2. Propylene Explosion at Formosa, Point Comfort, TX - 2006
3. BP Texas City - 2005
4. CAI / Arnel Chemical Plant Explosion - 2006
5. MGPI Processing, Inc. Toxic Chemical Release - 2016

Further we will be seeing what caused these disasters and how they could have prevented these disasters from happening.

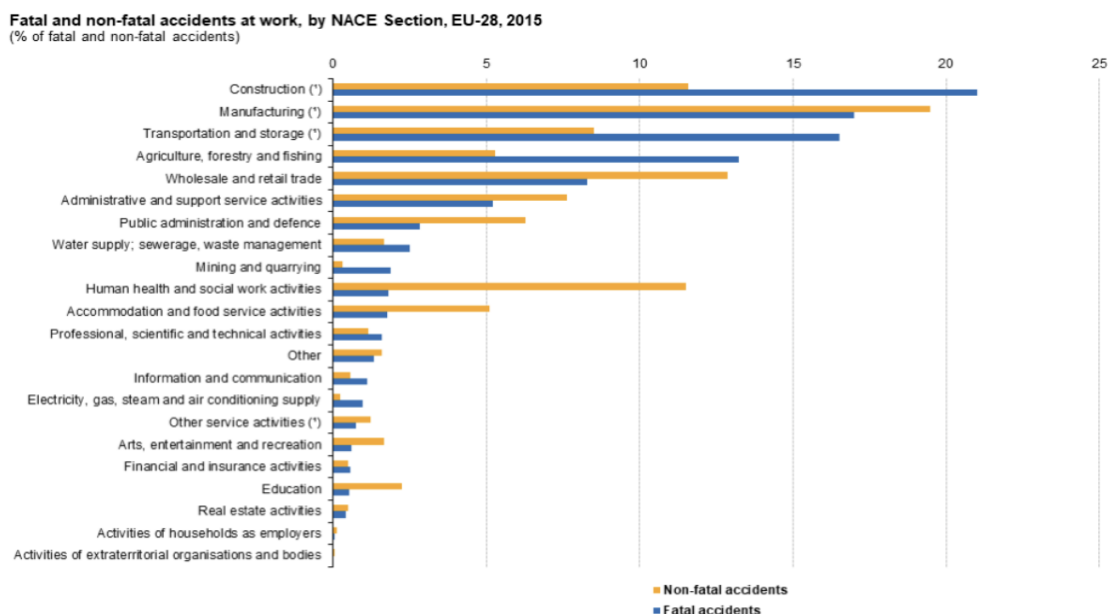


Fig 1. Graph showing accidents caused by Human errors in all industries.

LITERATURE REVIEW:

After reading and reviewing the investigation reports published by CSB on the incidents mentioned in this report, A combination of different human errors contributed to about 90% of the accidents I investigated. Chemical accidents were shown to be more frequently caused by human error than by violations, and analysis revealed that action errors rather than thinking errors were more common in mishaps. It was determined that many accidents happened because of a combination of inadequate knowledge and training regarding the risks posed by chemicals, unintentional work errors, a lack of education, a failure to conduct risk assessments, a failure to obtain work permits, and other factors. One can understand after reading investigation reports of Formosa blast 2004 and MGPI processing incidents it was clearly the fault of operators; in one case the operator bypassed the safety interlock system which was installed as a safety measure and in other case operator just left the unloading work to the truck driver who don't even know the potential risks of the chemical he's unloading. Going through these reports deeply we can see proper needed recommendations from the CSB.

INCIDENTS:

1. Vinyl chloride monomer explosion at Formosa, Illiopolis, IL - 2004

Incident description:

Workers in the factory heard a very loud tremor around 10:30 p.m., and some of them smelled like VCM. The shift supervisor and operators in the reactor building's south end heard the Paste section flooding alert, which signaled the activation of the downpour system in that area.

To monitor the reading from the vinyl chloride gas detection system, the supervisor went outside the control room. Two regions, according to the shift supervisor, had levels that were beyond the instrument's quantifiable limit, indicating a significant release. On his way to look into the release, he claimed to have passed an open doorway in the area next to reactor leaking and noticed material spewing out of the bottom of the reactor as well as a foaming substance about 1 foot deep on the floor. Operators on the top level of PVC1

reported that the pressure on the reactor was rapidly dropping to the shift supervisor. He told two operators that he had observed stuff spraying from reactor's bottom, and they started investigating reactors valves and controls right away. High VCM concentrations prevented the supervisor and one operator from descending through an inner stairwell to the lower level.

To release pressure and slow the discharge, the shift supervisor gave the order to the operators to open the vent valves on the reactor. Supervisor saw that the reactor pressure had dropped, further showing a significant leak.

The shift supervisor was attempting to descend an external stair to the lower level when several explosions started to take place. The explosions damaged the engineering, safety, and lab offices as well as the laboratory. The ensuing fire burned for hours, sent a plume of bad smoke into the neighborhood, and ultimately spread to the PVC store the other side of the reactor building.

As a result, authorities immediately evacuated 150 residents living around. This incident also resulted in the destruction of the plant and never reconstructed.

Human error:

when a facility employee opened the wrong valve, spilling the contents of a running PVC reactor. According to studies, a significant portion of deaths, injuries, and property damage in the chemical sector are caused by human error. Here things like reactors layout, communication, lack of safety knowledge and negligence resulted in the accident. If there were separate operating controls for different reactors this wouldn't have happened, communication also played a major role as there was no proper communication between operator on the high level and operator on lower level, they couldn't realize the mistake they have done. When operator tried to open bottom valve and drain valve, the bottom valve did not open as the Interlock was built to perform this as a safety mechanism while the reactor was under pressure to prevent an unintentional release. It did this by cutting off the air supply to the valve actuator. However, the operator chose to work around the interlock rather than knowing why that valve was closed, which led to the explosion. This step shows the negligence and lack of safety

knowledge. If he would have double checked why that bottom valve was not opened in the first place this accident wouldn't have occurred.

Problem analysis:

Process hazard analysis (PHA) is one of the tools for evaluating the human errors in the industries. This tool analyzes the potential threats from process hazard scenarios and human errors where there are chances for accidents, then gives safeguards and recommendations to avoid those accidents.

When the PHA team identified the potential threat of PVC process that involved the reactor components drain valve and bottom valve they accepted that the safety interlock system of bottom valve when pressure builds up will be helpful to avoid accidental release. Which eventually stopped the accidental release at a point of time.

Here the management of Formosa completely relied on the bottom valve interlock system to avoid accidental release which can be easily bypassed. Management could have set few rules or given authorization only to high level operators to bypass such safety measure.

Risk Assessment 5 x 5 Matrix														
Risk Likelihood	Severity					Risk Likelihood Definitions			Assessment Values	Meaning	Accountable Organizations			
	Catastrophic A	Critical B	Moderate C	Minor D	Negligible E	Likelihood	Chance of event	Value						
5 - Frequent	5A	5B	5C	5D	5E	Frequent	1 in 100	5	5A, 5B, 5C, 4A, 4B, 3A	Unacceptable - requires immediate action.	Risk Review Board and VPs of relevant departments.			
4 - Likely	4A	4B	4C	4D	4E	Likely	1 in 1,000	4	5D, 5E, 4C, 3B, 3C, 2A, 2B	Manageable under risk control and mitigation.	Managing Directors and Risk Review Board.			
3 - Occasional	3A	3B	3C	3D	3E	Occasional	1 in 10,000	3						
2 - Seldom	2A	2B	2C	2D	2E	Seldom	1 in 100,000	2	4D, 4E, 3D, 2C, 1A, 1B	Acceptable after review of the operation. Continued tracking and recorded action plans are required.	Managing Directors and relevant organization levels.			
1 - Improbable	1A	1B	1C	1D	1E	Improbable	1 in a million	1						
									3E, 2D, 2E, 1C, 1D, 1E	Acceptable - continued data collection and analysis for improvement is required.	Department Managers and relevant organization levels.			
Severity of Occurrences														
Severity	Impact to...										Value			
	Personnel Safety	Resources		Work Performance	Property Damage	Reputation								
Catastrophic	Multiple deaths		Institutional resources required		System-wide shutdown Operation suspension		Large environmental impact Equipment destroyed		Uncontrollable public relations events		A			
Critical	Serious injury or death		Institutional resources required		Major operational disruptions		Medium environmental impact Moderate equipment damage		Loss of confidence		B			
Moderate	Moderate to life impacting injuries		Additional resources required		Significant delays		Small environmental impact		Damaged		C			
Minor	Minor injuries		Moderate impact		Modest delays		No environmental impact Slight equipment damage		Potential damage		D			
Negligible	No injuries		No impact		No delays		Minor		No impact		E			

Fig 2. Process Hazard Analysis (PHA) What-If Automated Excel Spreadsheet

Conclusion:

This accident took place because of:

- Borden chemicals the constructor of the plant did not implement 1992 PHA recommendations.
- The operator easily bypassed the bottom valve interlock system where it was placed as a safety measure.
- Because of lack of communication there was no way for operator on the lower level to know if a reactor was active or not.
- Both Borden chemicals and Formosa failed in addressing the potential human errors.

Recommendations:

- CSB recommended Formosa to review their designs and operations of all its plants in USA.
- CSB also recommended Formosa to Assure chemical processes are built to reduce the effects of human mistake, enhance control of safety interlocks, more thoroughly assess high risk risks by taking all ramifications into account in near miss investigations, and enhance emergency actions including fast evacuations with regular drills.

2. Propylene Explosion at Formosa, Point Comfort, TX - 2006

Incident description:

A trailer being driven by a forklift became tangled on 6th of October 2005, at 3:00 PM, the right corner of a trailer struck a valve in the high-pressure liquid propylene flowing pipeline. The leaking propylene rapidly developed into a huge flammable vapor cloud. The factory was immediately shut down as personnel searched for the leak. They tried to locate and close manual valves that could have halted the discharge, but the vapor cloud that was growing compelled them to retreat. Employees in the control room turned off pumps, cut off valves, and vented machinery to the flare stack to divert flammable gases away from the fire.

Around 3:00 PM, the vapor ignited, causing an explosion. The flames of the fire reached a height of more than 500 feet. Because of the size of the fire, Formosa ordered a thorough site evacuation and evacuated all the employees on the site. In this incident 14 workers were treated for minor wounds and smoke inhalation. Due to significant damage, the facility had to be shut down for five months.

Human error:

This incident it began with very simple event in which a valve was struck by a forklift vehicle, which lead to a huge fire explosion and made a large plant to shut down its operations for 5 months, also injured 2 workers severely and 14 workers sustained minor injuries.

Problem analysis:

The propylene pipeline met with accident was extended into an open area without any project. Even though company knows propylene is highly flammable liquid flowing through those pipes they did not have any vehicle impact protection to the pipes or valve like concrete posts to protect them from accident impact.

If there were any impact protection for that valve at Formosa, when valve was struck by a vehicle the leak of propylene wouldn't have happened and incident would have stopped with small damage to the concrete post.

Conclusion:

- Formosa did a preliminary hazard analysis, a process hazard analysis, a site analysis, and a PSSR before operating the facility. These assessments did not, however, completely address the use of remotely operated valves to regulate a catastrophic release or the protection of specific process equipment against vehicle contact.
- Formosa did not provide their workers with fire resistant clothes even though there are high chances for flash fires.
- Critical piping to the flare system collapsed as it did not have any fire proofing on the structure. Which prevented gases safely burned.
- Company should have installed automatic isolation valves for potential release of hazardous materials.

Recommendations:

- CSB recommended Formosa to revise their hazard analysis policies and procedures.
- They also recommended that hazard analysis should consider vehicle impact risks, fireproofing structural steel material construction and technology for controlling releases such as remotely control isolation valves.
- CSB recommended the usage of fire-resistant clothing for all employees who are at the risk of flash fires.
- CSB recommended the construction company which constructed the facility to use current safety standards including fireproofing while constructing new facilities.

3. BP Texas city - 2005

Incident description:

The splitter tower in the Isomerization unit of the BP Texas refinery was reactivated after some days on the morning of 23rd March 2005, after a maintenance check. By putting flammable liquid into the tower for more than 180 minutes without even withdrawing any of the liquid, workers broke startup procedure standards. The operators did not know about the raised level in the tower as the critical alarms were failed. The one seventy-foot-tall tower was filled till top level, causing liquid to overflow into the tower's above pipe. The overhead pipe extended 148 feet below the tower's ground level to pressure relief valves. As the pipe filled with liquid, the pressure at the bottom quickly rose. The three pressure relief valves released a substantial amount of combustible liquid into a blowdown drum with an open vent stack for six minutes. A geyser-like burst of combustible liquid occurred when the blowdown drum and stack overflowed with the substance.

The liquid started to erupt out from the tower and spilled around, then a flammable vapor cloud was formed. There was a pickup truck near the blowdown drum which backfire of an idling diesel pickup truck worker failed to switch the ignition off and ran away which caused the ignition. Resulted in the deaths of 15 workers and 180 injured.

This explosion shattered building windows up to three quarters of a mile away and loss of 1.5 billion dollars to the company.

Human error:

In this incident lack of communication between supervisors and operators while changing shifts is one of the errors. Critical startup information was poorly communicated by operators and supervisors during the shift change.

The other error is that Lack of technical training and supervisory oversight during the startup, a particularly risky time like this. Supervisor left work with short note without replacing any experienced worker as substitution for him.

Leaving the truck engine on and running away might be the blunder as it caused the ignition for the flammable vapor. If worker were managed to turn off the engine this incident would not have happened.

Problem analysis:

BP Texas City lacked a culture of reporting and training. BP Texas City authorities frequently failed to properly investigate problems or implement the necessary corrective measures. The BP Group was not focused on reducing big risk hazards. Instead of emphasizing process safety, BP management focused on, evaluated, and rewarded personal safety. Management directions and controls were ineffective.

They were very poor at following PSM elements like training their operators, Pre startup safety reviews, mechanical integrity, and process safety information.

All these played a major role in this accident. If they would have followed these elements this would not have happened. The fluid level indicator in the tank failed which means company failed at following mechanical integrity element. And supervisor left without assigning any experienced worker during such critical startup.

Conclusion:

As the failure of compliance of PSM elements resulted these disasters.

- The efficiency of the safety systems at BP Texas City was impacted by mergers, reorganizations, staffing reductions and reassignments, budget cuts, and other policy changes.
- Procedures for preserving the integrity of process equipment are mandated by the PSM standard. The catastrophe was caused by inadequate ISOM instrumentation testing, inspection, and maintenance.
- The management of BP Texas did not properly address reducing major dangers. Personal safety was evaluated, rewarded, and given top priority, but process safety performance was not given the same priority.
- The management of BP Texas failed to effectively lead and monitor the safety culture to avert serious accidents.

Recommendations:

- CSB recommended to appoint a non-executive board of director with good experience in the industrial operations and process safety.
- To improve the safety culture that their senior executives start to report incidents without any fear.
- To assess refinery processes in order to ensure that crucial process equipment is designed safely.
- To assure that process equipment and instrumentation required for safe operation are regularly inspected and tested.
- Recommended to improve the workers safety training program.
- Make it mandatory to have a competent supervisor to be present during particularly risky operation phases like unit startup for whole time until the operation finishes completely.

4. CAI / Arnel Chemical Plant Explosion - 2006

Incident description:

The Danvers, Massachusetts, CAI/Arnel ink and paint manufacturing facility was destroyed early on November 22 by a huge explosion. Numerous surrounding homes and businesses suffered damage, some irreparable. Several residents were admitted to hospitals. The factory, which at the time was vacant, sustained no injuries.

During the CSB investigation they found human error as a major factor for this explosion. CAI production supervisor began mixing a two thousand gallons ink vehicle batch in a reactor at approximately 1 in the noon. Which needed to be heated by steam up to 90 to 120 Fahrenheit according to the production procedures. Production Supervisor opened the steam valve and started this heating procedure at 3:00 PM and left to the warehouse to unload the raw material. After finishing that loading, he believed that he closed the steam valve which he did not closed and left the work around 5:30 PM closing all the doors and shutting exhaust fans in the facilities.

Heptane (C_7H_{16}) & Propyl alcohol (C_3H_8O) Mixture in the reactors started heating up extensively for the next eight hours. Heating the mixture for so long resulted in releasing flammable vapor through the unsealed tank cover into the surrounding building. At 2:46AM the flammable vapor reached an undetermined ignition source, might be an automatic heater switch or other electrical device at the facility and exploded.

Human error:

In this incident it is identified that a small human error caused such destruction. During the CSB investigation when they interviewed the plant production supervisor he stated “I think I locked the steam valve”. Eventually which he forgot to close resulted in excessive heating and release of flammable vapor. This explosion wouldn't have happened if the production supervisor would have closed the steam valve.

Problem analysis:

The CAI did not conduct any PHA analysis ever before. The lack of automatic controls on the mix tanks made it possible for the process to go unsupervised while the mixture heated up. It's a big mistake that the company heated class 1 flammable liquids in unsealed reactors in a unventilated building. In order to store the hazardous material inside the structure or the flammable solids outside, CAI and Arnel did not have permits issued by the fire department. The building's storage of CAI hazardous liquids did not follow Massachusetts fire code requirements or OSHA regulations. The Massachusetts fire code does not establish a schedule for regular inspections of interior hazardous liquid storage places by the local fire department.

Conclusion:

- CSB concluded Process risks analysis or other comparable systematic reviews of processes involving hazardous materials were not carried out by CAI management.
- For the purpose of facilitating safe CAI management did not employ written procedures or checklists when conducting manufacturing activities.
- Throughout the entirety of the flammable liquids process operations, CAI failed to ensure proper building ventilation.
- When heating flammable chemicals in process equipment inside a unventilated area, CAI did not establish or use automated process controls, safety alarms, or process safeguards.

Recommendations:

- CSB recommended, to stop flammable liquids or combustible liquids from overheating, CAI should mandate safety measures in the facility.
- Apply and implement PSM elements.
- Comply with OSHA PSM standards.
- Comply with OSHA flammable and combustible liquids standards.
- Recommended to create a formal safety program to oversee risky process operations.

5. MGPI Processing, Inc. Toxic Chemical Release - 2016

Incident description:

On the morning of 20th October 2016, a delivery truck carrying sulfuric acid arrived at MGPI facility to do regular delivery. After reviewing the papers by the supervisors, the truck was allowed inside for unloading of the sulfuric acid into the storage tanks of facility. MGPI facility operator escorted truck driver to the chemical unloading area. After reaching the unloading area truck driver went back to the trucks cabin to keep all the paperwork in and to wear personal protection equipment, meanwhile the operator opened the gates of chemical unloading area and unlocked the sulfuric acid fill line for driver to unload the material in the tank. After unlocking the operator told the correct fill line to truck driver and left the place. As a matter of fact, there are so many pipes and lines as it is the chemical unload area. There was an unlocked sodium hypochlorite fill in line just 18 inches away from the sulfuric fill in line. As truck driver did not hear the operator before, connected his truck sulfuric acid hose to the sodium hypochlorite line which looked similar to sulfuric acid fill in line. And sulfuric acid began to flow into the sodium hypochlorite tank. Then truck driver returned to his truck cabin. After some time greenish yellow gas began to flow out of the sodium hypochlorite tank as sulfuric acid started mixing in the sodium hypochlorite tank. When driver noticed this gas he tried to go near the hose connected area and close the line but couldn't succeed as the gas did not allowed him to go near, then he ran to other part of the facility. Before emergency personnel closed the truck's valve, sulfuric acid flowed into the sodium hypochlorite tank for 40–50 minutes. Estimated amount of 4000 gallons of sulfuric acid had mixed with 5800 gallons of sodium hypochlorite resulted in forming dense chlorine gas cloud over Atchison city.

MGIP employees were evacuated from the site and more than 10,000 local Atchison residents were advised to evacuate or take a shelter in place. Total of 140 people including employees, truck driver and residents were hospitalized after the incident.

Human error:

In this particular incident it's clearly stated by CSB that human error is the major cause for this chemical release with few other contributing factors at management level and unloading area layout. When operator told truck driver the correct fill in line of sulfuric acid and if truck driver was attentive enough this mixed connection wouldn't took place. It was mentioned in the company's SOP that while connecting the tank hose while unloading any material it must be done under supervision of any operator, whereas here the operator just left the area after unlocking the fill in line which he shouldn't have done. Small minute errors like this might result in devastating incidents.

Problem analysis:

While investigating this incident CSB found out few deeper root causes. They identified that there was no appropriate labeling on the pipelines at the unloading are. Both sulfuric acid and sodium hypochlorite fill in pipelines looks similar with same color valves. Even though there was potential risk of mixed connection the fill in pipelines were just parted by 18 inches. Lack of proper safety training and supervision also one of the factors for this incident. If there was a strict unloading procedures checklist with requiring operators' signature for every step while unloading hazardous materials this wouldn't have happened. By using physical isolation or a distance between fill in lines might bring down the possibility of mixed connections during bulk unloading operations.

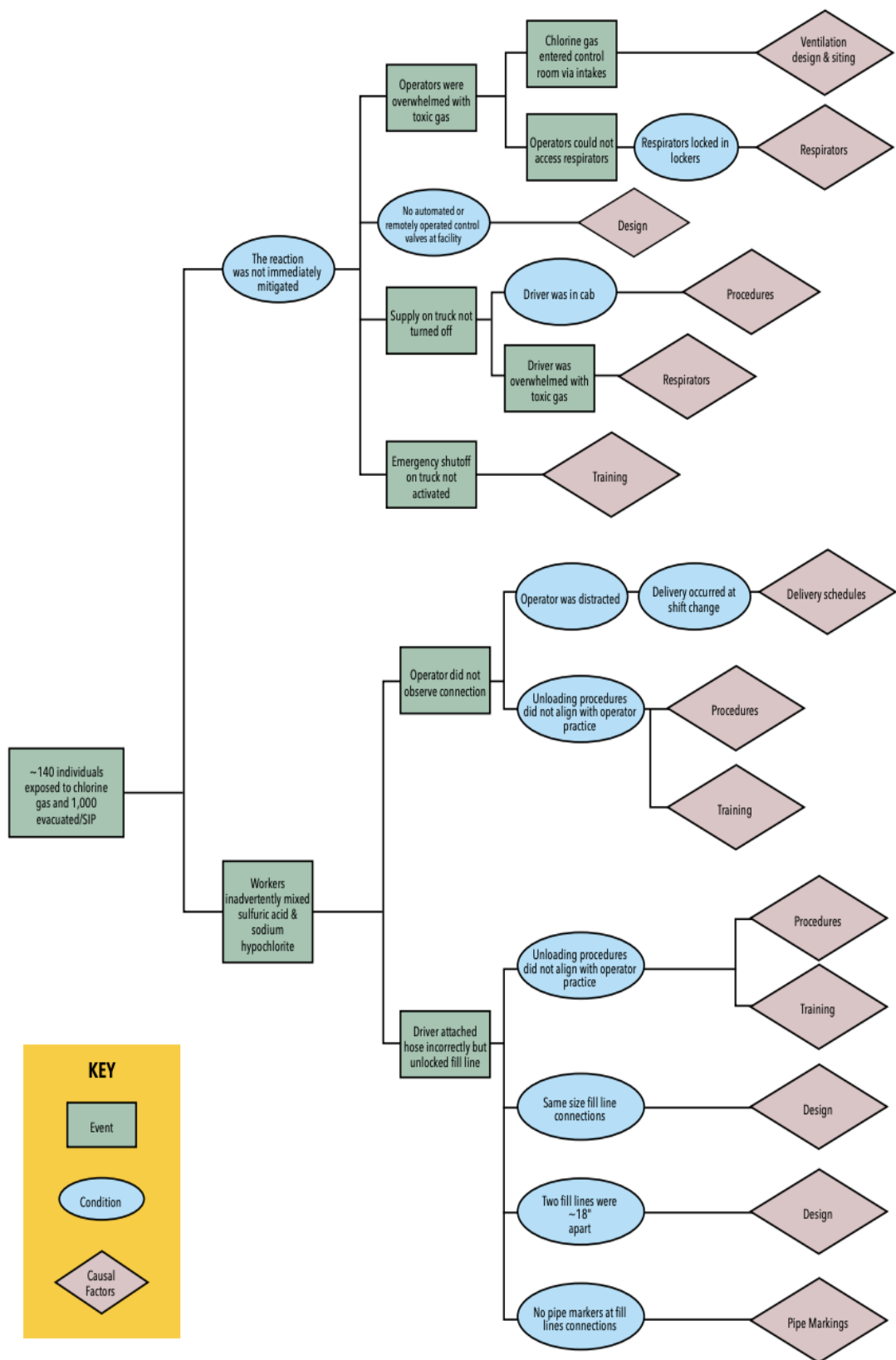


Fig 3. Simplified Casual Analysis

Conclusion:

- Even though unloading materials/chemical are simple procedures and very regular in industries, if they're not monitored properly and unload with all safety measures the impact may be very harsh.
- Lack of proper supervision caused, and design resulted in this incident at MGPI facility.
- Where automated process control and safety systems are not possible, it is better to configure transfer valves, process machines, pipeline valves and other mitigation systems so they may be activated remotely in an emergency from the control room to stop the flow of chemicals into facility pipes or receiving tanks.
- It is better if companies build fill lines, hose couplings with different shapes and different colors for each type of materials. Especially when handling hazardous materials so that they can be easily identified and avoid risk of mixed connection.

Recommendations:

- CSB recommended ASHRAE to develop guidance on the effective designs for HVAC systems in case of any hazardous toxic release in the facility.
- CSB also recommended MGPI to evaluate their unloading area When unloading bulk hazardous materials chemical transfer equipment should be equipped with the proper engineering safeguards to stop an unanticipated reaction from occurring, a chemical release from occurring, or a spill from occurring.
- It is recommended for facilities and material distributing companies to conduct a hazard analysis combined and then develop a standard operating procedure for chemicals or materials unloading activities, which will be helpful for both parties.
- It's always recommended to use remotely operated valves in case of leak or release which can be shut from the control room.
- It was recommended to HARCROS chemicals to establish a training program for drivers to make sure they are aware of where the various CTMV emergency shut-off mechanisms are, when to use them, and how well they work to stop the flow of chemicals in an emergency.

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