# ENGG404 TEAM PROJECT FINAL TECHNICAL REPORT:

**Submitted by Team #: Team 03**

**Case Study:**
**West Texas Fertilizer Explosion**
**West Fertilizer Company, Explosion of Ammonium Nitrate in Fertilizer Facility, 1471 Jerry Mashek Drive, West, Texas, U.S., April 17, 2013.**

**Date submitted: August 1, 2018**

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***Please note all information is from source [1] unless otherwise indicated.***

## EXECUTIVE SUMMARY

### Incident Description and Losses:

Reportings of smoke of the fire at the West b8b336Fertilizer Company (WFC) distribution facility in West, Texas on April 17, 2013 shortly preceded the loss incident of an explosion at the same site. The heat from the fire caused the detonation of 30 tons of ammonium nitrate (AN) at 19:51 central daylight time (CDT) resulted in widespread damage to WFC's assets and production but even more so to the community's people and environment. These damages were extensive to the point where the entire facility was destroyed and WFC filed for bankruptcy after the incident. 15 fatalities resulted from the explosion, along with more than 260 injuries. Property damage was extensive for the community of which included an apartment complex, 3 schools, a nursing home, and 350 homes. In addition to the $131 million costs of property damage, there was also $17 million of infrastructure damage to the city of West. Furthermore, over $2500 worth of environment damage was also present with scorched trees. Finally, WFC's facility was destroyed along with all equipment and material that was held within which was a total of $1.3 million in losses in addition to lost annual revenue of $5 to $10 million. These losses ultimately led to the bankruptcy of WFC as well as it faced $230 million in insurance-related losses. The company had a completely tarnished reputation.

### Context and Purpose:

This report is completed by our team for ABC Conglomerate Company, which operates in the same fertilizer industry as the West Fertilizer Company with similar operation, facility design and business model. Due to these similarities, to prevent a similar incident from happening to ABC Company, the investigation to the loss incident is conducted. The scope of the current project focuses on the explosion event and its causes with an aim to address the problems in our current AN storage technologies and facility design, and risk management program.

WFC was a company in the fertilizer industry, located in the city of West, Texas. They stored and distributed fertilizers, chemicals, grains, and various other farming supplies to farmers since its business operations started in 1962. The company also rented farming equipment and provided services such as spreading fertilizer on farmland, applying the chemicals to the fields for the farmers and blending and mixing of fertilizers to meet specific customer needs. Hence, its main contribution to the society lies in the positive support for agricultural production. This included an increase in productivity and protection for the quality of the products. The scope of the company was provincial with the main customer base was in the local area.

The WFC operated a building which served as a chemical warehouse, shop area, and office space where most chemicals purchased by farmers were stored. The company also owned a fertilizer building, constructed in the 1960s, where dry fertilizer was stored. There were some inherent and unique risks in the operation, facility, and activity of the company, and the most relatable to the incident is the storage of AN fertilizer. Under

normal conditions, it is a stable substance, but, as an oxidizer, AN demonstrates several fire hazards: explosion, uncontrollable fire and decomposition to form toxic gases. It can promote or even ignite combustion and increase the flammability of other substances after exposure to heat. Hence, AN demonstrates serious risks of explosions and previous AN incidents demonstrated so. There were many preventative measures to minimize the risk of storing AN that the WFC failed to perform, specifically the ventilation system and employing wooden materials in the storage space of AN.

This report provides a detailed description of the incidents along with its specific losses. The main objective of the project is to explore the latent causes and factors that led to the explosion on April 17, 2013, which resulted in significant loss to the people, environment, asset and production using the root cause analysis method and the cause and effect model. Weaknesses and shortcomings in the management system will be explored, studied and discussed, and key recommendations will be made to management to improve the system and prevent similar incident to happen again.

**Root Cause Analysis:**

The scope of this root cause analysis focuses on the direct causes and effects of the WFC explosion. What is outside the scope is the exact cause of the fire and the analysis of that incident. The contribution of limited ventilation in the AN storage area is also outside the scope of this investigation. The first key latent case we determined was that the company did not proactively assess and address the risks of AN. The AN storage area was almost completely flammable; this was the energy source, the fire, behind the explosion. This all occurred because of poor plant design and poor storage practice. There was no technical procedure as the company was not concerned or focused on the explosivity of AN. This lack of awareness was caused by the latent cause, the improper risk assessment regarding the risks of AN. The second key latent cause we identified was that management had approved an inadequate and unsafely designed facility with extremely minimal fire safeguards. The AN detonated because the facility fire was not contained. The employees were unable to contain the fire as there was an extreme lack of fire-safety features; the facility only had manual fire extinguishers. The company did not prioritize safety as they did not implement more safeguards. This all occurred because of the latent cause; the initial plant design was inadequate, yet management still approved it.

**List of Latent Causes:**

**RMS #1: Management Leadership, Commitment and Accountability**

- Management did not take measures to routinely check the psychological wellbeing of employees
- Management did not put in effort to have good security; potentially to cut cost
- Company did not prioritize safety as #1 as more safeguards in place would’ve cost more
- Both facility and community management did not make safety a priority
- There was very poor internal company regulation regarding the storage of AN

**RMS #2: Risk Assessment and Management of Risks**

- Company underestimated/did not assess the fire hazard risks adequately
- Poor risk assessment and management by both the company and the first responders
- There was improper risk assessment
- The company did not proactively assess and address the risks of AN
- Management did not assess the risks of the combustible material and construction in the design
- Employee responsibilities were not clearly outlined by management
- Management didn't priorities safe storage of fertilizer
- Management didn't checkup on employees following or even putting procedures in place

**RMS #3: Community Awareness and Emergency Preparedness**

- There were no plans or safety procedures in place in the event of an incident
- The community was not prepared for an incident of this magnitude and were not aware of the hazards and risks of the facility

**RMS #5: Incident Reporting, Investigation, Analysis and Actions**

- Incidents were not analyzed, and very little action was taken

**RMS #6: Program Evaluation and Continuous Improvement**

- Company did not continuously work to improve their own plant safety measures

**RMS #7: Design, Construction and Start-up**

- Management approved an inadequate and unsafely designed facility (no safeguards)
- The unsafe design was approved by management and therefore the facility was not adequate

**RMS #9: Employee competency and Training**

- The facility employees were not trained on safe storage methods
- Employees were not compliant with work standards

**RMS #11: Operations and Facilities Information and Documentation**

- The company did not maintain important documentation of the AN

## Key Recommendations and Alignment to Elements:

| Rank | Recommendation | Gain Index | Effort Index | Total Score | Nature of Fix | Latent Cause(s) Addressed | Alignment |
|---|---|---|---|---|---|---|---|
| 1 | Conduct a risk assessment to properly assess the risks regarding storage of FGAN within the facility, then create and implement new safety protocol. | 4 | 20 | 80 | The solution is not technology. | • Company underestimated/did not assess the fire hazard risks adequately<br>• Poor risk assessment and management by both the company and the first responders regarding blast radius of the AN and its combustibility<br>• There was improper risk assessment regarding the storage of AN<br>• The company did not proactively assess and address the risks regarding combustibility of AN<br>• Management did not assess the risks of the combustible material and construction in the design<br>• There as very poor internal company regulation regarding the storage of AN<br>• Facility employees were not trained on safe storage methods<br>• Employee responsibilities regarding AN storage were not clearly outline by management<br>• Management didn't prioritize the safe storage of fertilizer as they were unconcerned about all the hazards and risks<br>• The company did not continuously work to improve their own plant safety measures by consistently reassessing any new risks and making the appropriate changes<br>• Management didn't checkup on employees following or even putting safety procedures in place | RMS #1<br>RMS #2<br>RMS #6<br>RMS #9 |
| 2 | Implement engineering safeguards and controls to ensure safe storage practises and prevent the fire from occurring. | 4 | 18 | 72 | Apply simple technology. | ○ Management approved an inadequate and unsafely designed facility (no fire safeguards) .<br>○ The unsafe design was approved by management and the facility was not adequate<br>○ Management did not put in effort to have good security; potentially to cut cost<br>○ Company did not prioritize safety as #1 as more safeguards in place would have costed more.<br>○ Management did not prioritize safe storage of fertilizer. | RMS #1<br>RMS #7 |
| 3 | Improve employee safety culture to ensure that safety is the number one priority throughout the company. | 4 | 18 | 72 | The solution is not technology. | • Management did not take measures to routinely check the psychological wellbeing of employees<br>• Employees were not compliant with work standards<br>• Management didn't checkup on employees following or even putting procedures in place | RMS #1<br>RMS #9 |
| 4 | Increase communication with the community (local fire department) and have emergency plans in place in the event of an incident. | 3 | 21 | 63 | The solution is not technology. | ○ There were no plans or safety procedures in place in the event of an incident (emergency response inadequate)<br>○ The community was not prepared for an incident of this magnitude and were not aware of the hazards and risks of the facility (city built towards the facility) | RMS #3 |
| 5 | Analyze precedent AN explosions and learn how and why incidents could occur to continuously improve upon own risk management program. | 3 | 17 | 51 | The solution is not technology. | • Company did not continuously work to improve their own plant safety measures<br>• Incidents were not analyzed, and very little action was taken | RMS #5<br>RMS #6 |

**Business Case Analysis:**
Through the business case analysis, we determined that the net benefit of implementing the top two recommendations was a positive value. The annual cost of risk exposure is greatly reduced when the improvements are made; the cost saved by preventing an incident greatly outweighs the cost of implementing the recommendations. We determined that both recommendations were Low Hanging Fruit; therefore, low effort with high gain. The analysis only covered the loss of assets in PEAP, including the other categories would significantly increase the net benefit and further prove that the recommendations are worth implementing.

**Issues with Implementation:**
Implementing a risk management safety system with risk assessment as a key element of the program is this report's top key recommendation. In looking at the topic of leadership, specifically what makes an effective leader, the top two challenges of our recommendation are providing the vision for the team (an essential process skill for the leader) and leading by example (a characteristic of effective leadership in a team environment).

In simple terms, the leader of WFC needs to define that safety is part of what the company stands for. The vision for a company would guide the goals and the underlying values for the company. Donald Adair, the owner of WFC, did not have a vision for the company, this was evidenced by how little effort was put into safety practices. The company was fined prior to the loss incident for having a lack of an risk management plan in place. Thus, to implement a risk management program with regular risk assessments, Adair would need to re-haul the existing inadequate program practises and ensure safety is part of the vision for his company in addition to daily practises such as field level hazard risk assessments. This is an issue for implementation as clearly none of these safe practises and risk assessments were in place or carried out at WFC. Adair would need to sell the vision of committing to safe practises to his team.

As for leading by example, Adair needs to 'walk the talk'. In other words, not only should Adair define the company's commitment to safety, but also needs to personally participate in implementing in risk management program steps by to set an example for his employees. The way WFC was run was very relaxed and without safety as a value or priority. For example, the perimeter of the facility was not fenced, and the facility had no burglar alarms or security guards. [16] There was a blasé way to how the company was run, like a hometown situation where everybody trusts everybody. By implementing risk assessments and a risk management program, Adair needs to demonstrate through his actions what he wants for how the company runs. Whatever the risk management system implements, leadership and management should follow suit to set an example for employees. Again, this is an issue to implementation because these were not in place prior. His company of barely 10 people was run in a laidback fashion, but risk management is by no means like that, so Adair has to demonstrate his commitment to safety and risk management through his visible and observable actions (conducting risk assessments himself), and these actions are congruent with his words.

**Next Steps:**

Elevator Pitch
Imagine you had $12 that was soaked in gasoline near a lit match. If you could pay $5 to not have the gasoline or lit match anywhere near your $12, would you do it? Now imagine that in millions. Imagine the $12 being human lives and the reputation of ABC Company.

After studying the external loss incident of the West Texas Fertilizer Explosion, we are asking for management's approval to not only fund and proceed with our recommendations but also to approve saving lives and millions in lost profits. As part of ABC Company, it is in our best interests to implement the key recommendations of conducting risk assessments, implementing engineering safeguards, and improving safety culture. The benefits will include hazards becoming known and proper safety programs and safeguards put in place before a risk of an incident can occur. Prevention is the most cost-effective method to safety as company reputation cannot be salvaged after a loss incident occurs. Our three recommendations allow for ABC to prevent the incident by first identifying the risks (risk assessment), putting safeguards in place to rid or lower the risk (engineering safeguards), and finally keep the company and employees committed to safe practises (improving safety culture). All three prevent a loss incident like that of WFC's because it allows for eliminating the initiating events of an uncontrolled fire and unsafe storage practices. If these recommendations are not put into place, ABC Company's facility's most probably outcome is a loss incident. We are putting everything at stake including the bankruptcy of the company if such an incident occurs. Without these recommendations implemented, it is only a matter of time when ABC will only be known for a loss incident and its reputation ruined.

## APPENDICES:

## Appendix A: Incident Description and Losses:

### Incident Description:

Sequence of Events leading up to loss incident:

At 19:29 in the city of West, Texas, community members reported smoke sightings which the West Volunteer Fire Department (WVFD) and police began to respond to by identifying it was a fire at the West Fertilizer Company (WFC) facility, followed by evacuating nearby WFC people at a basketball court and playground. By 19:37, first of 3 firetrucks are reported departed to the WFC facility and had arrived at 19:39 [2].

Loss incident:

At 19:51, 30 tons of fertilizer grade ammonium nitrate (FGAN) detonated at the WFC facility where the fire (that was unable to be put out by emergency responders) was, this explosion was the equivalent of 11.4 tons of TNT occurred or a 2.1 magnitude earthquake on the Richter scale [2]. The explosion occurred less than 20 minutes after the first notification, 16 minutes after dispatch, and only 11 minutes after the arrival of the first fire truck. The initial explosion originated at the elevator pit which was next to the main FGAN storage bin, followed a fraction of a second later by an explosion of the auxiliary west storage FGAN bin [2].

Pertinent subsequent events:

The aftermath of the explosion included essentially the full destruction of the WFC facility and a 3m deep by 23m diameter crater created below the main FGAN storage bin. Further consequences to PEAP in a timeframe of less than 20 minutes were 15 fatalities (12 of which were firefighters and EMTs, 3 community members), over 260 injuries (both community and 12 emergency responders), and community damage (which included an apartment complex, 3 schools (2 of which needed to be demolished), a nursing home, 350 homes damaged of which 142 private residences that were destroyed beyond repair) [3]. The list below is a comprehensive summary of the PEAP losses:

### Losses:

People:

- There were fatalities of 12 emergency responders and 3 members of the public
- Community members were among the 260+ injured victims from minor wounds (such as contusions, abrasions, and lacerations) or serious injuries (such as fractures, closed head injuries, traumatic brain injuries, and skin burns)
    - These included abrasions/contusions, lacerations/penetrating trauma, traumatic brain injuries/concussions, tinnitus/hearing problems, eye injuries, inhalation injuries, sprains/strains, fractures/dislocations, blast injuries, tympanic membrane ruptures, and burns.

Environment:

- There were scorched trees downwind of anhydrous ammonia pressure vessels.
    - $255 per tree, estimate 10 trees = $2550 [5]

Assets:

- WFC had declared bankruptcy shortly after the incidence and it had a tarnished company reputation.
    - The cost in *company funds* included $230 million in insurance-related losses, as they only held a $1 million insurance policy
- There was the complete destruction of the WFC facility which included the *building, raw materials, and equipment*. Specifically, a completely demolished scale house, flattened the chemical storage, and destroyed office building.
    - facility was ~$1million appraised market value [6]
    - facility contained the following chemicals with market prices from 2013 [7]
        - ~150 tons of AN priced at $400/short ton of AN = $66,000
        - ~17 tons of anhydrous ammonia priced at $640/short ton = $11,993
        - ~85 tons of Diammonium phosphate at $440/short ton = $41,226
        - ~70 tons of Ammonium sulfate at $385/short ton = $29,707
    - blast also heavily damaged the above-ground vertical liquid fertilizer storage tanks. Its cost was $25,000/tank x 6 tanks = $150,000 [14]
- West Intermediate School was damaged externally and internally. Internally, debris accumulated in the hallway outside of rooms 11 and 12. As well, the acoustic ceiling, light fixtures, and other debris fell into classroom 12. Finally, the technical department that housed school servers and data were also damaged. Externally, the window on the north side of the school failed violently and a large shard of glass (approximately 3 inches long) was embedded in the south wall of the classroom. The roofs of the cafeteria and gym were damaged, with heat damage to the gym roof along with blast overpressure causing deformation of roof purlins, propelled windows in the gym. Lastly, northeast corner was heavily damaged by blast overpressure and was also fully engulfed in flames.
    - Cost to build middle school $26.5 million [8]
- West High School was also damaged externally and internally. Internally, the supporting structure was compromised and hanging ceiling rendered unstable for the auditorium. The ceiling and walls were damaged as shown through cracking and separations near walls and light fixtures.
    - Cost to build high school $45 million [8]
- West Middle School sustained damages for its roof and windows as well. Its new drop ceiling failed and windows facing towards the WFC facility were broken, along with damage to its roof purlins and frames. The pre-engineered frames buckled after the explosion thus causing deformation of the roof purlins.
    - Cost to build middle school $26.5 million [8]
- West Rest Haven Nursing Home was irreparably damaged, especially its easternmost corridor of the building where the wall failed and roof trusses collapsed. As well, flying wall debris, window fragments, failing drywall, insulation and light fixtures from the ceiling damaged its eastern rooms. The great rooms, patient rooms, and lobby also had broken shards of glass.
    - Overall, the construction cost is an estimated $11 million.
- West Terrace Apartment Complex was where 2 deaths of the public occurred and its roof and walls of the building completely failed.
    - Cost of constructing $9.4million [9]

- Private Residences
    - 350 homes were impacted— with 142 homes damaged beyond repair [3]
        - 2013 West TX Average home cost $89,200x142 = $12,666,400 [10]
    - 51 homes suffering major damage, 27 homes incurring minor damage, and 130 homes otherwise affected
        - Average major damage repair cost $5000/home = $255,000 [11]
        - Average minor damage repair cost $500/home = $13,500 [11]
    - broken windows, facade damage, and non-structural and structural component (e.g., wall and roof system) failures
- Infrastructure damage to the city of West: As of June 2013, the city of West indicated that the fire and explosion at WFC had cost the city $17 million in actual damages; however, the total cost-to-date may be greater as additional demolition, renovation, and construction projects continue throughout the city. The cost includes repairs mentioned below for railroad tracks, water lines, etc.
    - explosion, overpressure, and debris completely destroyed a WVFD brush truck, water tender, and fire engine
        - average cost per vehicle $250,000 x 3 vehicles = $750,000 [12] [13] (note this cost is included in the $17 million specified above)
    - Railroad tracks between the WFC property and the park were damaged.
    - A playground, basketball court, and park equipment located a few hundred feet west of the WFC facility also sustained damages.
    - Ruptured water lines, deformed sewer manholes, damaged water storage tanks, further rendered wells unusable, cracked walls of a pump house, and caused the loss of water supply to the community
    - Affected Infrastructure/Cost to Repair Damage → Total = $450,200 (also included in 17 million from above)
        - Well 4, Ground Storage Tank $365,000
        - Well 4, Pump Station Door and Window $2,000
        - Davis Street Water Line $74,000
        - Walnut Street Sewer Manhole $9,200
    - On April 15, 2014, the State of Texas provided additional disaster grant assistance to the city of West in the amount of $4,853,500 to fund the disaster recovery work on the water plants, water tank rehabilitation, wastewater outfall interceptor, and disaster zone infrastructure repairs. The first infrastructure project (costing $400,000) was completed in August 2014 and involved installation of a new well and upgrading of a storage tank located by the new nursing home.

Production:

- WFC's annual revenues were between $5-$10 million, this is completely lost as the company went under after this incident. [15]

## Appendix B: Context and Purpose:

### Context:

This report is completed by our team for ABC Conglomerate Company, which operates in the same fertilizer industry as the West Fertilizer Company with similar operation, facility design and business model. Due to these similarities, to prevent a similar incident from happening to ABC Company, the investigation to the loss incident is conducted. The scope of the current project focuses on the explosion event and its causes with an aim to address the problems in our current AN storage technologies and facility design, and risk management program.

The West Fertilizer Company (WFC) was a company in the fertilizer industry, located in the city of West, Texas, which is approximately 80 miles south of Dallas, Texas. The WFC stored and distributed fertilizers, chemicals (pesticides and herbicides), grains, and various other farming supplies (such as barbed wire, baling twine, and fencing) to farmers since its business operations started in 1962. The company also rented farming equipment and provided services such as spreading fertilizer on farmland. The scope of the company was provincial with the main customer base was in the local area.

The WFC operated a building which served as a chemical warehouse, shop area, and office space where most chemicals purchased by farmers were stored. The chemicals included Roundup, Sevin, and other additives like Weedmaster® and Grazonnext®. They were stored in containers and storage tanks of sizes from 2 to 300 gallons. The WFC also owned a fertilizer building, constructed in the 1960s, where dry fertilizer, which included diammonium phosphate, ammonium sulfate, potash, potassium magnesium sulfate, etc., was stored. The company also performed liquid fertilizer blending to meet the specific needs of farmers and provided delivery services, applied the chemicals and fertilizers on the fields for farmers if requested. There was no product manufactured onsite as it was a distribution center of suppliers.

The company supplied not only fertilizers and chemicals to the farmers community but also provided services such as delivery, mixing and applying the chemicals to the fields for the farmers. Hence, its main contribution to the society lies in the positive support for agricultural production. This included an increase in productivity and protection for the quality of the products (pesticides, herbicides, etc).

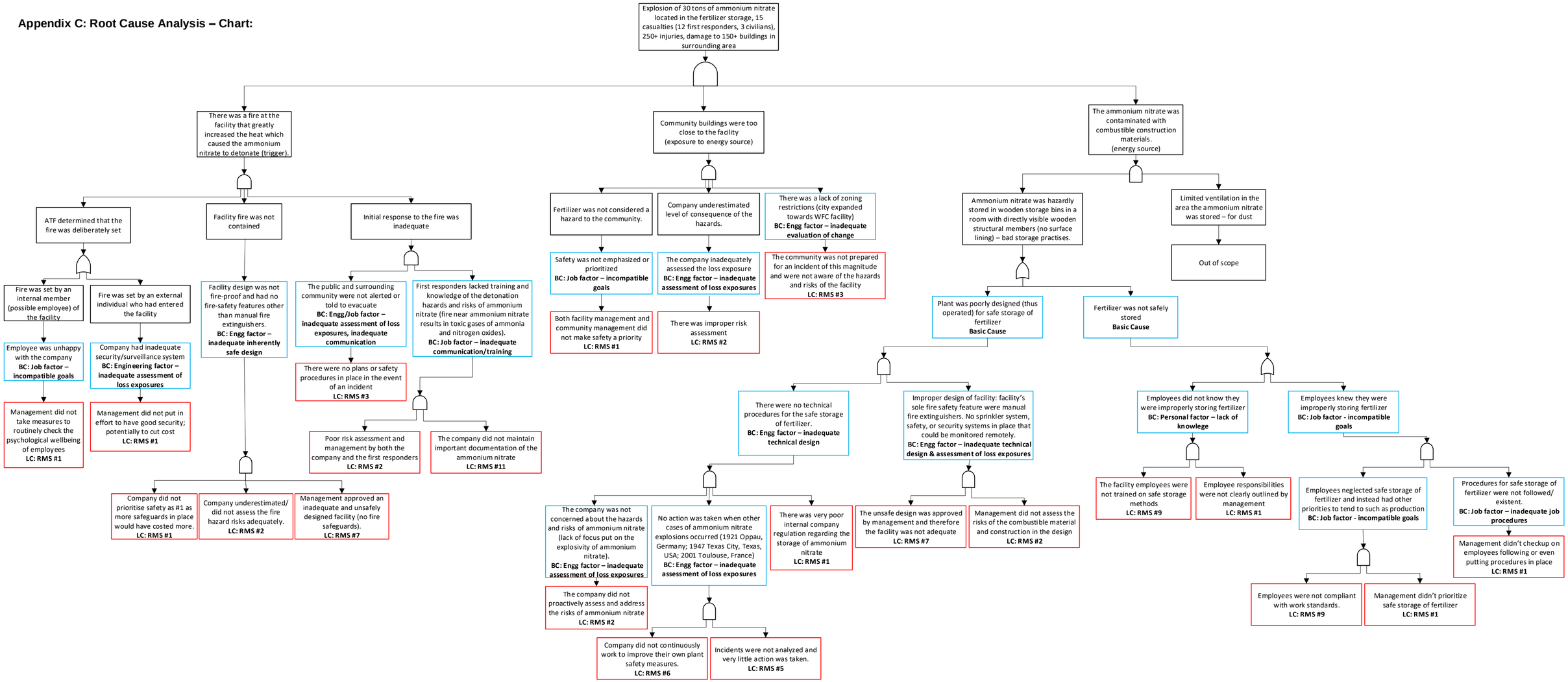
There are some inherent and unique risks in the operation, facility, and activity of the company. The most important of all is the storage of chemical combustible materials. In fact, on many occasions, the WFC, having had two 12,000-gallon ammonia(NH3) storage vessels which were located to the south of the fertilizer building, demonstrated its incompetencies in complying with chemical safety regulations. The company was fined before the incident for improper storage of ammonia (1985 - $30, 2012 - $5250) as well as not meeting other safety regulations standards (2006 - $2300). Furthermore, the company did not have a surveillance system (no perimeter fencing and burglar alarms) until 2009, and it has been reported several times that thefts had visited the facility to steal ammonia to make methamphetamine.

More specifically to the 2013 incident, the storage of ammonium nitrate was a very important hazard that was neglected by management, and it directly impacted the incident. Liquid and solid ammonium nitrate, an important fertilizer that provides nitrogen compounds to the soils to enhance crop production, was one of the main products of WFC. Because plants usually do not obtain enough nitrogen to form the necessary proteins, it is critical in agriculture to provide nitrogen in the form of fertilizer to them, and ammonium nitrate, among other fertilizers such as ammonium sulfate, calcium nitrate and ammonium sulfate, delivers the most amount of nitrogen by volume. Under normal physical conditions, ammonium nitrate is a stable chemical material, and is not sensitive to low to moderate shock, friction and sparks. Nonetheless, as an oxidizer, AN demonstrates several fire hazards, which include explosion, uncontrollable fire and decomposition to form toxic gases such as ammonia, nitric acid and nitrous oxide, etc. It has the ability to promote or even ignite, in favorable conditions of pressure and heating, combustion and increase the flammability of other substances after exposure to heat. Hence, AN demonstrates serious risks of explosions, and there were many previous fire and explosion incidents were determined to be related to AN. Some of these include the East Texas Ag Supply incident in 2014, the EDC incident in Bryan, Texas in 2009, the Cory's Warehouse incident in 1982 and the Chrokee incident in 1973. There were many preventative measures to minimize the risk of storing AN that the WFC failed to perform and directly contributed to the incident, specifically the ventilation system and employing wooden materials in the confined storage space of AN.

**Purpose:**

Our company has very similar facilities, operation, plant design, business model and management system with the West Fertilizer Company. The two companies are in the same fertilizer industry, and both store a large amount of AN, which demonstrates high combustible hazard. Thus, there is a high probability that such a severe incident at WFC would also happen to ABC Conglomerate if improvements are not made in time. Hence, an investigation is conducted to provide a detailed description of the incident along with its specific losses regarding people, environment, asset and production and to identify the factors that lead to the incident. Based on the result of the investigation which involved developing a root cause analysis of the West Texas Fertilizer explosion incident that drilled down to the latent causes, weaknesses and shortcomings in the management system at WFC are identified, explored, studied and discussed in detail, and recommendations to safeguard ABC Conglomerate from having a similar incident are made to management for approval. The main objective of this report is to deliver these key recommendations to address the latent causes, enhance the AN storage technology, facility design, emergency response plan and most importantly, improve ABC's current risk management system. They will help either eliminate the existing hazards in our facility or better control the residual risk safely. The priority of the recommendations is also presented based on the use of the gain and effort model.

## Appendix C: Root Cause Analysis – Chart:



## Appendix D: Root Cause Analysis – Discussion:

### Scope and Boundaries:

The investigation focuses on the causes and effects of the WFC explosion. We focused the analysis on the explosion incident rather than the fire that contributed to the cause. The scope and boundaries of the root cause investigation include the explosion that occurred after the fire began at the WFC, thus all causes relate to why the detonation occurred. What is outside the scope include the exact cause of the fire and the analysis of that incident as a separate situation. The specific causes of the limited ventilation in the AN storage area are also outside the scope of this investigation.

### Key Latent Cause #1:

**The company did not proactively assess and address the risks of AN.**

The explosion of 30 tons of ammonium nitrate destroyed the facility and caused heavy damage to the surrounding community. The ammonium nitrate was contaminated with combustible construction materials which caused it to be the energy source that caused the to the explosion to occur. This happened because the ammonium nitrate was hazard stored in wooden storage bins in a room with directly visible structural member. This poor storage practice occurred because the plant was poorly designed, and therefore operated, for the safe storage of fertilizer. Poor design of the facility happened because there were no technical procedures in place regarding safe storage of fertilizer. The lack of technical procedure happened because the company was no concerned about the hazards and risks of ammonium nitrate. There was a large lack of focus put on the explosivity of ammonium nitrate. This lack of focus occurred because the company did not proactively assess and address the risks of ammonium nitrate. By not performing proper risk assessment and risk management, the company exposed themselves to a lack of information and were unable to properly store the FGAN.

### Key Latent Cause #2:

**Management approved an inadequate and unsafely designed facility (no fire safeguards).**

The AN explosion extensively damaged the surroundings and the facility; many lives were lost, and hundreds of injuries occurred. The explosion was caused by a fire at the facility that greatly increased the heat in the storage area of the AN; AN is extremely combustible when exposed to heat and detonated when it was exposed to the fire. The exposure of AN to the fire occurred because the initial facility fire was not contained. The fire was not properly contained because the facility was not designed to be fire-proof. There were no fire-safety features other than manual fire extinguisher. The lack of fire controls happened because the company did not prioritize safety as #1; more safeguards would have costed more and therefore they chose to save money instead of increasing safety. The company did not prioritize safety as management approved an inadequate and unsafely designed facility with no fire safeguards. The lack of safeguards caused the fire to continue out of control and eventually reach the combustible tanks of AN, causing the explosion.

## Appendix E: Application of the Cause and Effect Model – Discussion:

### Immediate Causes:

*Substandard Conditions*:

Exposure to Fire and Explosion:

- The community buildings were too close to the facility, exposing them to the energy source:
    - When constructing the facility and surrounding community, the government did not consider the need for a safe distance between the two. This also contributed to the casualties and residents did not have sufficient time or knowledge to evacuate. No zoning regulations existed at the time WFC began operations and the City of West developed over the years and expanded toward WFC [4]. Due to this, the WFC facility was not subject to zoning regulations governing the siting of a FGAN facility. [4]

Possibly Inadequate Equipment:

- The fire at the facility was not contained, the heat from the facility fire caused the AN to detonate:
    - There were no fire safeguards within the facility other than manual fire extinguishers, the employees were unable to control the fire causing it to reach the storage of AN

*Substandard Work Practices*:

Lack of Knowledge of Hazards

- The AN was contaminated with combustible construction materials making it extremely susceptible to the fire
    - The storage of the fertilizer was inadequate as it was surrounded by flammable material (the roof was underlain with plywood and had asphalt shingles and it was a timber-framed building with wooden structural members been directly visible in the interior) and was in an area that encouraged fire [3] [4]

### Basic Causes:

*Engineering Design Factors*:

Inadequate Assessment of Loss Exposures:

- The company had an inadequate security/surveillance system:
    - A possible external individual was able to enter the facility without being noticed. This is due to neglect on the security system by the company
- The public and surrounding community were not alerted or told to evacuate:

    - When the hazard was finally recognized, no procedures and training were in place for immediate evacuation. Residents remained in their homes and student/staff in the nearby school until it was too late
- The company inadequately assessed the loss exposure
    - The company underestimated the consequence and possibility of the explosion
- No action was taken when other cases of ammonium nitrate explosions occurred:
    - Despite multiple cases of ammonium nitrate explosion that happened in the past, but the company took no action in education themselves about the risks and hazards behind the incident
    - Examples of similar cases include:
        - 1921 Oppau, Germany
        - 1947 Texas City, Texas USA
        - 2001 Toulouse, France
- The company was not concerned about the hazards and risks of AN:
    - The company knew that there was potential danger and aware of the possibility of an explosion, However, they did not take it seriously and paid little attention to it.
- Improper design of facility:
    - Facility's sole fire safety feature were manual fire extinguishers. No sprinkler system, safety, or security systems in place that could be monitored remotely

Inadequate Evaluation of Change:

- There was a lack of zoning restrictions (buffer between facility and community):
    - While construction the city, there was no restriction zone between the community and the facility. If the hazard occurred, the community as well as its residents would be subject to great damage. The city was also continually expanding towards the WFC facility

Inadequate Inherently Safe Design:

- The facility design was not fire-proof and had no fire-safety features other than manual fire extinguishers:
    - The facility design was very poor as it was in no way fire-proof. The safeguards were inadequate and incomplete.

Inadequate Technical Design:

- There were no technical procedures for the safe storage of fertilizer:
    - While designing the factory, the explosivity risk of the fertilizer was not taken into account; safe design was not implemented
- Improper design of facility:
    - Facility's sole fire safety feature were manual fire extinguishers. There were no sprinkler system, safety, or security systems in place that could be monitored remotely. There were extremely limited fire safety features. This made it extremely hard to control the fire and therefore caused more loss.

*Job Factors*:

Inadequate Communication:

- The public and surrounding community were not alerted or told to evacuate:
    - When the hazard was finally recognized, no procedures and training were in place for immediate evacuation. Residents remained in their homes and student/staff in the nearby school until it was too late
- The first responders lacked training and knowledge of the detonation hazards:
    - They were unaware that fire near ammonium nitrate results in toxic gases of ammonia and nitrogen oxides. The responders did not know how to deal with a such huge fire coupled with ammonium nitrate in the facility. They exposed themselves to risk by being within the blast radius when the fertilizer finally detonated; this caused the 12 first responder casualties.

Inadequate Training:

- The first responders lacked training and knowledge of the detonation hazards:
    - They were unaware that fire near ammonium nitrate results in toxic gases of ammonia and nitrogen oxides. The responders did not know how to deal with a such huge fire coupled with ammonium nitrate in the facility. They exposed themselves to risk by being within the blast radius when the fertilizer finally detonated; this caused the 12 first responder casualties.

Incompatible Goals:

- An employee was potentially unstable and set the fire intentionally:
    - One of more employee may not have satisfied with the company or they may have been under stress due to personal reasons. This could have caused mental instability. The company lacked communication with their employees. They did not prioritize or check the well-being of the employees
- Safety was not emphasized or prioritized:
    - The dangers and risks regarding AN were not prioritized as there was a large lack of both safety procedure and safe design. Despite knowledge of the combustibility, there were no fire-safety safeguards to prevent and control fire.
- Employees knew they were improperly storying fertilizer:
    - They lacked knowledge about how to store the ammonium nitrate. Either the company did not teach them proper safety procedures or there were no safety procedures even put in place.
- Employees neglected safe storage of fertilizer and had other priorities to attend to such as production:
    - The employees potentially did not follow the safety guide of how to store fertilizer. They could have acted on their own and assumed their own methods were better or wanted to increase production.

Inadequate Job Procedures:

- Procedures for safe storage of fertilizer were not followed/existent:

- The employees potentially did not value safety. There was no emphasis on management checking if safety procedures and standards were maintained.

*Personal Factors*:

Lack of Knowledge:

- Employees did not know they were improperly storing fertilizer:
  - They lacked knowledge about how to store the ammonium nitrate. Either the company did not teach them proper safety procedures or there were no safety procedures even put in place.

**Latent Causes (weaknesses in Management System Elements):**

**RMS #1: Management Leadership, Commitment and Accountability**

- Management did not take measures to routinely check the psychological wellbeing of employees
  - Management didn't prioritize the psychological wellbeing of their employees. This was caused by a lack of communication with their workers. They had no measures to check up on how the employees were doing. This was a fail in leadership. The manager did not motivate the workers successfully.
- Management did not put in effort to have good security; potentially to cut cost
  - The company spent very little time and money on the security system. Perhaps they thought it was unnecessary. This is the why a potential external individual was able to enter the facility.
- Company did not prioritize safety as #1 as more safeguards in place would've cost more:
  - Safety was not placed as the number one priority as the company failed to purchase and implement more safeguards. Purchasing more safeguards would've cost them money.
- Both facility management and community management did not make safety a priority
  - Facility management did not properly assess the risks, they had a very lacking and almost non-existent safety system for storing the AN. They did not ensure safe procedure was being followed and did not ensure proper safeguards were in place
  - Community management did not assess the risks of the facility being so close to the community. They did not create proper protocol in the case on incident such as this one occurring
- There was very poor internal company regulation regarding the storage of AN:
  - There was extremely little regulation within the company regarding the storage of AN. There was a lack of safety protocol and poor facility design was not attended to
- Employee responsibilities were not clearly outlined by management

    - The employees were not thoroughly trained on safe practices how to do their job. Management lacked leadership and communication to the workers.
- Management didn't prioritize safe storage of fertilizer
    - The management did not have good safety culture. They potentially ignored safe facility design because it could cut cost. They did not proactively learn from similar incidents at other facilities.
- Management didn't checkup on employees following or even putting procedures in place
    - The management did not check that their workers followed the standard and procedures they required. They may not have even put in any safety regulations that pertained to the hazards and risks of ammonium nitrate.

**RMS #2: Risk Assessment and Management of Risks**

- Company underestimated/did not assess the fire hazard risks adequately
    - The company did not assess the risk of a fire causing the AN to detonate. They were not prepared for an explosion of such high magnitude. They allowed the AN to be stored unsafely and allowed the facility to run despite inadequate safeguards
- Poor risk assessment and management by both the company and the first responders
    - The company did not do proper risk assessments and left the explosive fertilizer with extremely minimal fire safety measures. The missing fire protections aggravated the damage and increased the loss.
    - The first responders did not assess the situation properly. They were untrained to handle the possible explosion and should not have been in the possible blast area. They also did not assess the fire properly and were unable to contain/control it.
- There was improper risk assessment:
    - The high risk of the AN being stored in surroundings so flammable and susceptible to fire was not assessed. The secondary risk of the combustibility of the AN when exposed to heat was also not properly assessed.
- The company did not proactively assess and address the risks of AN
    - The company did not realize the explosivity of the ammonium nitrate. They neglected to perform routine safety checks and make improvements in safety procedure.
- Management did not assess the risks of the combustible material and construction in the design
    - When the facility was under design, the risk of project and the consequences should have been better evaluated. They should have performed a risk assessment before operating and designing the facility.

**RMS #3: Community Awareness and Emergency Preparedness**

- There were no plans or safety procedures in place in the event of an incident
    - Residents of the surrounding community were not educated on how to safely evacuate if a hazard occurred. They took slow actions and wasted

time. If the government planned and trained the community on how to react and safety procedures to take, then less loss would have happened.

- The community was not prepared for an incident of this magnitude and were not aware of the hazards and risks of the facility
    - The community was unaware of the risk regarding the explosivity of AN. They were unprepared for an incident like this as they were not educated on the risks. The surrounding community did not evacuate when the fire occurred; therefore civilians were within the blast radius when the AN detonated.

**RMS #5: Incident Reporting, Investigation, Analysis and Actions**

- Incidents were not analyzed, and very little action was taken
    - There was no information on if documentation existed regarding previous hazardous incidents at the facility or other facilities owned by WFC. Incidents were known to have occurred before; this means no documentation was written up.

**RMS #6: Program Evaluation and Continuous Improvement**

- Company did not continuously work to improve their own plant safety measures
    - Similar past cases happened in the past but the company did not take them as an improvement opportunity. They did not learn anything or improve their safety system to avoid an incident in their own facility. They failed to analyze on those cases and take actions to reduce the possibility of a loss incident.

**RMS #7: Design, Construction and Start-up**

- Management approved an inadequate and unsafely designed facility (no safeguards)
    - The design of the facility lacked to include fire safeguards. The only fire suppression equipment were manual fire extinguishers
- The unsafe design was approved by management and therefore the facility was not adequate
    - The design of the factory had flaws such as limited fire safety measures and extremely flammable structure. The storage method for ammonia nitrate was also inadequate. Despite these flaws, the factory was operated and ran.

**RMS #9: Employee competency and Training**

- The facility employees were not trained on safe storage methods
    - The employees lacked training on how to handle the fertilizer. This caused the improper storage and exposed the risks associated with the detonation of the fertilizer.
- Employees were not compliant with work standards
    - Employees did not follow proper safety practice and poorly stored the AN in a surrounding that was extremely susceptible to fire. This caused the AN to be in a situation where it was exposed to risk of explosion.

**RMS #11: Operations and Facilities Information and Documentation**

- The company did not maintain important documentation of the AN
    - The company did not mention the danger of ammonia nitrate to the public before they started the project. They also failed to report to the government just how large amount their facility was storing.

**Appendix F: Key Recommendations:**

The following gain and effort indices were deemed to be appropriate for this case study and thus was adapted from 'ESRM Module 4-09'.

Gain Index Criteria.

| Gain Index | Gain Index Criteria (any one of or combination of) |
|---|---|
| 4 | • Addresses latent causes.<br>• Eliminates hazards or has the greatest reduction in risk levels.<br>• Eliminate initiating events. |
| 3 | • Addresses basic causes.<br>• Reduces risk levels to a lesser extent than "4".<br>• Prevent incident by eliminating subsequent condition splits.<br>• Eliminates impact in overall PEAP despite having an event. |
| 2 | • Addresses immediate causes.<br>• Reduces risk levels to a lesser extent than "3".<br>• Minimizes impact significantly in overall PEAP i.e. mitigates the consequence of an incident |
| 1 | • Minimizes impact slightly in overall PEAP i.e. mitigates the consequence of an incident.<br>• Does not address any cause.<br>• Reduces risk levels to a lesser extent than "2", or not at all. |

Effort Index Criteria.

| | 1 (high effort) | 2 | 3 | 4 (low effort) |
|---|---|---|---|---|
| **Practicability** | difficult / challenging / develop new technology | apply complex technology | apply simple technology | the solution is not technology |
| **Initial Cost** | > $2M | $1M - $2M | $0.1M - $1M | <$100,000 |
| **On-going Costs** | > 100,000 per year | $100K > cost per year > $10K | <$10,000 per year | no additional on-going cost |
| **Timeline (time before the action can be implemented)** | implemented more than one year | can be implemented within 1 year | can be implemented within 3 months | can be implemented immediately |
| **Duration (time it takes to put the action into place)** | requires more than 3 months | requires less than 3 months | requires less than one month | requires less than one week |
| **Frequency (how often does the action need to be repeated)** | once per month or more often | once per quarter | once per year | one-time |

1) **Immediately conduct a risk assessment to properly assess the risks regarding storage of FGAN within the facility, then create and implement new safety protocol.**
   - The company failed to evaluate the risks regarding proper storage. This allowed issues such as flammability of storage surroundings and combustibility of the ammonium nitrate to go unnoticed. Because the flammability of the storage surroundings was not controlled, the fire reached the tanks of ammonium nitrate; the combustibility of ammonium nitrate when exposed to fire then caused the explosion. Company management needs to begin by performing an assessment of the facility regarding the hazards and risks that FGAN. This can be done both internally, through hiring experienced individuals to form a safety committee, or externally by inviting a third-party organization. By performing a risk assessment, the hazards will become known and proper safety programs can be put in place. Management must then create new safety procedure and ensure that they are properly followed by employees by providing proper training and creating procedural checklists that are easy to work with.
     - Deliverable #1: Immediately conduct a formal risk assessment/safety inspection of the facility. This can be done in one of two ways:
       - Hire individuals to form a safety committee for the company
       - Hire an external safety committee.

       Whomever is hired must be specifically fit to do the risk assessment; they are properly trained in assessing safety and are highly knowledgeable on the hazards of AN. This risk assessment should also be redone annually to combat new risks that can arise in the workplace.
     - Deliverable #2: Document the feedback from the risk assessment. Management must then assess what changes must be made to their current operating procedures and improve it by making specific changes. Areas of importance include:
       - The storage of AN
       - Emergency procedure in the event of an incident
       - The blast radius of AN
       - The detonation temperature of AN
     - Deliverable #3: Management must then ensure the changes are implemented and consistently followed.
       Specific steps include:
       - Holding a formal and detailed training for current employees to ensure they are familiar with the new safety procedure and do bi-annual or annual refresher training
       - Ensuring all new employees receive formal and detailed training about the company's safety procedures
       - Creating checklists that outline the exact steps for employees to follow operating in the facility, especially for the storage of AN
   - Gain Index: 4
     - This recommendation directly addresses many latent causes. It eliminates the hazards and greatly reduces the risk of an incident happening. It would

eliminate the initiating events of the fire not being controlled and the AN being in an unsafe storage area.

- Effort Index: 20
  - Practicability: 4
    The solution is not based on technology
  - Initial Cost: 4
    - The initial cost would be of hiring some sort of committee to conduct the risk assessment. This should cost <$100,000
  - On-going Costs: 4
    - There should be no ongoing cost, as the training and procedures done by management are part of their responsibilities already. No additional incentive (raises, bonuses) should be needed.
  - Timeline: 3
    - The risk assessment can be implemented immediately, the following implantation of protocols and new training require more time; this should all be able to be implemented within three months
  - Duration: 2
    - The duration of time in total for the risk assessment to be done, new protocols to be made, and training employees for the new protocols should take no more than 3 months
  - Frequency: 3
    - The risk assessment and training should be redone annually.
- Total Score 80, “Low Hanging Fruit”.
- Nature of fix: The solution is not technology.
- State the specific latent cause(s) addressed by this recommendation.
  - Company underestimated/did not assess the fire hazard risks adequately
  - Poor risk assessment and management by both the company and the first responders regarding blast radius of the AN and its combustibility
  - There was improper risk assessment regarding the storage of AN
  - The company did not proactively assess and address the risks regarding combustibility of AN
  - Management did not assess the risks of the combustible material and construction in the design
  - There as very poor internal company regulation regarding the storage of AN
  - Facility employees were not trained on safe storage methods
  - Employee responsibilities regarding AN storage were not clearly outline by management
  - Management didn’t prioritize the safe storage of fertilizer as they were unconcerned about all the hazards and risks
  - The company did not continuously work to improve their own plant safety measures by consistently reassessing any new risks and making the appropriate changes
  - Management didn’t checkup on employees following or even putting safety procedures in place
- Alignment to Element(s):

- RMS Element #1 – Management Leadership, Commitment and Accountability
- RMS Element #2 – Risk Assessment and Management of Risks
- RMS Element #6 – Program Evaluation and Continuous Improvement
- RMS Element #9 – Employee Competency and Training

**2) Implement engineering safeguards and controls to ensure safe storage practises and prevent the fire from occurring.**

- After recognizing the risks aforementioned in key recommendation 1, to eliminate the risk of Ammonium Nitrate completely is impossible thus the next step is to lower the risk through applying engineered controls. These controls should include preventing the fire in the first place (surveillance), containing the fire (fire-proofing), and lowering the risk of AN detonation (safe storage practices). Firstly, a security and surveillance system at the facility would prevent the arson from occurring in the first place. Remote and 24/7 monitoring should always be in place to ensure all company assets are secure and if an incident occurs, immediate notification and action is taken. In addition, another layer of engineering controls should include fire safety features that not only include manual fire extinguishers but also fire-proof exits, automatic sprinklers, and fire alarms. Although rebuilding the facility with fire safe and non-combustible materials would have the highest gain index the effort is far too high. Thus, to retrofit the existing facility with these features such as a fire suppression system such as an automatic sprinkler system is the next best option. These fire-preventing features will contain fires at the facility. Lastly, the final layer of engineering controls should include safe storage practices to decrease the risk of AN detonation. Specifically, using non-flammable materials to construct storage bins instead of wooden storage bins which would reduce the explosion hazard of AN. Also, in the process of replacing the bins, to store AN in areas that avoid heating, not exposed to shock waves, and avoid contamination with combustibles and inorganic materials.
    - Deliverable #1: As-built drawings with areas of risk highlighted and suggestions of engineering controls in these areas.
        - Engineers to review drawings and safeguard suggestions, cost analysis also to be done.
    - Deliverable #2: Third party check (such as a safety committee) and management approval of design.
        - Safety committee and management to review safeguard suggestions.
        - Management to approve or reject safeguard suggestions.
    - Deliverable #3: Implementation of engineering controls in the facility, these would include surveillance cameras, fire-safe features including fire alarms and sprinklers, and replacement of flammable materials storing and surrounding where the AN was stored.
        - Order, buy, and install engineering safeguard features.
        - Engineers to update drawings with updated features of facility.
- Gain index: 4

- Eliminates the initiating event of the fire occurring in the first place, as the surveillance cameras would have caught the culprit on scene prior or during the act and authorities would have been notified far before the smoke was noticed. This would have allowed the fire to be detected and contained much earlier, thus preventing the explosion from occurring due to the fire. In addition, this recommendation addresses latent causes of an inappropriately management-approved unsafe facility design regarding fire safety. By fire-proofing the facility with fire alarms, sprinklers, and constructing storage bins with non-flammable materials, this would lower the risk of an uncontained fire and AN exploding due to a fire. Fire safeguards in place has the greatest reduction in fire risk levels along with surveillance systems.

- Effort Index: 18
  - Practicability: 3
    - Requires simple technology for surveillance, fireproofing, and decreasing the risk of explosion/fire (cameras, sprinklers, fire alarms, concrete bins). Security cameras monitored 24/7, sprinklers and fire alarms, and concrete bins are simple technologies can be easily implemented in the existing facility.
  - Initial Cost: 2
    - Initial purchase cost of the concrete bins, fire alarms, sprinklers, and surveillance cameras should result in $1M to $2M. Most of the cost is due to good quality concrete whereas security cameras are not as expensive, nor are fire alarms or sprinklers.
  - On-going Costs: 2
    - Between $10 to $100k primarily due to paying somebody to watch the surveillance cameras 24/7.
  - Timeline: 4
    - All engineering controls suggested can be implemented immediately such as the ordering of security cameras, fire alarms, sprinklers, and concrete bins.
  - Duration: 3
    - Design and fabrication of the concrete bins possibly taking up to a month. As for fire alarms
  - Frequency: 4
    - One-time installation of concrete bins, fire alarms, sprinklers, and cameras.
- Total Score 72, “Low Hanging Fruit”.
- Nature of fix: apply simple technology
- State the specific latent cause(s) addressed by this recommendation.
  - Management approved an inadequate and unsafely designed facility (no fire safeguards)
  - The unsafe design was approved by management and the facility was not adequate
  - Management did not put in effort to have good security; potentially to cut cost
  - Company did not prioritize safety as #1 as more safeguards in place would have costed more. (LC: RMS #1)

- Management did not prioritize safe storage of fertilizer (LC: RMS #1)

- Alignment to Element(s):
  - RMS #7 – Design, Construction and Start-up
  - RMS #1 – Management Leadership, Commitment and Accountability

***Justification for choosing key recommendation #2 versus #3***

Key recommendation #2 and #3 contain the same overall score of 72. We chose the recommendation regarding the engineering design and safeguards as recommendation #2 it was more in our scope and our investigation did more thorough focus on it. The other recommendation regarding safety culture was not as heavily emphasized on our investigation as the fault rested more on management not even having proper safety procedures in the first place.

**3) Improve employee safety culture to ensure that safety is the number one priority throughout the company.**

- The employees were not familiar with proper safety culture; the company lacked to provide them with adequate safety training. Because of this the employees were not operating the facility under safe conditions. This directly lead to the issue regarding how the AN was improperly stored. Because of the improper storage, it was in great risk to detonate which ultimately led to the incident occurring. Company management needs to ensure that the employees are constantly following the outline safety procedures to ensure the safety of all plant employees and the surround community. They must perform routine planned inspections to check on the follow through of safety protocols; unplanned inspections should also be conducted to ensure the employees are following safety protocol even when they are not expecting the inspection. Management also needs to provide positive feedback when procedures are properly followed and apply necessary action when there is indication of inadequate following of procedure. Management needs to provide an all around larger focus of safety within the company.
  - Deliverable #1: Management must conduct routine planned inspections of how the employees are adhering to the safety procedures. This can be done by checking that the AN is properly stored in the correct surroundings and proper storage containers. These checks should be done monthly. Unplanned checks should also be done monthly to ensure the employees are working with integrity and are not just fixing/hiding their safety issues when they know an inspection is happening.
  - Deliverable #2: Management needs to provide positive incentive to employees who follow proper safety protocol to encourage all facility employees to follow suit. This can be done by providing rewards to separate operation teams if inspections show that they are properly following safety procedures. Positive feedback and encouragement should always follow positive results.
  - Deliverable #3: Proper action should be taken when it is discovered that individual(s) are not adhering to the safety protocol.
    Steps for this are:

1. Have a private meeting with the individual(s) to discuss the reasons that they are not following protocol. Give them time off if there are personal issues going on and provide encouragement to follow procedure. Make sure the individual(s) are well educated on the risks they are putting themselves, their coworkers, and the surrounding community at by not following protocol.
2. Place an emphasis on the individual(s) when doing routine inspections to make sure they have changed and are now following safety procedures. Continue to keep an eye on them to make sure they don't fall back into bad habits. Do all this discreetly so the employee does not feel heavily scrutinized and singled out.
3. If the employee does not respond with change and has an inadequate attitude to safety, let them know that this is unacceptable at the company and will result in asking them to leave. If no improvements are made, ask the employee(s) to leave the company

- Deliverable #4: Management needs to provide more all-around safety culture and promote it so that employees are constantly focused on it being the first priority. Annual safety meetings for employees where management will refresh them on the consequences of not following safety procedure. A presentation can be done that includes incidents that happened to other companies and hypotheticals allowing the employees to see what consequence would occur if our own incident occurred.

- Gain Index: 4
  - This recommendation will directly address the latent causes. It will eliminate the hazards of the employees not prioritizing safety and reduce the risks of not adhering to safety protocol. This will eliminate the initiating events of not storing the AN properly and the fire, had an employee been the one that started it.
- Effort Index: 18
  - Practicability: 4
    - The solution is not based on technology
  - Initial Cost: 4
    - There should be no initial cost as conducting inspections and taking proper positive/negative action is all part of managements' job responsibilities.
  - On-going Costs: 3
    - There are no ongoing costs regarding doing the inspections and taking proper actions following those. There will be some costs in terms of taking the employees away from their work to do the annual safety meetings. This loss of production should cost <$10,000 per year
  - Timeline: 3

        - The inspections can be implemented immediately but might take time for management to come up with a good procedure for conducting them. The safety meetings will also take time to implement as the presentation for them needs to be prepared. This should all be implemented within 3 months.
    - Duration: 3
        - The duration of time it takes after the proper preparation is done will be less then a month as it takes time for the inspections and safety meetings to be scheduled at a time that works for the company and its different operational departments.
    - Frequency: 1
        - The inspections must be done monthly to ensure that safety protocol is consistently met. The interaction between employee and management regarding positive/negative feedback should be occurring consistently.
- Total Score 72, “Low Hanging Fruit”.
- Nature of fix: The solution is not technology
- State the specific latent cause(s) addressed by this recommendation:
    - Management did not take measures to routinely check the psychological wellbeing of employees
    - Employees were not compliant with work standards
    - Management didn’t checkup on employees following or even putting procedures in place
- Alignment to Element(s):
    - RMS Element #1 – Management Leadership, Commitment and Accountability
    - RMS Element #9 – Employee Competency and Training

4) **Increase communication with the community (local fire department) and have emergency plans in place in the event of an incident.** By community, ABC Company specifically means the local fire department composed of local community volunteers who respond to emergencies in the area.
    - Increased communication would not only mean being prepared with plans but also implementing these plans in a timely manner. Firstly, emergency procedures would need to be made by collaboration with the local community to address the community’s concerns. This would allow the fire department to be aware of the hazards that are present at the facility. Secondly, these emergency plans need to be approved by both WFC and the fire department as an agreement to follow them in case of emergency. This would allow the emergency response teams to be prepared for evacuation in case of a fire or explosion, which would greatly reduce the exposure and potential loss in lives. Also, these plans would include how fire department is notified in a timely manner. Specifically, the surveillance implemented in recommendation #2 would be responsible for timely notification. Finally, for full preparation, notifying and carrying out these procedures in a timely manner through annual mock incident drills would ensure maximum reduction in risk and exposure to potential hazards/incidents at the facility.

- Deliverable #1: Management meeting with local emergency response teams to address concerns of risks of company hazards.
- Deliverable #2: Creation of emergency response plan with local emergency.
- Deliverable #3: Fire drills and mock emergency plans to be executed annually.

- Gain Index: 3
  - Latent causes of having no emergency procedures in place and making the community/emergency response teams aware of the hazards of the facility are addressed. This recommendation eliminates the hazards as it greatly reduces exposure to the fire and explosion by having evacuation plans in place in case of emergency. Although it addresses latent causes as specified in gain index 4, it would not eliminate the initiating events of the fire or explosion. It also addresses basic causes where the city expanded toward the facility whereas this recommendation would allow the city to be aware of the hazards. The other basic cause it addresses is the lack of notification to the community of the fire at the facility as timely notification would be part of the emergency response plan. Furthermore, this recommendation prevents future incidents by eliminating subsequent condition splits as the emergency response team would be much better prepared in case of incidents and make informed decisions. Finally, it eliminates impact in overall PEAP despite having an event as no lives would be lost if emergency procedures are in place and the community notified timely.
- Effort Index: 21
  - Practicability: 4
    - Low effort as the solution is not technology, solely emergency plans and annual emergency mock drills.
  - Initial cost: 4
    - Low effort as emergency plans are generated with the local volunteer firefighters and management as part of normal work duties.
  - On-going cost: 3
    - <$10,000 per year, costs are largely associated with the interruption of daily work for annual fire drills.
  - Timeline: 4
    - Making the emergency response plan can be begun immediately.
  - Duration: 4
    - Making the emergency procedures then carrying them out in a mock emergency drill requires less than one month to put the action into place.
  - Frequency: 3
    - Annual emergency drills require yearly repeats of the action.
- Total Score 63, “Low Hanging Fruit”.
- Nature of Fix: the solution is not technology
- State the specific latent cause(s) addressed by this recommendation.

- There were no plans or safety procedures in place in the event of an incident (emergency response inadequate)
- The community was not prepared for an incident of this magnitude and were not aware of the hazards and risks of the facility (city built towards the facility)

- Alignment to Element(s):
  - RMS #3 – Community Awareness and Emergency Preparedness

**5) Analyze precedent AN explosions and learn how and why incidents could occur to continuously improve upon own risk management program.**

- Deliverable #1: Identify and analyze previous cases about the AN explosions in the past, ensure risks and hazards that led to the explosion are examined. Ensure immediate, basic, and latent causes are studied through risk cause analysis.
- Deliverable #2: Identify similar flaws inside ABC company systems that could lead to explosions, then evaluate current risk management safety program possible flaws to those of failed companies.
- Deliverable #3: improve the current risk management system to avoid the same incidents from happening to ABC Company.

- Gain Index: 3
  - Addressed to latent cause of the company not continuously working to improve their own plant safety measures as previous AN explosions including 1921 Oppau, Germany; 1947 Texas City, Texas; and 2001 Toulouse, France were not examined with respect to their existing risk management program. These incidents were not analyzed, and no action was taken.
  - Eliminates hazards and has the greatest reduction in risk levels as once key recommendation #1 is implemented, the possible hazards or risks that are missed in the newly implement risk management program can be caught using this recommendation of examining previous similar incidents.
  - Does not eliminates the initial event of the incident as this is solely improving upon the risk management safety program as similar incidents occur.
- Effort Index: 18
  - Practicability: 4
    - This solution is not technology as performing risk cause analysis of previous incidents does not require technology, the actual implementation of changes (such as in recommendation #2) may be but this is solely analyzing possible shortcomings in the company to similar previous incidents.
  - Initial cost: 4
    - To evaluate the existing risk management program this does not need much cost to start investigation or analysis done by ABC company as it should be an extension of the risk management program done by management as part of work duties.
  - On-going cost: 3

        - Since it is an extension of the existing risk management program to continuously evaluate similar incidents as they occur and improve the existing program, extra hours to workers should be considered to investigate and study the case.
    - Timeline: 4
        - Can start investigation immediately.
    - Duration: 2
        - This specific recommendation to analyze incidents is done to previously occurred incidents but also to incidents as they occur in the world thus time during risk cause analysis varies greatly. To give a generous estimate, investigating similar cases as they occur and identifying existing program shortcomings could take more than three months for a full thorough analysis.
    - Frequency: 1
        - Also a generous estimate as how often the risk management program needs to be re-evaluated and improved upon depends on how frequent incidents occur thus it is a level 1 in this case.
- Total Score 54, “Low Hanging Fruit”.
- Nature of Fix: the solution is not technology
- State the specific latent cause(s) addressed by this recommendation.
    - Company did not continuously work to improve their own plant safety measures
    - Incidents were not analyzed, and very little action was taken
- Alignment to Element(s):
    - RMS #5 - Incident Reporting, Investigation, Analysis and Actions
    - RMS #6 - Program Evaluation and Continuous Improvement

## Appendix G: Summary of the Recommendations:

| Rank | Recommendation | Gain Index | Effort Index | Total Score | Nature of Fix | Latent Cause(s) Addressed | Alignment |
|---|---|---|---|---|---|---|---|
| 1 | Conduct a risk assessment to properly assess the risks regarding storage of FGAN within the facility, then create and implement new safety protocol. | 4 | 20 | 80 | The solution is not technology. | • Company underestimated/did not assess the fire hazard risks adequately<br>• Poor risk assessment and management by both the company and the first responders regarding blast radius of the AN and its combustibility<br>• There was improper risk assessment regarding the storage of AN<br>• The company did not proactively assess and address the risks regarding combustibility of AN<br>• Management did not assess the risks of the combustible material and construction in the design<br>• There as very poor internal company regulation regarding the storage of AN<br>• Facility employees were not trained on safe storage methods<br>• Employee responsibilities regarding AN storage were not clearly outline by management<br>• Management didn't prioritize the safe storage of fertilizer as they were unconcerned about all the hazards and risks<br>• The company did not continuously work to improve their own plant safety measures by consistently reassessing any new risks and making the appropriate changes<br>• Management didn't checkup on employees following or even putting safety procedures in place | RMS #1<br>RMS #2<br>RMS #6<br>RMS #9 |
| 2 | Implement engineering safeguards and controls to ensure safe storage practises and prevent the fire from occurring. | 4 | 18 | 72 | Apply simple technology. | ○ Management approved an inadequate and unsafely designed facility (no fire safeguards) .<br>○ The unsafe design was approved by management and the facility was not adequate<br>○ Management did not put in effort to have good security; potentially to cut cost<br>○ Company did not prioritize safety as #1 as more safeguards in place would have costed more.<br>○ Management did not prioritize safe storage of fertilizer. | RMS #1<br>RMS #7 |
| 3 | Improve employee safety culture to ensure that safety is the number one priority throughout the company. | 4 | 18 | 72 | The solution is not technology. | • Management did not take measures to routinely check the psychological wellbeing of employees<br>• Employees were not compliant with work standards<br>• Management didn't checkup on employees following or even putting procedures in place | RMS #1<br>RMS #9 |
| 4 | Increase communication with the community (local fire department) and have emergency plans in place in the event of an incident. | 3 | 21 | 63 | The solution is not technology. | ○ There were no plans or safety procedures in place in the event of an incident (emergency response inadequate)<br>○ The community was not prepared for an incident of this magnitude and were not aware of the hazards and risks of the facility (city built towards the facility) | RMS #3 |
| 5 | Analyze precedent AN explosions and learn how and why incidents could occur to continuously improve upon own risk management program. | 3 | 17 | 51 | The solution is not technology. | • Company did not continuously work to improve their own plant safety measures<br>• Incidents were not analyzed, and very little action was taken | RMS #5<br>RMS #6 |

## Appendix H: Business Case Analysis:

| | **Top Two Recommendations** |
|---|---|
| **Cost Avoidance of a Loss Incident** | $379,633,826 |
| **Initial Costs of Improvements** | $2,100,000 |
| **On-going Costs of Improvements per Year** | $100,000 |
| **Life of Project** | 30 |
| **Total Cost of Improvements** | $5,100,000 |
| **Annual Risk Exposure without Improvements** | $12,654,461 |
| **Annual Risk Exposure with Improvements** | $379,633.83 |
| **Gross Benefit** | $12,274,827 |
| **Net Benefit** | **$7,174,827** |

### 1) Referring to the Complex Effort v Gain Tool, in which quadrant does this case fall? Explain.

This case falls under the Low Hanging Fruit quadrant. The recommendations directly address numerous latent causes. They do not require extraneous effort to implement and greatly reduces, or even eliminates, the risk of an incident. As seen from the above table, the annual risk exposure without improvements is almost $13 million while the risk exposure with improvements is barely $400 000. The cost saved by implementing the recommendations is immense.

### 2) What conclusion do you draw about this Business Case Analysis? Explain.

From this Business Case Analysis, we determine that the top two recommendations are worth implementing as the net benefit value is positive. It shows that the cost of implementing and maintaining the recommendations is outweighed by the cost avoidance of a loss. The annual risk exposure would be drastically decreased if the improvements were made.

### 3) What other factors must you consider? Recall, that this approach is a preliminary assessment of the Case under study and is definitely not a sound basis on which to make a final decision.

The Business Case analysis only takes into consideration the loss of assets. Appendix A outlines a plethora of other loses; loss to people, production and environment. Although the cost of a human life and injury cannot be directly determined, if it were included along with production and environmental losses in the calculation of net benefit, the value would be much higher. It would show that the recommendations are even more worth implementing. Despite all the calculations, safety should always be prioritized over the potential loss through costs of improvements.

**Appendix I: References:**

**Please note all information is from source [1] unless otherwise indicated.**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## Module 3-07-404-1: Final Technical Report Marking Rubric – For Use by Students

| | |
|---|---|
| Date: Aug 1, 2018 | Team #: 03 Case Study Name: West Texas Fertilizer Explosion |
| Team Members: | Patricia Yan, Siyuan Zhang, Yujie Qi, Bach Vo |

| **Final Technical Report Focus Areas** | **Comments** | **Team's Marks** | **Total Marks** |
|---|---|---|---|
| Cover Page and Table of Contents | | | **5** |
| **Executive Summary:** | | | |
| ES: Incident Description and Losses | | | **5** |
| ES: Context and Purpose of the Incident Investigation | | | **5** |
| ES: Root Cause Analysis Summary | | | **5** |
| ES: List of the Latent Causes | | | **5** |
| ES: Recommendations: | | | **5** |
| ES: Business Case Analysis | | | **5** |
| ES: Issues with Implementation | | | **10** |
| ES: Next Steps: | | | **15** |
| **Appendices:** | | | |
| A: Incident Description and Losses | | | **10** |
| B: Context and Purpose of the Incident Investigation | | | **10** |
| C: Root Cause Analysis – Chart | | | **20** |
| D: Root Cause Analysis – Discussion: | | | **15** |
| E: Application of the Cause and Effect Model: | | | **20** |
| F: Key Recommendations | | | **30** |
| G: Summary of Recommendations | | | **10** |
| H: Business Case Analysis | | | **15** |
| I: References | | | **5** |
| **Overall:** Spelling, Grammar, Format, Organization, Presentation, Rational and Logic; Overall Flow | | | **10** |
| | **Total:** | | **205** |

| **Team Project Total Mark:** | **Team's Marks** | **Total Marks** | **Total Marks, %** |
|---|---|---|---|
| The Progress Report | 93 | 120 | / 5% |
| The Final Technical Report | | 205 | / 25% |
| Total | | n/a | / 30% |

U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

# INVESTIGATION REPORT

**FINAL**

## WEST FERTILIZER COMPANY FIRE AND EXPLOSION

**(15 Fatalities, More Than 260 Injured)**

**WEST FERTILIZER COMPANY**

WEST, TX

APRIL 17, 2013

## KEY ISSUES:

- REGULATORY OVERSIGHT
- HAZARD AWARENESS
- EMERGENCY PLANNING AND RESPONSE
- FERTILIZER GRADE AMMONIUM NITRATE STORAGE PRACTICES
- LAND USE PLANNING AND ZONING

REPORT 2013-02-I-TX

# Contents

# 1.0 Executive Summary

## 1.1 Overview

On April 17, 2013, a fire and explosion occurred at the West Fertilizer Company (WFC), a fertilizer blending, retail, and distribution facility in West, Texas. The violent detonation fatally injured 12 emergency responders and three members of the public. Local hospitals treated more than 260 injured victims, many of whom required hospital admission. The blast completely destroyed the WFC facility and caused widespread damage to more than 150 offsite buildings. The WFC explosion is one of the most destructive incidents ever investigated by the U.S. Chemical Safety and Hazard Investigation Board (CSB) as measured by the loss of life among emergency responders and civilians; the many injuries sustained by people both inside and outside the facility fenceline; and the extensive damage to residences, schools, and other structures. Following the explosion, WFC filed for bankruptcy.

The explosion happened at about 7:51 pm central daylight time (CDT), approximately 20 minutes after the first signs of a fire were reported to the local 911 emergency response dispatch center. Several local volunteer fire departments responded to the facility, which had a stockpile of between 40 and 60 tons (80,000 to 120,000 pounds) fertilizer grade ammonium nitrate (FGAN), not counting additional FGAN not yet offloaded from a railcar.

More than half of the structures damaged during the explosion were demolished to make way for reconstruction. The demolished buildings include an intermediate school (552 feet southwest of the facility), a high school (1,263 feet southeast), a two-story apartment complex with 22 units (450 feet west) where two members of the public were fatally injured, and a 145-bed nursing home (500 feet west) where many of the seriously injured civilians resided. A middle school (2,000 feet southwest) also sustained serious but reparable damage. Section 3 describes the incident and its consequences in detail.

The CSB investigated the factors that contributed to the detonation of FGAN. Section 4 describes the properties of FGAN and posits three scenarios that could lead to its detonation under the conditions present during the WFC fire. CSB concluded that the construction of the bins and other building materials as well as the lack of an automatic sprinkler system plausibly contributed to the detonation. Section 6 describes inherently safer approaches to FGAN use and storage that reduce the risk of an FGAN detonation.

The total insurance-related losses from the explosion are estimated to be around $230 million and federal disaster assistance is estimated to exceed $16 million. WFC was only insured for $1 million, which fell far short of the incident's damage. Section 5 presents CSB's analysis of the policies and regulations that led to this as well as to the failure of the insurer to identify the risks posed by FGAN. A few years prior to the incident, WFC was dropped by one insurer for failing to address safety concerns identified in loss control surveys. The company that insured WFC at the time of the incident did not appear to have conducted its own safety inspections of the facility.

CSB's analysis of the emergency response, found in Section 7, concludes that the West Volunteer Fire Department did not conduct pre-incident planning or response training at WFC, was likely unaware of the potential for FGAN detonation, did not take recommended incident response actions at the fire scene, and did not have appropriate training in hazardous materials response.

CSB found several shortcomings in federal and state regulations and standards that could reduce the risk of another incident of this type. These include the Occupational Safety and Health Administration's Explosives and Blasting Agents and Process Safety Management standards, the Environmental Protection Agency's Risk Management Program and Emergency Planning and Community Right-to-Know Act, and training provided or certified by the Texas Commission on Fire Protection and the State Firefighters' and Fire Marshals' Association of Texas. CSB's complete analysis is presented in Section 8.

The location of the WFC relative to the surrounding community exacerbated the offsite consequences, leading CSB to assess whether other FGAN storage facilities could pose significant offsite risks. CSB's analysis shows that the risk to the public from a catastrophic incident exists at least within the state of Texas, if not more broadly. For example, 19 other Texas facilities storing more than 10,000 pounds of FGAN are located within 0.5 miles of a school, hospital, or nursing home, raising concerns that an incident with offsite consequences of this magnitude could happen again. Section 9 explores the connection between land use planning and offsite consequences.

## 1.2 Federal and State Response

In response to this incident, President Barack Obama issued Executive Order (EO) 13650, "Improving Chemical Facility Safety and Security" to coordinate federal actions to reduce the risks of another incident of this type.[1] Details and updates on the status of the EO are included in Section 8.1.

Early investigation activities focused on law enforcement efforts to determine if there was a criminal element to the incident. Responding governmental agencies included the U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) National Response Team, Texas State Fire Marshal's Office (SFMO), U.S. Occupational Safety and Health Administration (OSHA), Texas Commission on Environmental Equality, U.S. Federal Emergency Management Agency (FEMA), and U.S. Environmental Protection Agency (EPA). In addition, multiple state and local law enforcement and emergency response organizations responded to the scene.

### 1.2.1 Joint SFMO/ATF Investigation

Immediately following the incident, ATF deployed to West at the invitation of SFMO and assumed control of the WFC site to conduct a joint investigation of the immediate cause and origin of the fire and explosion and determine whether the initiating fire was intentionally set. The two agencies retained

[1] Executive Order 13650. "Improving Chemical Facility Safety and Security," August 1, 2013. *See*: https://www.whitehouse.gov/the-press-office/2013/08/01/executive-order-improving-chemical-facility-safety-and-security (accessed on December 8, 2015).

control of the scene for about four weeks, interviewing witnesses, excavating the WFC site, and reconstructing the electrical system. To date, law enforcement has not made a final determination of the cause of the fire and ensuing explosion. Three possible scenarios remain under consideration: (1) faulty electrical wiring, (2) short circuit in an electrical golf cart, and (3) intentional act of arson.[2]

### 1.2.2 CSB Response

CSB investigators from both the Washington, DC, and Denver, Colorado, offices deployed on April 18, 2013, supported by a contingent of contractors that included blast modeling, structural, urban search and rescue, and fire and explosion experts. The joint ATF-SFMO control of the site as a crime scene limited CSB site access and delayed CSB investigator execution of evidence-gathering protocols, chemical testing, and witness interviews. Despite the limited access in the initial stages, driven by the criminal investigation, CSB continued with its investigation.

The investigation of the WFC incident analyzed several root causes and considered multiple contributing causes. Investigative teams partnered with urban search and rescue experts and fire and explosion consultants to survey damage to residences, schools, the nursing home, and other structures. The teams also conducted interviews with eyewitnesses, WFC managers, and hourly workers and gathered physical evidence for further laboratory testing and analysis.

**Key Findings**

The CSB's analysis includes findings on the technical causes of the fire and explosion; regulatory changes that could have resulted in safety enhancements to the facility; the failure of the insurer to conduct safety inspections or provide an adequate level of coverage; shortcomings in emergency response, including pre-incident planning or response training of the volunteer fire fighters; and deficiencies in land use planning that permitted the City of West to encroach upon the WFC over the years. Section 10 presents the CSB's key findings on the WFC incident.

**Recommendations**

As a result of the investigation of the WFC fire and explosion, CSB developed recommendations and directed them to the following recipients:

- Environmental Protection Agency (EPA).
- Occupational Safety and Health Administration (OSHA), U.S. Department of Labor.
- Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security.
- International Codes Council.
- Texas Department of Insurance.
- Texas Commission on Fire Protection.
- State Firefighters' and Fire Marshals' Association of Texas.
- Texas A&M Engineering Extension Services (TEEX).

[2] *See*: http://www.tdi.texas.gov/news/2013/news201320.html (accessed on December 22, 2015).

- El Dorado Chemical Company (EDC).
- West Volunteer Fire Department (WVFD).

Section 11 contains the complete set of recommendations.

# 2.0 Background

## 2.1 West Fertilizer Company

The West Fertilizer Company (WFC) was located in the city of West, Texas. The city is approximately 80 miles south of Dallas, Texas, and has a population of about 2,800.[3] The WFC stored and distributed fertilizers, chemicals, grains, and various other farming supplies. At the time of the incident, stockpiles of about 40 to 60 tons of FGAN were estimated to be onsite, and about 30 tons detonated. Table 1 shows the WFC inventory at the time of the explosion and fire.

Table 1. WFC Fertilizer Inventory in April 2013

| Fertilizer Name | Amount (in tons) |
|---|---|
| FGAN (fertilizer building) | 40 to 60 |
| FGAN (railcar) | 100 |
| Anhydrous ammonia | 17 |
| Potash[4] | 45 |
| Diammonium phosphate[5] | 70 |
| Diammonium phosphate and potash | 25 |
| Ammonium sulfate[6] | 60 to 70 |
| Zinc sulfate[7] | 17.5 |

The fertilizer building was constructed in 1961, and business operations started in 1962. Photographs from 1972 show the closest residence about 265 feet from the WFC property. In addition, a baseball field

[3] The 2010 U.S. Census data indicate that the population of West, Texas, is 2,807. *See*: http://www.census.gov/2010census/popmap/ (accessed on December 8, 2015).
[4] Potash is an agricultural fertilizer and is a source of soluble potassium (K).
[5] Diammonium phosphate (DAP), $(NH_4)_2HPO_4$, is one of a series of water-soluble ammonium phosphate salts that can be produced when ammonia reacts with phosphoric acid.
[6] Ammonium sulfate, $(NH_4)_2SO_4$, is an inorganic salt with a number of commercial uses. The most common use is as a soil fertilizer.
[7] Zinc sulfate, $ZnSO_4$, is an inorganic compound and is a colorless solid that is a common source of soluble zinc ions.