Tornadoes Disaster Impacts Based on Data Analytics, Protections and Disaster Management with New Technologies for Rapid Recovery

C. Vipulanandan Ph.D., P.E.
Honorable Daniel Wong Endowed Professorship
"**Smart Cement**" Inventor and Text Book
"**Vipulanandan Rheological Model**"
"**Vipulanandan Failure Model**"
Chief Editor – Advances in Civil Engineering
Director, Center for Innovative Grouting Material and Technology (CIGMAT)
Director, Texas Hurricane Center for Innovative Technology (THC-IT)
Professor of Civil and Environmental Engineering
University of Houston, Houston, Texas 77204-4003

Abstract

About 2000 tornadoes/year are happening around the world and in the U.S.A. there are about 1200 tornadoes per year. United States and Bangladesh are the two countries with the worst tornadoes in history and one reason is that the atmospheric condition in the Gulf of Mexico in the U.S.A. is very similar the Bay of Bengal in Bangladesh. Also in the U.S.A tornadoes can occur throughout the year, but based on the data analyses March to July are the critical months. The **natural tornadoes are initiated by the warm moist air meets and mixtures mixing with cold dry air resulting in violently rotating columns of air forming vortex and is in contact with ground and often visible as a tunnel cloud. Also there is only about 15 minutes pre-warning and** very limited time for preparedness unlike the hurricane disasters where there are days of pre-warning**.** Also the tornado disasters have had major losses compared to the flooding disasters. Tornado disasters can result in power failures, flooding, fire and major infrastructure damages including failure of houses, buildings, bridges, and pipelines (water, wastewater and oil and gas). The **rapid recovery (RR)** due to tornado disasters will also take a **longer time** compared to some of the other natural disasters because of the **greater impact on the earth and the environment**.

In recent years, tornado disasters and human made disasters including cyber-attacks have become a major problem in power failures of critical operations such as water supplies, hospitals, transportation systems, oil supplies and charging electric cars and other vehicles. Hence there is a need for developing resilient methods to minimize the tornado disasters with alternative protection systems to minimize major disruptions in multiple operations and also the losses in the time and revenue and minimize the pollution of the environment. In this study handling of **Preparedness (P), Disaster Response (DR) and Raid Recovery (RR)** using the 3 Phase Model during multiple disasters coupled with tornado disaster have been investigated. Also the benefit of adopting new technologies to minimize losses have been investigated.

Introduction

Tornadoes are violent weather phenomena. Tornadoes are happening around the world throughout the year. During the tornado there will be high speed wind with highly dense rainfall causing rapid flooding and also lightening causing fires, so tornado is a multiple disaster. Tornado produce wind speeds up to 300 mph that lift cars into the air, shred houses apart in seconds, and turn glass and debris into destructive missiles. More than 2,000 tornadoes occur worldwide every year, causing hundreds of deaths and millions in damage. The Daulatpur-Saturia in Bangladesh was the worst tornado in the history of the world (Figure 1). On April 25, 1989, an F4 tornado ripped through the Manikganj District in Bangladesh. Its path was 50 miles long, and its wind speed was between 210 and 260 mph. The exact death toll is uncertain, but it’s estimated to be around 1,300 people, with 12,000 injured. The tornado uprooted trees, destroyed countless homes, and left 80,000 people homeless.

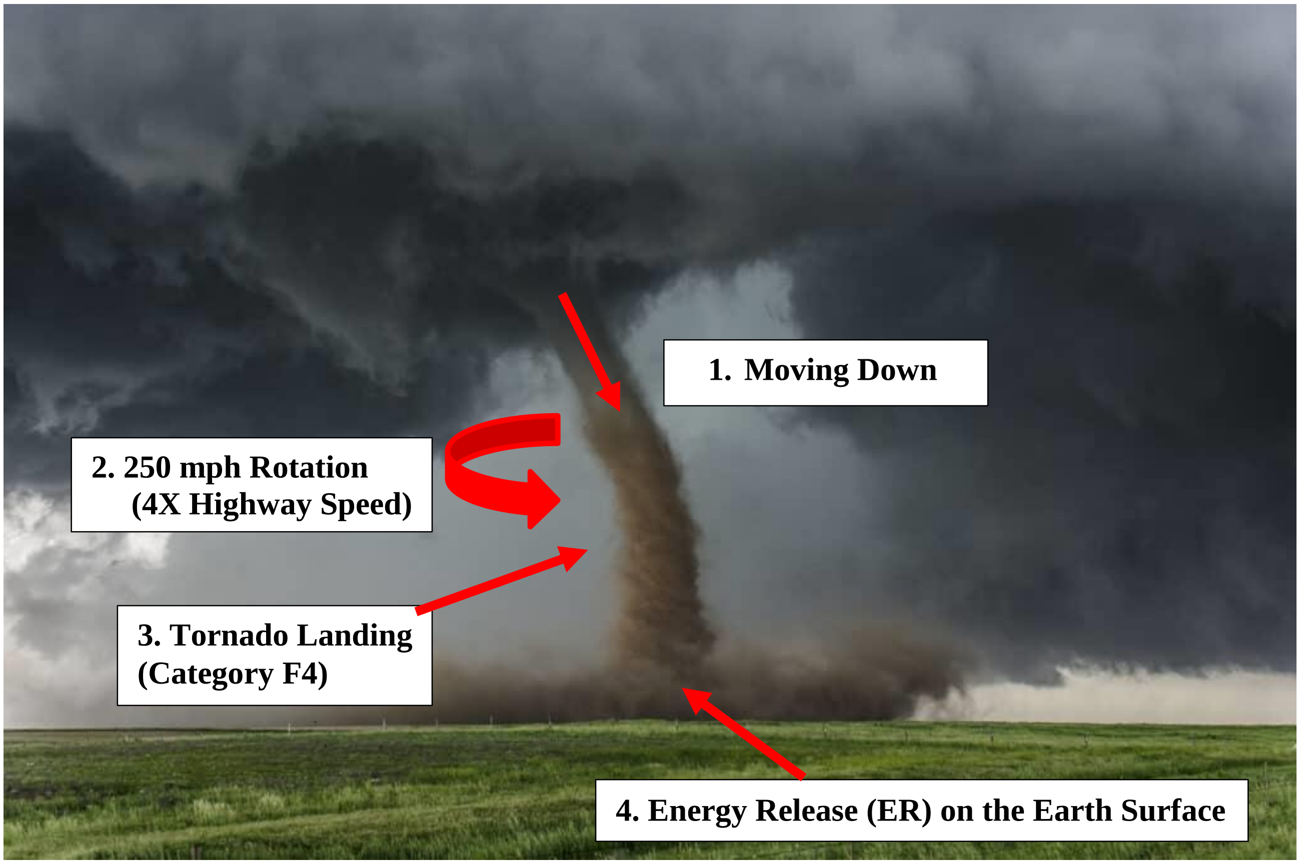


Figure 1. The Daulatpur-Saturia in Bangladesh (1989) was the deadliest tornado in human history (Ocean - Bay of Bengal).

The Tri-State tornado was the deadliest in United States history and the second deadliest on earth (Figure 2). A deadly outbreak of at least 12 tornadoes mowed down homes, schools, and businesses across Missouri, Illinois, Alabama, Indiana, and Kansas. These tornadoes spawned mid-afternoon on March 18, 1925, while children were in school and people were at work. The worst of the bunch was the F5 Tri-State tornado that tore through Southeastern Missouri, Southern Illinois, and Southwestern Indiana. The outbreak lasted 7 hours, claiming 659 lives and causing billions in damages.

Figure 2. The Tri-State Outbreak in March 1925 was the Worst Recorded Tornado in the United States (Ocean – Gulf of Mexico).

Based on the past history it is important to investigate and analyze the available data on tornadoes and the losses to build the lessons learned for disaster preparedness (P), disaster response (DR) and repaid recovery (RR).

World

The worst 10 tornadoes around the world in the past 200 years are summarized in Table 1 and are ranked based on the deaths. Also 50% of the tornadoes were in April followed by May. As summarized in Table 1, U.S.A. had 5 worst tornadoes followed by Bangladesh with 3 worst tornadoes. Studies have shown that Gulf of Mexico wind conditions in the U.S.A. is similar the Bay of Bengal condition in Bangladesh causing the tornadoes.

Table 1. Summary of 10 Deadliest Tornadoes around the World in past 200 Years

Ranking Based on Deaths	Date	Location	Category	Deaths	Remarks
1	**25 April 1989**	**Bangladesh**	**F4**	**1300**	**Worst in the world**
2	**18 March 1925**	**Tri-State (MO/IL/IN), U.S.A.**	**F5**	**695**	**Worst in the U.S.A.**

3	17 April 1973	Bangladesh	F4	681	2nd Worst in Bangladesh
4	08 December 1851	West Sicily, Italy	NA	500	Ranked 1 in Italy
5	1 April 1977	Bangladesh	NA	500	3rd Worst in Bangladesh
6	5 April 1936	U.S.A. (MS & GA)	F5	454	2nd Worst in the U.S.A.
7	9 June 1984	Russia (North of Moscow)	F4	400	Worst in Russia
8	23 April 1908	U.S.A. (Midwest)	F4	324	3rd Worst in the U.S.A.
9	7 May 1840	U.S.A. (MS)	NA	317	4th Worst in the U.S.A.
10	27 May 1896	U.S.A (St. Louis MO)	F4	255	5th Worst in the U.S.A.
Remarks (10 Tornadoes)	1 in March 5 in April 2 in May 1 in June 1 in Dec.	5 in U.S.A. 3 in Bangladesh 1 in Russia 1 in Italy (Continents: North America, Asia and Europe)	Mainly F4 and F5	Ranked Based on the total deaths	All are above the Equator On Earth

It is of interest to note that all the 10 worst tornadoes around the world occurred above equator. Also the total deaths varied from 1,300 to 255.

U.S. History

It is of interest to investigate the worst tornadoes in the U.S.A. In Table 2 the 25 worst tornadoes in the U.S.A. over the past 200 years are summarized and compared. Highest number of tornadoes happened in the month of May followed by April and June as summarized in Table 2.

Table 2. Summary of 25 Deadliest Tornadoes around the U.S.A. in the Past 200 Years

Ranking Based on Deaths	Date	Location	Deaths	Remarks
1	18 Mar 1925	Tri-State (MO/IL/IN)	695	Worst in the U.S.A. and ranked 2nd worst in the world
2	06 May 1840	Natchez MS	317	Ranked 1st in MS. Ranked

				6th in the World.
3	**27 May 1896**	**St. Louis MO**	**255**	**Ranked 1st in MO. Ranked 7th in the World**
4	**05 Apr 1936**	**Tupelo MS**	**216**	**Ranked 2 in MS.**
5	**06 Apr 1936**	**Gainesville GA**	**203**	**Ranked 1st in GA.**
6	**09 Apr 1947**	**Woodward OK**	**181**	**Ranked 1st in OK.**
7	**22 May 2011**	**Joplin MO**	**158**	**Ranked 2nd in MO.**
8	**24 Apr 1908**	**Amite LA, Purvis MS**	**143**	**Ranked 1 in LA. Ranked 3rd in MS.**
9	**12 Jun 1899**	**New Richmond WI**	**117**	**Ranked 1St in WI.**
10	**8 Jun 1953**	**Flint MI**	**116**	**Ranked 1St in MI.**
11	**11 May 1953**	**Waco TX**	**114**	**Ranked 1St in TX.**
12	**18 May 1902**	**Goliad TX**	**114**	**Ranked 2nd in TX.**
13	**23 Mar 1913**	**Omaha NE**	**103**	**Ranked 1St in NE.**
14	**26 May 1917**	**Mattoon IL**	**101**	**Ranked 2nd in IL.**
15	**23 Jun 1944**	**Shinnston WV**	**100**	**Ranked 1St in West Virginia.**
16	**18 Apr 1880**	**Marshfield MO**	**99**	**Ranked 3rd in MO.**
17	**01 Jun 1903**	**Gainesville GA**	**98**	**Ranked 2nd in GA.**
18	**09 May 1927**	**Poplar Bluff MO**	**98**	**Ranked 4th in MO.**
19	**10 May 1905**	**Snyder OK**	**97**	**Ranked 2nd in OK.**
20	**3 Jun 1860**	**Comanche IA, Albany IL**	**92**	**Ranked 1St in IA and 3rd in IL.**

21	**24 Apr 1908**	**Natchez MS**	**91**	**Ranked 4th in MS.**
22	**09 Jun 1953**	**Worcester MA**	**90**	**Ranked 1St in MA.**
23	**20 Apr 1920**	**Starkville MS to Waco AL**	**88**	**Ranked 5th in MS and 1st in AL.**
24	**28 Jun 1924**	**Lorain/Sandusky OH**	**85**	**Ranked 1St in OH.**
25	**25 May 1955**	**Udall KS**	**80**	**Ranked 1St in KS.**
Remarks (25 Worst Tornadoes)	**2 in March 7 in April 9 in May 7 June**	**5 MO; 5 MS; 3IL; 2GA; 2OK; 2 TX;1 IN; 1 Al; 1 LA**	**Varied from 695 (tri states) to 80**	**Month of May had the highest of 9. Also Gulf of Mexico coastal states (MS, TX, AL, and LA) had 9 worst tornadoes.**

Most Costly Tornadoes

The worst tornado occurred in Joplin, MO in May 2011 as summarized in Table 3 and it cost $2.8 billion. In April 2011, Alabama was struck particularly hard, with tornadoes rated EF-5 (the most intense) on the Enhanced Fujita scale hitting Hacklesburg, Birmingham and Tuscaloosa. Also April 2011 had the highest number of tornadoes, total of 750 in a month in the U.S.A.

Table 3. Ten Most Costliest (based on actual cost) Tornadoes Since 1950 in the U.S.A.

Rank	DATE	LOCATION(S)	ACTUAL $
1	22 May 2011	Joplin MO	2.80 billion
2	27 April 2011	Tuscaloosa AL	2.45 billion
3	20 May 2013	Moore OK	2.00 billion
4	27 Apr 2011	Hackleburg AL	1.29 billion
5	3 May 1999	Moore/Oklahoma City OK	1.00 billion
6	10 Apr 1979	Wichita Falls TX	277.8 million
7	6 May 1975	Omaha NE	250.6 million
8	8 Jun 1966	Topeka KS	250 million
9	11 May 1970	Lubbock TX	250 million
10	3 Apr 1974	Xenia OH	250 million

Remarks	**4 April 5 May 1 June**	**2 TX, 2 AL, 2 OK, 1 MO, 1 KS, 1OH, 1 NE**	**Varied from $2.8 billion to $250 million**

Based on the cost, largest number of tornadoes occurred in May followed by April and June.In 2021, tornadoes resulted in approximately $229 million worth of damage across the United States. This was the lowest figure reported since 2016. On the other hand, the economic damage caused by tornadoes peaked in 2011, at nearly $9.5 billion.

Table 4. Number of Tornadoes per Month since 1950 in the U.S.A. (NOAA- Nation Center for Environmental Information (NCEI))

Month	Number of Tornadoes/Month (Minimum to Maximum)	Average	Remarks
January	**0 - 210**	**39**	**Ranked No. 10 Based on the Average Tornadoes per Month.**
February	**2 - 150**	**36**	**Ranked No. 11 Based on the Average Tornadoes per Month.**
March	**5 - 240**	**80**	**Worst Tornado in 1925. Ranked No. 6 Based on the Average Tornadoes per Month.**
April	**10 – 750***	**182**	**Highest Number of 750 Tornadoes in 2011. Ranked No. 3 Based on the Average Tornadoes per Month.**
May	**30 - 550**	**268**	**Worst Month for Top 25 Tornadoes Disasters. Ranked No. 1 Based on the Average Tornadoes per Month.**
June	**30 - 400**	**213**	**Ranked No. 2 Based on the Average Tornadoes per Month.**
July	**20 - 240**	**119**	**Ranked No. 4 Based on the Average Tornadoes per Month.**

August	**10 -180**	**81**	**Ranked No. 5 Based on the Average Tornadoes per Month.**
September	**4 -290**	**66**	**Ranked No. 7A Based on the Average Tornadoes per Month.**
October	**0 - 150**	**66**	**Ranked No. 7B Based on the Average Tornadoes per Month.**
November	**0 - 150**	**54**	**Ranked No. 9 Based on the Average Tornadoes per Month.**
December	**0 - 230**	**28**	**Ranked No. 12 Based on the Average Tornadoes per Month.**
Remarks	**Large variation from month to month. April 2011 had the highest number of tornadoes.**	**Month of May has the largest average number of tornadoes.**	**Total average per year is 1232 tornadoes, Highest in the World. U.S.A. is ranked No. 1 in the total number of Tornadoes. Also U.S.A. in No. 1 in GDP and also COVID-19 Virus Deaths.**

(c) Texas

Texas is ranked #2 in the GDP in the U.S.A. and also located on the Gulf of Mexico (GOM) coast and is impacted by the hurricanes, oil well failures, oil spills and also tornadoes. Texas is also ranked No.2 based on the number of hurricanes in the GOM, next to west Florida. Also Texas was ranked No.2 along the GOM next to Mississippi in the top 25 worst tornado disasters in the U.S.A. (Table 2). It will be interesting to evaluate some of the worst tornadoes in Texas and are summarized in Table 5.

Table 5. Eleven Worst Tornadoes in Texas Since 1900

Rank	Date	Location (Catageory)	Deaths	Damages	Remarks
1	**4:00 p.m. May 11, 1953**	**Waco (F5)**	**114**	**Destroyed 600 homes; Damaged 1000 buildings**	**Based on the deaths and damages it was Ranked No. 1.**

				and 2000 vehicles	
2	4:00 p.m. May 18, 1902	Goliad (F4)	114	Damaged 100 buildings	Ranked No. 2 based on the losses.
3	April 12, 1927	Rockspring (F5)	74	Destroyed 235 buildings	Ranked No. 3 based on the losses.
4	April 9, 1947	Glazier/Higgins (Moved from Western Okohoma)	68	Not Available (NA)	Ranked No. 4 based on the losses.
5	April 10, 1979	Wichita falls (F4)	42	Destroyed 3000 homes. Damaged shopping center.	Ranked No. 5 based on the losses.
6	May 6, 1930	Forest (F4)	41	NA	Ranked No. 6 based on the losses.
7	May 6, 1930	Karnes-Dewitt (F4)	36	NA	Ranked No. 7 based on the losses.
8	May 30, 1909	Zephyr (F4)	36	Damaged 50 homes, 6 businesses, high school.	Ranked No. 8 based on the losses.
9	May 22, 1987	Saragosa (F4)	30	Damaged several buildings and killed people at graduation ceremony.	Ranked No. 9 based on the losses.
10	May 27, 1997	Jarrell (F5)	27	Destroyed more than 40 homes and some were removed from the foundations.	Ranked No. 10 based on the losses.
11	May 11, 1970	Lubbock (F5)	26	Destroyed 1000 homes and apartments, 10,000 vehicles and	Ranked No. 11 based on the losses.

				over 100 aircrafts.	
Remarks	**8 in May 3 in April**	**F5 and F4 tornadoes**	**Deaths from 114 to 26.**	**Destroyed or damaged homes, businesses and vehicles.**	**Northwest and Central Texas were Impacted.**

In Texas, 8 of the worst tornadoes happened in the month of May followed by April. The deaths varied from 114 to 26. The worst tornadoes had impacted northwest and central Texas.

Lessons Learned

There are thousands of tornadoes per year around the world impacting not only countries and also the global operations. There is need for building redundancy to protect against tornadoes starting at local levels to cities, counties, states and the county.

Hence there is need for preparedness (P), disaster response (DR) and rapid recovery (RR) for major natural and human made fires to minimize the humans, animals and birds life losses, time and revenue losses with rapid recovery.

Objectives

The objectives of this study is to investigate the critical issues related to tornadoes and developing disaster protection and building resilience in disaster management. The specific objectives are as follows:

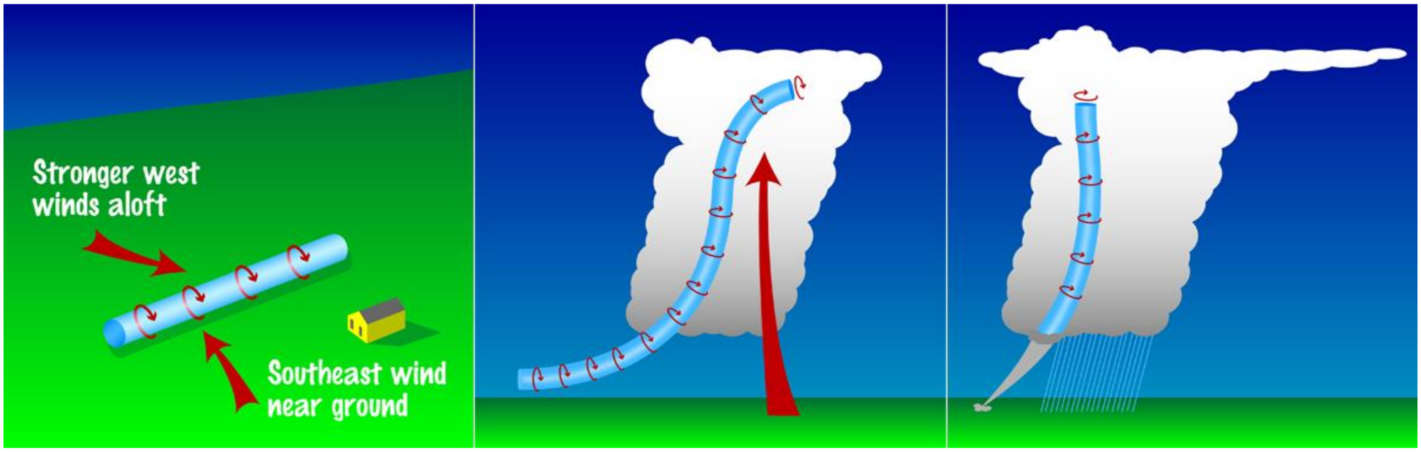
(a) Identify the critical parameters causing the natural disaster tornado resulting in major losses and also polluting the environment.

(b) Develop disaster management plans including preparedness (P), disaster response (DR) and rapid recovery (RR) plans to build the community resilience.

In this study, the data was collected on the critical issues related to tornadoes with the building of resilience to maintain the operating systems functioning under critical events.

How do tornadoes form?

Most tornadoes form **from thunderstorms**. You need **warm, moist air from the Gulf of Mexico** and **cool, dry air from Canada (Figure 3)**. When these two air masses meet, they create instability in the atmosphere. A change in wind direction and an increase in wind speed with increasing height creates an invisible, horizontal spinning effect in the lower atmosphere. Rising air within the updraft tilts the rotating air from horizontal to vertical. An area of rotation, 2-6 miles wide, now extends through much of the storm. Most strong and violent tornadoes form within this area of strong rotation.



(a) Forming (b) Warm Air Going Up (c) Tornado Coming Down

Figure 3 Formation of Tornados

Inside the huge thundercloud, **warm and humid air is rising**, while cool air is falling, along with rain or hail. All these conditions **can result in rolling, spinning air currents inside the cloud**. Although this spinning column of air starts out horizontal, it can easily go vertical and drop down out of the cloud. When it touches the ground, it's a tornado and a big problem to anything in its path.

The winds inside the spinning column of some tornadoes are the fastest of any on Earth. They have been clocked at over 300 miles per hour. Sometimes the spinning column of air lifts off the ground, then touches down again some distance along its path.

Figure 4 Tornado Landing

How do tornadoes stop?

It is not fully understood about how exactly tornadoes form, grow and die. Tornado researchers are **still trying to solve the tornado puzzle**, but for every piece that seems to fit they often uncover new pieces that need to be studied.

What is hail?

Hail is created **when small water droplets** are caught in the updraft of a thunderstorm. **These water droplets are lifted higher and higher into the sky until they freeze into ice**. Once they become heavy, they will start to fall. If the smaller hailstones get caught in the updraft again, they will get more water on them and get lifted higher in the sky and get bigger. Once they get lifted again, **they freeze and fall**. This happens over and over again until the **hailstone is too heavy** and then falls to the ground as shown in Figure 5.

Figure 5 Hail Stone

What is the largest hailstone recorded in the United States?

According to the National Weather Service, the largest hailstone is 8 inches in diameter and weights approximately 2 pounds. It fell in Vivian, South Dakota on July 23, 2010 as shown in Figure 6.

Figure 6. Largest Hail Stone in the U.S.A

When are tornadoes most likely to occur?

Tornadoes can happen at any time of the year and at any time of the day. In the southern states,

peak tornado season is from March through May. Peak times for tornadoes in the northern states are during the summer. A few southern states have a second peak time for tornado outbreaks in the fall. Tornadoes are **most likely to occur between 3 p.m. and 9 p.m.**

Where are tornadoes most likely to occur?

The geography of the central part of the United States, known as the Great Plains, is suited to bring all of the ingredients together to forms tornadoes. More than 500 tornadoes typically occur in this area every year and is why it is commonly known **as "Tornado Alley". Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Iowa, Missouri, Arkansas and Louisiana all make up Tornado Alley as shown in Figure 7**.

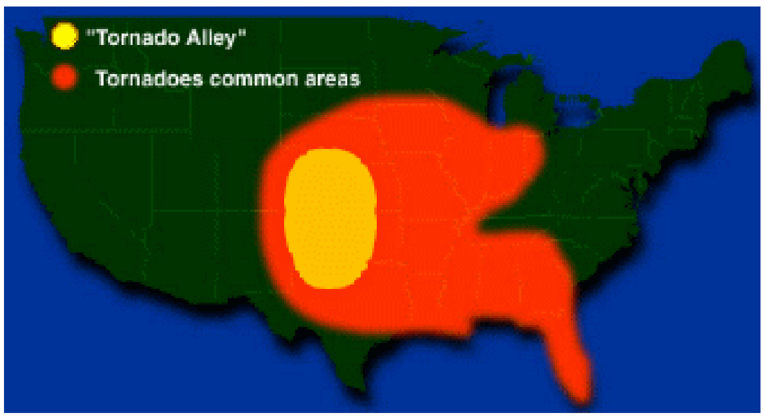


Figure 7. Tornado Alley in the U.S.A.

Also tornadoes are characterized based on the wind speeds, similar to the hurricanes and summarized in Table 6.

Table 6. Fujita Scale of Tornado Intensity

SCALE	WIND SPEED	POSSIBLE DAMAGE	Enhanced, Operational Fujita Scale
F0	40-72 mph	Light damage: Branches broken off trees; minor roof damage	EFO 65-85 mph
F1	73-112 mph	Moderate damage: Trees snapped; mobile home pushed off foundations; roofs damaged	EF1 86-110 mph
F2	113-157 mph	Considerable damage: Mobile homes demolished; trees uprooted; strong built homes unroofed	EF2 111-135 mph
F3	158-206 mph	Severe damage: Trains overturned; cars lifted off the ground; strong built homes have outside walls	EF3 136-165 mph

		blown away	
F4	207-260 mph	Devastating damage: Houses leveled leaving piles of debris; cars thrown 300 yards or more in the air	EF4 166-200 mph
F5	261-318 mph	Incredible damage: Strongly built homes completely blown away; automobile-sized missiles generated	EF5 over 200 mph

Tornado Safety Tips

DURING A TORNADO: Go to a basement. **If you do not have a basement, go to an interior room without windows on the lowest floor such as a bathroom or closet.** If you can, get under a sturdy piece of furniture, like a table. If you live in a mobile home get out. They offer little protection against tornadoes. Get out of automobiles. **Do not try to outrun a tornado in your car, leave it immediately. If you're outside, go to a ditch or low lying area and lie flat in it. Stay away from fallen power lines and stay out of damaged areas.**

IF YOU'RE IN ANOTHER BUILDING DURING A TORNADO: Every building should have a disaster plan and have frequent drills. Basements offer the best protection. Building without basements should use interior rooms and hallways on the lowest floor away from windows. Crouch down on your knees and protect your head with your arms.

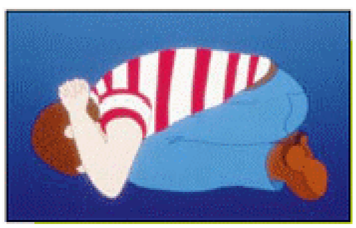


Figure 8. Crouch Down on your Knee

AFTER A TORNADO: Stay indoors until it is safe to come out. Check for injured or trapped people, without putting yourself in danger. Watch out for downed power lines. Use a flashlight to inspect your home.

Monitoring

Satellite and aerial monitoring through the use of **planes, helicopter, or UAVs** cannot be used for monitoring the tornado because of its rapid formation in very cloudy environment with heavy rainfall and lightening. In the future laser imaging units must be placed on the ground to clearly identify the formation of tornadoes and also monitoring the pathways. After the tornado, **drones** can be used to both day time and night to identify the very localized locations of the infrastructure and building damages, power failures, flooding, fires, and debris on the ground.

Predicting the Pathway

Prediction of the tornado pathway is very difficult because it is influences by the wind velocity (speed and direction), moisture content in the air and temperature gradients. Although tornadoes are formed on land near the ground surface very rapidly detecting the location of formation and the initial movement are impossible to monitor with the available technologies. Because of very limited data available on the formation and movement pathways of tornadoes using artificial intelligent (AI) for predictions are also not available.

Critical parameters

(1). Need to develop **protection systems** (external and internal) for tornado disasters with power failures.

(2). Identify the critical elements related to **maintaining and monitoring** of the tornado before, during and after the disaster.

(3). Develop redundancy systems with **alternative mobile power generators**, storage facilities and distribution systems,

(4). For the affected humans develop a preparedness (P), disaster response (DR) and rapid recovery (RR) processes for tornado disasters without and with multiple disasters.

Economic Impact of Tornado Disasters

Tornado disasters can impact not only the local activities but also the global activities and many economies due to interruption of critical supplies. Also the manufacturing industries will be affected impacting the critical medical supplies, chemical supplies and also oil supplies. Tornado disasters can impact the airports, ports and rail systems related to transportation of the critical supplies. Also the power failures can impact the construction industries in many ways. The economical impact can vary across the regions, and the consequences can be largely dependent on a region's economic position.

Cyber attacks

All the important control systems are computer based and connected to the internet platforms resulting in random cyber-attacks. Based on the type of cyber-attack and the type of supply system impacted such as power station, substations or distribution systems it can result in both **brownout** and **blackout.**

Cyber-attack is a human based disaster. With the advancement of technologies almost all operations are controlled using computers connected to the internet. The internet platform is connected to the world and once any computer opened it is connected to the world. **Philosophically, internet is considered as the battery charger** for all the connected computers. Internet platform will provide all the requested information with minimum time delay, transfer data and also control systems including the power grids and water supplies. All **the connectivity (electrical connection with computer language)** makes the system very **vulnerable to misuse**

using the computer language, **known as cyber-attacks**. Cyber-attacks can result in minor to major losses of personnel information and also security of the operating systems impacting individuals, cities, businesses and entire country. Cyber-attacks happen rapidly and by knowing the problem **pre-planning with security filtering and blocking will help**. Virus attack will start slowly but can spread rapidly. Hence it is important to **develop comprehensive disaster management and rapid recovery plans** to minimize the losses. Cyber-attack will impact human mental balance. Unlike **contaminated** sites, cyber-attacks has no **rules and regulations**. For cyber-attack pre-planning based on past experience is important **for preparedness**. The **rapid recovery (RR)** due to **cyber-attack (loosing personal information to large operating systems) can take a lot of time and money.**

A cyberattack is a malicious and deliberate attempt by an individual or organization to breach the information system of another individual or organization. Usually, the attacker seeks some type of benefit from disrupting the victim's network. It can also endanger public health, contaminate the water, devastate natural resources, and disrupt the economy. **It will also affect the animals and birds.** In an increasingly technological era, the world has become more dependent **upon computer controlled operations to maintain our high standard of living**. Also cyber-attack can impact the security, manufacturing and transportation industries and all other businesses.

2. Disaster Management and Rapid Recovery Plans (DMRRP)

In order to optimize the DMRRP, it is important to identify and quantify the major processes based on the scale of the tornado disasters. Also the tornado disaster can be characterized as **local** (short-term-1 day or less than a week) or **large-scale** (long-term - for weeks, months or years)

Models

It is important to develop models to quantify the (a) Preparedness, (b) Disaster response and (c) Rapid recovery for various disasters. Based on experiences it is being proposed to represent Disaster Management and Rapid Recovery as a 3- Phase Model as shown in as follows:

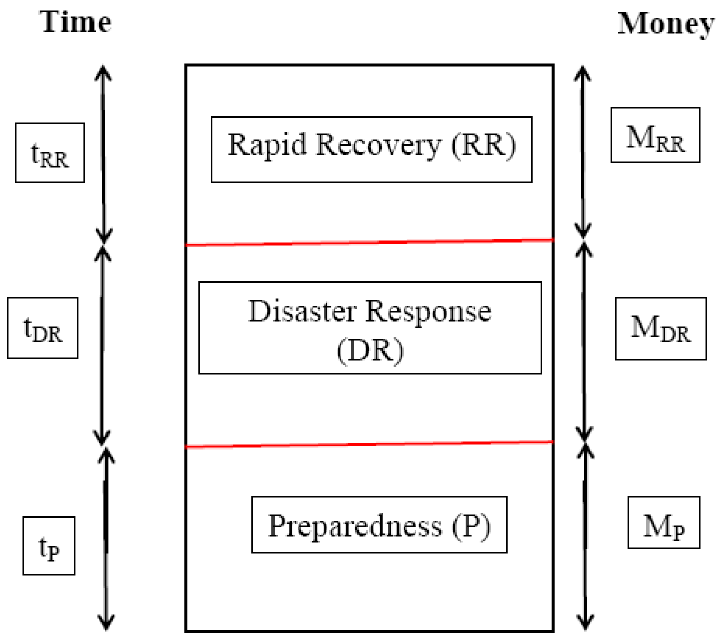


Figure 11 Phase Representation of Disaster Management and Rapid Recovery

Both time (t) and money (M) are two most important parameters. Many factors will influence the **parameter M**, and will depend on the time (t), sources (Local, State, Federal), regulations and many other factors. The preparedness parameters tp and Mp will depend on the approaches selected to do the preparations including communications and evacuation because of power loss, fires, flooding and critical infrastructure failures (including pipelines) because of the tornado.

(ii). Preparedness (P) and Critical Parameters (tp and Mp)

It is important to identify the critical parameters for preparedness for tornado disaster related to **individuals, families, project teams, communities and commercial activities**.

OBJECTIVES

Overall objective of **preparedness (P)** includes **plans to minimize losses** of humans (H), animals (A), environment (E) and property damages as shown in Figure 12. Also organize the **temporary removal of people** (Evacuation) and property (valuables) from threatened locations, and facilitate timely and effective rescue, relief and rehabilitation. The specific objectives are as follows:

(1). Building a networking team **with leaders** representing communities, schools, hospitals, nursing homes, cities, counties, state emergency managers, power utilities, groceries, department of transportation and industries.

(2). Identify the **potential single and multiple disasters** related to tornado with natural, human made and virus for the **area of interest**.

(3). Develop alternative plans (add gas cookers, gas lamps, gas based generators) to **build resiliency** in the communities and also **training programs** for kids and adults.

(4). Preparedness plans should identify the **critical elements** to be purchased (water, food, medicine) and **filling the gas tanks in the vehicles** before the disaster. Also prepare the communities for **power failures**. Add gas based systems to build the needed resiliency. Identify the amounts to be stored in your **food banks**. Have **multiple insurances** for health, cars and home (flooding, fire, broken windows).

(5). Develop alternative **evacuation plans**.

(6). **Minimize** the parameter **tp** and **optimize** the parameter **Mp** based on the alternative plans.

(7). Develop alternative **communication methods** for pre-warning before fire disasters and also for communicating during and after the disaster with and without the impact of **cyber attacks**.

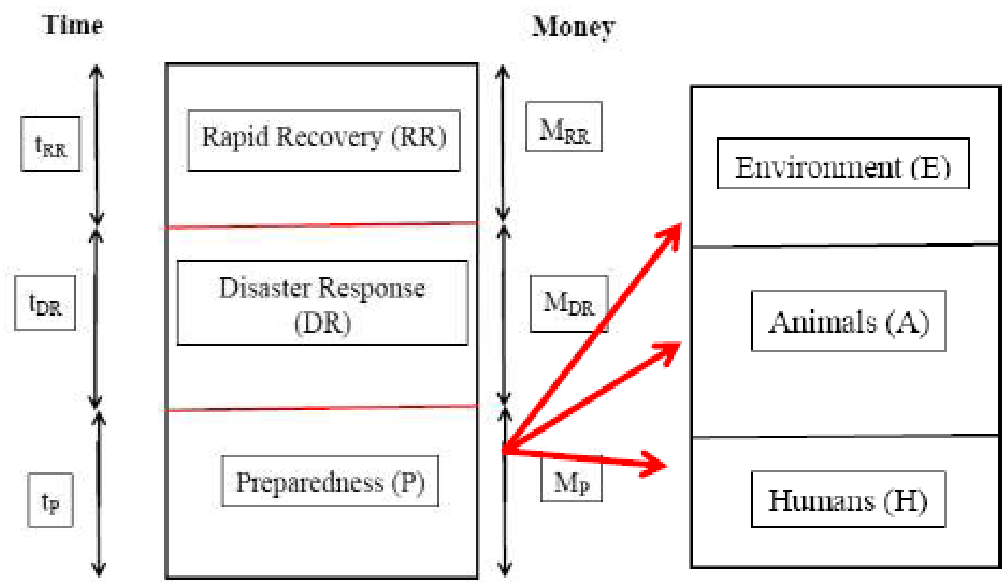


Figure 12 Parameters for Preparedness (P) (for you, family, team, city, country)

EVACUATION OBJECTIVES

Overall objective for **evacuation** due to tornado disaster includes **plans to temporarily move** the humans (H), animals (A), and valuable properties (cars, computers, phones) and documents. Also must have charged batteries for multiple applications. The specific objectives are as follows:

(1). Identify the **types of potential tornado disasters** with the other potential natural, human made and virus for the **location of interest**. Based on tornado disaster develop the evacuation plans.

(2). Determine the mode of **public transport** (trains, buses) or **private transport** (cars, vans) that can be used for evacuation.

(3). Identify **more than one safe location** to evacuate with the **family and pets** based on weather predictions and government guidelines to build the resiliency in the evacuation plan This will also help with **avoiding road blocks and traffic** to reach the safer place quickly. Be aware of **cyber-attacks.**

(4). Select the evacuation location (Government shelter, hotels, schools) with faster returning opportunity. Protect against **virus spread**. Attention to **sanitation issues, drinking water and food**.

(5). **Basic items** that need to be taken during the evacuation are as follows:

- Flashlight, battery-powered radio and extra batteries
- Prescriptions and other medicines
- First aid kit
- Important documents (birth certificates, passport, home insurance, bank accounts)
- Bottled water
- Food (canned, bagged)
- Clothing and bedding (sleeping bags, pillows)
- Masks
- Special equipment for infants or elderly or disabled family members
- "Comfort items," such as special toys for children
- **Computer hard drive and laptop with charge batteries**
- Pet food and other items for pets (litter boxes, leashes)
- Avoid glassware

(7). Check your home/office before leaving

- Turn off all the electrically powered equipment including the refrigerators.

(8). Develop plans for **quick return** and **potential repairs** for the house and job related construction sites and applying for loans and insurance.

This will be part of the **Disaster Response (DR) parameters t_{DR} and M_{DR}.**

(iii). Disaster Response (DR) and Critical Parameters (t_{DR} and M_{DR})

It is important to identify the major issues related to disaster response (DR) and rapid recovery (RR) with parameters, t_{DR}, t_{RR} M_{DR} and M_{RR}. The tornado disaster response and recovery are very much influenced by the losses, time to restore the power and debris removal due to multiple disasters.

Return from Evacuation

In order to accelerate the DR and RR, it is important to return home as soon as possible taking the safe pathway. There could be road blocks and damages that needs to be factored into the return plan.

Losses

The losses can be divided into short-term and long-term losses. Losses will result in influencing the **<u>parameters time and money.</u>**

Short-term Losses

The time line will be between 0.5 month and 1 month to recover and get the lost items (less than 1 month) for **you, family and team.**

- Road blocks
- Prescription medicine
- Damaged car or truck
- Insurance policies — homeowners, auto, life and any others
- Employment information
- Failure of refrigerators, air conditioners and heaters
- Traffic lights failure
- Closed restaurants and stores
- Lost phones, computers and charges
- Financial information such as bank accounts and credit cards

(iv). Rapid Recovery (RR) and Critical Parameters (t_{RR} and M_{RR})

It is important to identify the major issues related to tornado disaster responses to rapid recovery (RR) with parameters, t_{RR} and M_{RR}. The disaster response and recovery are very much influenced by the losses and debris removal.

Long-term Losses

The time line will be **<u>over one (1) month</u>** to recover and get back most of the lost items for **you, family, team, community, city, country.**

- Power Loss and Grid Failures
- Debris

- Road blocks
- Deaths (humans, pets, animals)
- Property lost (house, buildings, highways)
- Damaged transport facilities (trains, buses, cars, 18 wheelers and others)
- Closed businesses, schools, Universities
- Closed Airports and Ports

3. MULTIPLE DISASTERS

There are multiple disasters happening around the world. Also the current COVID-19 pandemic and cyber-attacks will add to the multiple disasters. Multiple disasters could be totally natural or human based or a combination. Multiple disasters will have two or more disasters at one time. For example during tornado disaster there can be power failure, virus pandemic (human) and also cyber-attacks (human) and oil spills (human).

In planning all these potential challenges it is important to integrate the GIS (Geographical Information System) to identify the critical locations including hospitals, food supply and gas supply. It is also important to determine the resources available for preparedness (P), disaster response (DR) and rapid recovery (RR) plans.

Modelling of Multiple Disasters

It is important to understand the import parameter need for modelling multiple disasters. Base on the model, importance of various parameters can be identified for disaster management and rapid recovery planning

Monitoring

It is important to develop new technologies for **real time monitoring of the multiple disasters. To ensure the health and safety of the humans and animals**, real-time **monitoring of disasters (fire and flooding scale and locations, wind speeds, power grids), evacuations, hospital and other critical facilities** will be a good use in disaster response and rapid recovery. Real-time monitoring will also help in developing procedures to minimize the virus attacks and cyber-attacks. Real-time monitoring system must have alternative powering systems including batteries.

Disaster Management and Rapid Recovery Plans

During a multiple disasters (more than one), it is import to have a comprehensive disaster management and rapid recovery plans. Base on the disasters, following plans can be considered for implementation.

PLAN 1: Combine processes (**mixture theory**) for the disaster management plans for multiple disasters including power failures. For example, if there was a power failure (PF) with tornado disaster (home failures, infrastructure failures, debris and more) in the same area the DMRRP can be a combined process (PLAN 1) by integrating both disasters to minimize the cost (M_{PF}) and time (t_{PF}) (Figure 13).

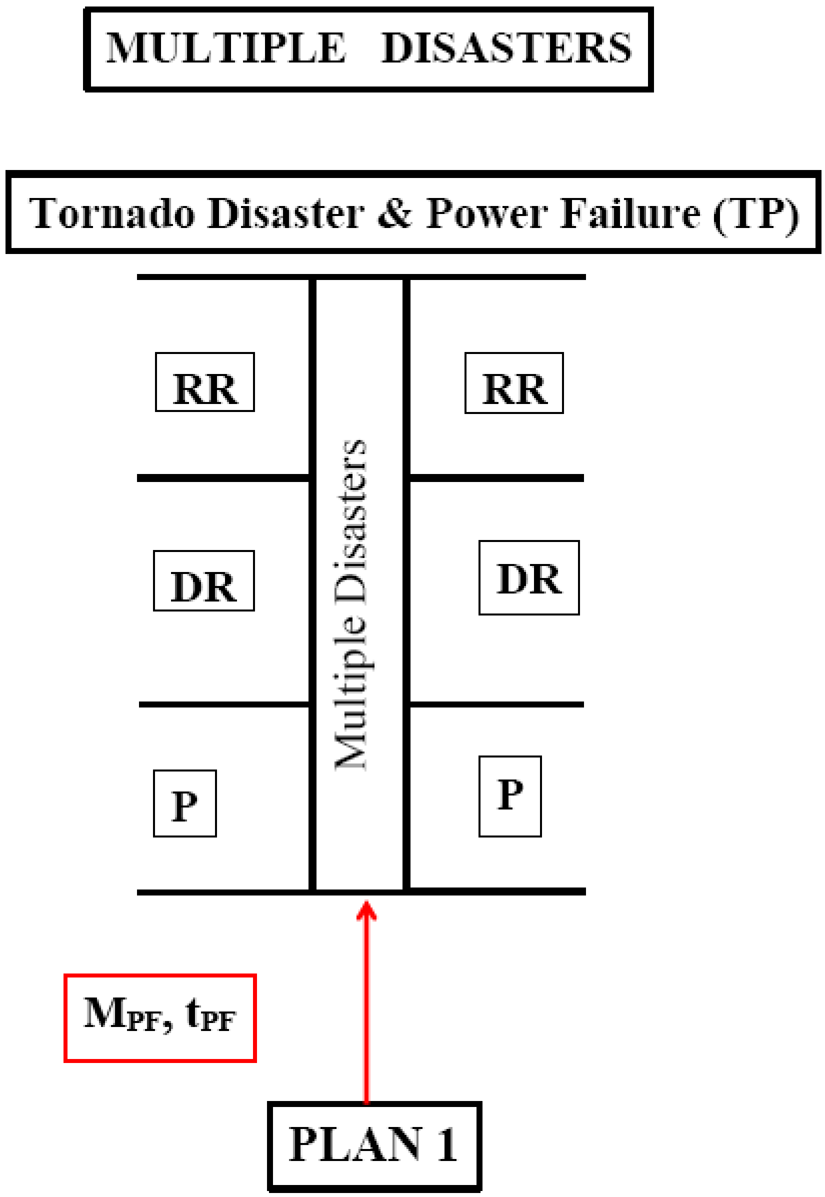
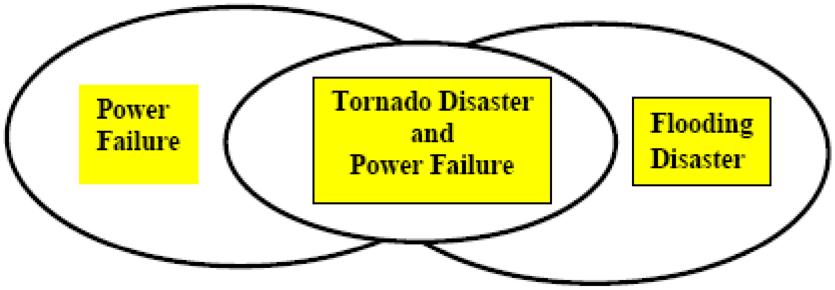
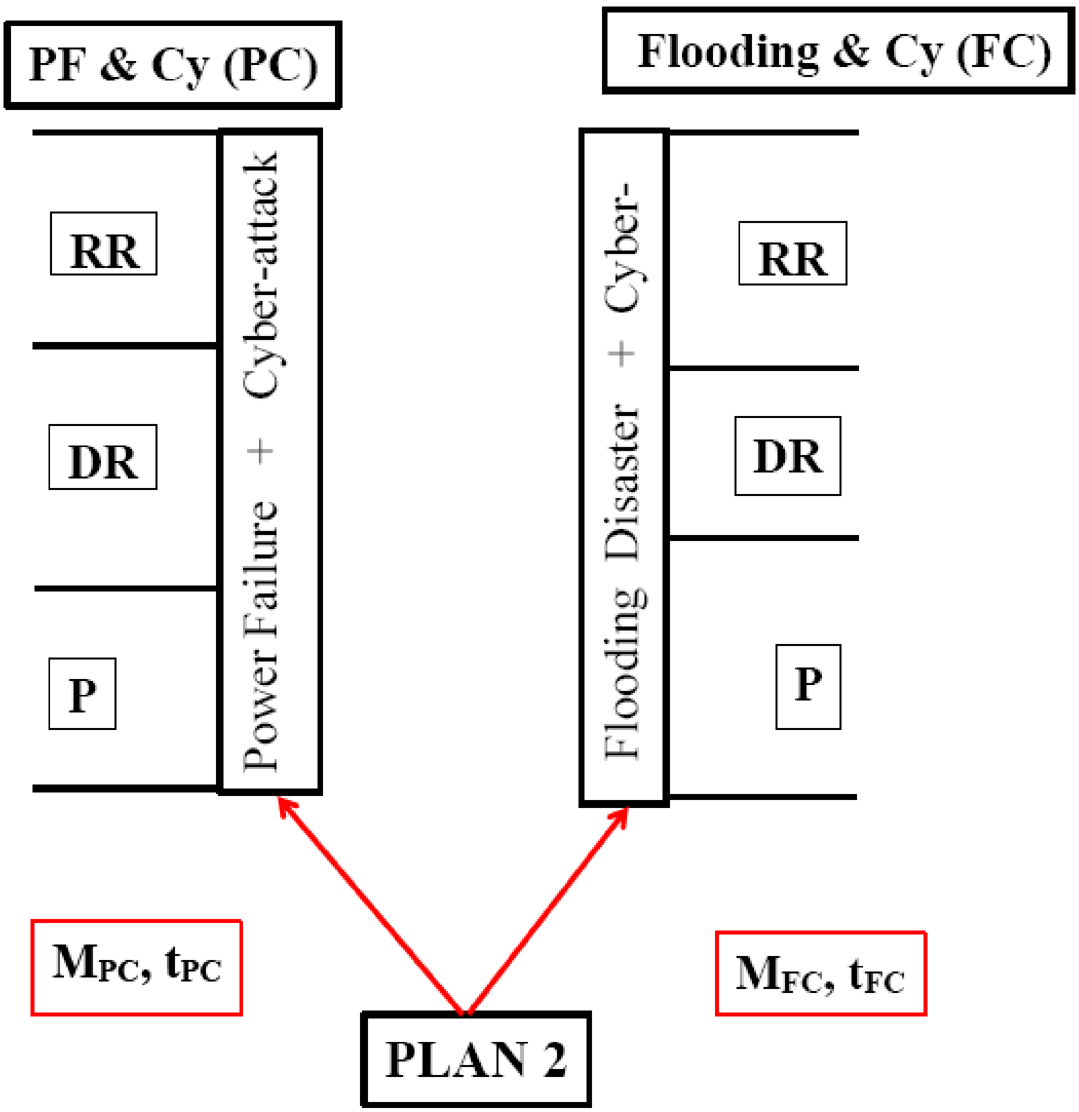


Figure 13 Multiple Disaster PLAN 1 Combined Process

PLAN 2: Develop a **parallel process** (**similar to parallel electrical circuits**) for the disaster management and rapid recovery plan. This will be the approach with the cyber-attacks in place, because the fire disaster and power failure could be only partly overlapping the affected regions (Figure 14(a)). Hence the DMRRP can be a parallel process (PLAN 2) to minimize the costs (M_{PC} and M_{FC}) and time (t_{PC} and t_{FC}) as shown in Figure 14.



(a)



(b)

Figure 14 Multiple Disaster PLAN 2 Parallel Process (a) Affected Regions and (b) DMRRP with the Cyber Attack

Preparedness (P)

Based on the potential disasters, PLAN 1 or PLAN 2 must be selected for the preparedness (P) process. There will be **almost no warning for tornado disaster** and hence **preplanning and preparedness with adequate training will be important.** Fire disaster and power failure with and without cyber-attacks may result in **shut down of schools, businesses, airports** and **grocery stores** which have to be taken into account for when developing the preparedness (P) with PLAN 2. Based on the fire disaster region with and without power failure, people can be evacuated to different regions. Also **resilience communication methods** have to be developed taking the fire disaster and power failure into account. This will help with the disaster response (DR) and rapid recovery (RR).

Disaster Response (DR)

Based on the tornao disaster and power loss disaster regions with and without overlapping, PLAN 1 or PLAN 2 must be selected. This will also be related to the **available evacuation places with electric power. Also ways and methods to open the business, schools and stores with the needed protection systems must be considered.**

Rapid Recovery (RR)

Based on the disasters, PLAN 1 or PLAN 2 must be selected. PLAN 2 will be very much impacted by the **scale of the tornado disaster and power failure** on the population and daily operations. Also comprehensive plans have to be developed for **rapidly recover after the multiple disasters including power failure**. The rapid recovery time and cost must be minimized. With the COVID-19 virus, the disposal of debris could become an issue and must be planned alternative methods during the preparedness (P).

4. New Technologies

(a) **Real-Time Monitoring**: Recent advances in sensor technology and communication have catalyzed progress in remote monitoring capabilities using **batteries**. Monitoring is only effective if the collected information can be stored and interpreted real-time. These advances have led to improved statistical and mechanistic modeling in monitoring.

(b) **Drones:** The earliest recorded use of an unmanned aerial vehicle (UAV) for warfighting occurred on July 1849. Since then technology has evolved to make very efficient light weight aircrafts with cameras for monitoring before and after disasters.

(c) **Smart Cement**: Highly sensing smart cement has been recently developed for real-time monitoring. Smart cement is a chemo-thermo-piezoresistive cement and a 3D sensor that could detect loadings on buildings, gas and water leaks, flood rising levels, seismic activities and fire (Vipulanandan 2021)

(d) **Fire Protection**: There is an urgent need to developing simple and innovative methods to protect houses, building, storage facilities and streets from fire. Also develop methods to protect against oil spills and vehicle accidents.

(e) **Modeling:** It is important to quantify the 3-Phase DMRRP model parameters (losses, money and time). Also developing new models and also using Artificial Neural Network (ANN) for Artificial Intelligent (AI) to do the predictions related to losses and debris.

CONCLUSIONS

Based on the experiences from the tornadoes, power failure, flooding, and cyber attacks Disaster Management and Rapid Recovery Plans (DMRRP) were developed Also data was collected on tornadoes disasters, relevant electric power and also evaluated new technologies and following conclusions are advanced:

1. Power failure is one of the major disasters and must be integrated in all the Disaster Management and Rapid Recovery Plans (DMRRP).
2. It is important to have mobile electrical power generators as backup to support some of the critical activities.
3. During multiple disasters like tornado with power failure and cyber attack consider PLAN 1 (combining all activates in the same region) or parallel process (disasters distributed in multiple regions), PLAN 2, for the DMRRP with and without cyber-attacks.
4. Real-time monitoring is critical for minimizing urban areas impacted by the multiple disaster due to flooding, power failure and cyber-attacks.
5. Educate the communities regarding preparedness, minimize losses and rapid recovery.
6. Minimize the drinking water infrastructure damages. Build redundancy in the power grids to minimize losses.
7. Improve debris removal and minimize the delay. Also consider the effects of flooding, power loss and cyber-attacks in the debris removal and also disposal.
8. Consider adopting new technologies for real-time monitoring using drones, smart cement, fire protection and debris removal.
9. Evaluate the adaptation of the new 3-phase model with prediction models and Artificial Neural Network (ANN) in Artificial Intelligent (AI) for alternative approach methods with losses, money and time predictions related to preparedness (P), disaster response (DR) and rapid recovery (RR).

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