Fire Disaster Impacts, Protections and Disaster Management with New Technologies for Rapid Recovery

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Abstract

Fire based disasters from small scale to very large scale are happening around the world. The **natural fires are initiated by the environmental (droughts), weather (temperature, low humidity, lightening), forest (trees and vegetation) conditions and volcanic activity**. For **natural fires** such as **forest fires and bush fires**, there will be pre-warning based on the environmental conditions and also the conditions of the forests, vegetation and very dry ground conditions. Also volcanic disasters have also greatly impacted the humans, animals and the environment. If the fires are initiated by the humans it will have very limited time for preparedness. Fire disaster can be initiated by oil spills (onshore and offshore), failure of oil and gas wells (onshore and offshore) and also different types of accidents. Also the fire disasters have had the highest number of disasters and major losses compared to the drought disasters. Fire can result in power failures and major infrastructure damages including failure of water, wastewater and oil and gas pipelines. The **rapid recovery (RR)** due to fire disasters will also take a **longer time** compared to the other natural disasters because of the **greater impact on the earth and the environment**.

In recent years, fire 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 fire 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 fire disaster have been investigated. Also the benefit of adopting new technologies to minimize losses have been investigated.

Introduction

In the past 10 years there have been major wild fires in North and South America (U.S.A., Canada, and Brazil), Australia, Asia and Europe (England). Wild fires have resulted in large number of evacuations, human and animal fatalities and buildings destroyed.

In 2019 extreme heat and dryness caused massive wildfires in Siberia, Alaska, Canary Islands, Australia, and in the **Amazon rainforest**. The fires in the **Amazon rainforest** were caused mainly by **illegal logging**. The smoke from these fires expanded into huge territories including major cities and also dramatically reducing the air quality.

Wild Fires and Bush Fires

Wildfires occur when **vegetated areas** are set alight and are particularly common during **hot and dry periods** as shown in Figure 1. They can occur in forests, grasslands, brush and deserts, and with **sufficient wind** can rapidly spread.

Figure 1 Closer View of Fire Disaster

Unchecked (without any maintenance and monitoring), such fires can cause devastation to the forests and other areas of vegetation. If fires approach or occur near towns or cities it often prompts a **precautionary evacuation (P)**, since the **direction fire growth cannot be predicted** and also the air quality and ash deposited.

A side-effect of wildfires that also threatens **inhabited areas** with smoke. Fires create large quantities of smoke, which can spread far by wind and poses a respiratory hazard for humans, animals and birds.

(a). North America

The incidence of large, uncontained fires (**wildfires, oil well failures and others) in North America** has **increased in recent years,** significantly impacting both urban and agriculturally-focused areas. Also oil well failures onshore and offshore with fire explosions have resulted in major losses. The physical damage and health pressures left in the wake of uncontrolled fires has especially devastated farm and ranch operators in affected areas, and also oil and gas productions prompting concern from the **community of healthcare providers and advocates servicing** this specialized occupational population.

Especially large fires may affect air currents in their immediate vicinities by the stack effect: air rises as it is heated, and large wildfires create powerful updrafts that will draw in new, cooler air from surrounding areas in thermal columns. Great vertical differences in temperature and humidity encourage pyro-cumulus clouds, strong winds, and fire whirls with the force of tornadoes at speeds of more than 80 kilometers per hour (50 mph). Rapid rates of spread, prolific crowning or spotting, the presence of fire whirls, and strong convection columns signify extreme conditions.

The thermal heat from a fire can cause significant weathering of rocks and boulders, heat can rapidly expand a boulder and thermal shock can occur, which may cause any structure to fail.

Effects of climate

In Nevada during the summer it is very dry and lightening initiated the fire as shown in Figure 2. This fire had no warning and was also not predicted.

Figure 2. Lightning-sparked wildfires are frequent occurrences during the dry summer season in Nevada.

Texas (onshore)

As shown in Figure 3, Texas has very dry ground surface condition, especially during summer. Texas has very dry season followed by drought and wild fires, especially in the northwest region. This has impacted animals and also humans and there is a need to develop better protection and response systems.

Recently there was a fire on the wind turbine caused by lightning strike as shown in Figure 4. Hence it is essential to protect the wind turbines, since 34% of the electricity in Texas are produced by the wind turbines.

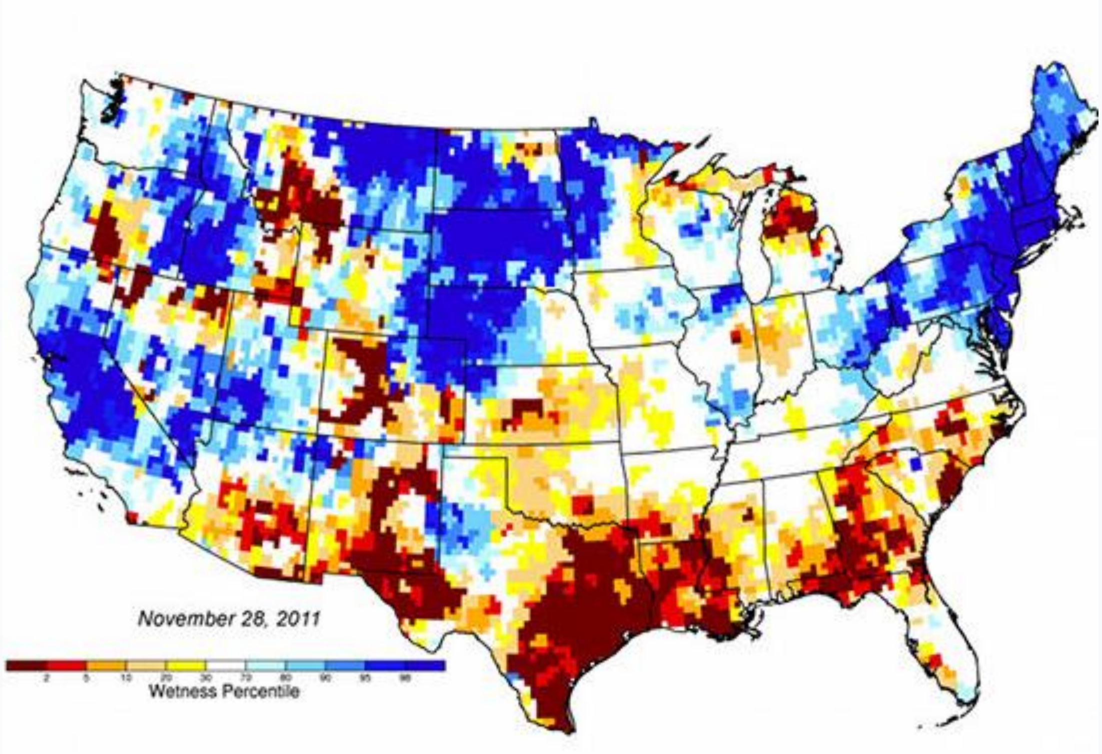


Figure 3 National map of ground soil moisture in the United States of America. It shows the very low soil moisture associated with the fire season in Texas.

Figure 4 Lightening strike caused fire in the Texas wind turbine (Weather Issue)

(b). South America

Brazil (onshore)

In the Amazon Rainforest, drought, logging, cattle ranching practices, and slash-and-burning of agricultural wastes has damaged the fire-resistant forests and has promoted the growth of flammable brush, creating a cycle that encourages more burning. Fires in the rainforest threaten its collection of diverse species and produce large amounts of CO_2. Also, fires in the rainforest, along with drought and human involvement, could damage or destroy more than half of the Amazon rainforest by the year 2030. Wildfires generate ash, reduce the availability of organic nutrients, and cause an increase in water runoff, eroding away other nutrients and creating flash flood conditions.

(c). Europe

England

A 2003 wildfire in the North Yorkshire Moors in England burned off 2.5 square kilometers (600 acres) of heather and the underlying peat layers. Afterwards, wind erosion stripped the ash and the exposed soil, revealing archaeological remains dating back to 10,000 BC. **Wildfires can also have an effect on climate change, increasing the amount of carbon released into the atmosphere and inhibiting vegetation growth, which affects overall carbon uptake by plants**.

(d). Gulf of Mexico (offshore)

The catastrophic accident in the Gulf of Mexico in April 2010 as shown in Figure 5 is one of the world's worst oil spills (Shadravan et al., 2012). The explosion at the drilling rig, Deepwater Horizon, which explored oil and gas at the Macondo well claimed eleven lives and caused severe injuries and record-breaking sea pollution from the release of about five million barrels of crude oil (Cristou et al., 2012).

Figure 5 Fire in Gulf of Mexico due to Oil Well Failure (Human Made Disaster)

Two studies done during the period of 1971 to 1991 and 1992 to 2006 clearly identified cement failures as the major cause for blowouts. Cementing failures increased significantly during the second period of study when 18 of the 39 blowouts were due to cementing problem (Izon et al., 2007). With some of the reported failures and growing interest in environmental and economic concerns in the oil and gas industry, integrity of the cement sheath is of major importance. Therefore, proper monitoring and tracking the entire process of well cement become important to ensure cement integrity during the service life of the well (Vipulanandan et al., 2014; Vipulanandan 2021).

Local Fire

This can start from individual impact due to car accidents, oil spills and also house fires which can be a major loss. Fire in a house can result in roof collapse as shown in Figure 6. It is important to monitor the critical locations in the houses, offices, shopping malls, storage facilites and vehicle parking garages to minimize the fire and losses.

Figure 6 House Fire and Roof Failure (Human Made Disaster)

Lessons Learned

There have been many major fires around the world impacting not only countries and also the global operations. This includes the forest fires in California and Australia (2019) and many other places around the world. There is need for building redundancy to protect against fires 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, birds life losses, time and revenue losses with rapid recovery.

Objectives

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

(a) Identify the critical parameters causing the natural, human made and combination of fire disasters both onshore and offshore 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 all types of fires with the building of resilience to maintain the operating systems functioning under critical events.

Fires (Rapid Oxidation of Materials)

Wild fires are caused by the **release of energy** from the **hot and dry ground (energized)** and **weather conditions** (hot wind, very low humidity, lightening) with **dry vegetation and trees**. This is another environmental natural disaster. Also **burning of vegetation and buildings results in energy release on the earth surface and also into the environment**.

There are natural**,** human made or a combination **of fires occurring around the world.** The **most common causes of fires** are lightning strikes, sparks during arid conditions, the eruption of volcanoes, and **Human-made fires arising from deliberate arson or accidents**.

Potential causes of fires are listed below.

Natural Fires:

- Long period of dry condition.
- Low humidity.
- Hot winds.
- Lightening
- Dead vegetation and trees

Human caused Fires:

- Electrical shocks and transformers failure
- Leaking oil and gas

- Accidents (onshore and offshore (ships))
- Aging infrastructures
- Accidents/failures in Chemical storage facilities

With the industrial growth and population growth coupled with **aging infrastructures and major fuel tank accidents** fire disasters are happening around the world. Fire in one country, **especially wild fire**, results in polluting the environment across many countries. Also fires can happen at **home, vehicles, work place, streets and also recreational areas**. There is a need to develop methods to minimize the natural and human made fire disasters.

Chemistry/Science

Vegetation + Dry Soil + HOT AIR → **Wild Fire** …..(1)

$$C_xH_yO_z + aN_2 + bO_2 + Heat \longrightarrow dCO_2 + aN_2O + Steam\ (H_2O) + Ash + Smoke\ (CO + Others) + Heat \ldots \quad (2)$$

Fire is the rapid oxidation of a material in the **exothermic chemical process** of combustion resulting in releasing heat, light, and various reaction products. Fire is hot because the conversion of the **weak double bond in molecular oxygen, O_2**, to the stronger bonds in the combustion **products carbon dioxide and steam releases energy** (Eqns (1) and (2)).

At a certain point in the combustion reaction, **called the ignition point, flames are produced**. The flame is the visible portion of the fire. **Flames consist primarily of carbon dioxide, water vapor, smoke and ash.**

Fire in its most common form can result in conflagration, which has the potential to cause physical damage through burning. **Fire is an important process that affects ecological systems around the globe.** The **positive effects** of fire include **stimulating growth and maintaining various ecological systems**. Its **negative effects** include **hazard to life and property, atmospheric pollution, and water contamination**.

Also, when vegetation is burned, the nitrogen it contains is released into the atmosphere, unlike elements such as **potassium and phosphorus which remain in the ash and are quickly recycled into the soil**. This loss of nitrogen caused by a fire produces a long-term reduction in the fertility of the soil.

Once ignited, a chain reaction must take place whereby **fires can sustain their own heat** by further **release of heat energy** in the process of combustion and may propagate, provided there is a continuous supply of an oxidizer and fuel.

Human activity

Humans-caused wildfires account for about 40% of wildfires, and are caused by **activities such as open burning, the use of engines or vehicles, dropping burning substances such as cigarettes, or any other human-related activities** that can create a spark or a heat source sufficient to ignite a wildfire.

The spread of wildfires varies based on the **flammable material present**, **its vertical arrangement and moisture content, and weather conditions**. Fuel arrangement and density is governed in part by topography, as land shape determines **factors such as available sunlight and water for plant growth**. Overall, fire types can be generally **characterized by their fuels** as follows:

- **Ground** fires are fed by subterranean roots, duff and other buried organic matter. This fuel type is especially susceptible to ignition due to spotting. Ground fires typically burn by smoldering, and can burn slowly for days to months, such as peat fires which result from the ground conditions.
- **Crawling** or **surface** fires are fueled by low-lying vegetation on the forest floor such as leaf and timber litter, debris, grass, and low-lying shrubbery. This kind of fire often burns at a relatively lower temperature than crown fires (less than 400 °C (752 °F)) and may spread at slow rate, though steep slopes and wind can accelerate the rate of spread.
- **Ladder** fires consume material between **low-level vegetation and tree canopies**, such as small trees, downed logs, and vines. Also scale trees may also encourage ladder fires.
- **Crown**, **canopy**, or **aerial** fires burn suspended material at the canopy level, such as tall trees, vines, and mosses. The ignition of a crown fire, termed *crowning*, is dependent on the density of the suspended material, canopy height, canopy continuity, sufficient surface and ladder fires, vegetation moisture content, and weather conditions during the blaze.[48] Stand-replacing fires lit by humans can spread into the Amazon rain forest, damaging ecosystems not particularly suited for heat or arid conditions.[49]
- In monsoonal areas of **north Australia**, **surface fire** spread, including across intended firebreaks, by burning or smoldering pieces of wood or burning tufts of grass carried intentionally by large flying birds accustomed to catch prey flushed out by wildfires. **Species implicated are Black Kite (Milvus migrans), Whistling Kite (Haliastur sphenurus), and Brown Falcon (Falco berigora). Local Aborigines have known of this behavior for a long time, including in their mythology**.

Physical properties

Wildfires occur when all the necessary elements of a **fire triforce come together** in a susceptible area: an **ignition source** is brought into contact with a combustible material such as vegetation that is subjected to enough heat and has an **adequate supply of oxygen** from the ambient air. **A high moisture content usually prevents ignition** and slows propagation, because higher temperatures are needed to evaporate any water in the material and heat the material to its fire point. **Dense forests usually provide more shade, resulting in lower ambient temperatures and greater humidity, and are therefore less susceptible to wildfires**. **Less dense material such as grasses and leaves are easier to ignite** because they contain less water than denser material such as branches and trunks. Plants continuously lose water by evapotranspiration, but water loss is usually balanced by water absorbed from the soil, humidity, or rain. When this balance is not maintained, plants dry out and are therefore more flammable, often a consequence of droughts.

Wildfires have a rapid **forward rate of spread (FROS)** when burning through dense uninterrupted fuels. **They can move as fast as 10.8 kilometres per hour (6.7 mph) in forests and 22 kilometres per hour (14 mph) in grasslands.** Wildfires can advance tangential to the main front to form a flanking front, or burn in the opposite direction of the main front by backing. They may also spread by jumping or spotting as winds and vertical convection columns carry firebrands (hot wood embers) and other burning materials through the air over roads, rivers, and other barriers that may otherwise act as firebreaks. Torching can create fires in tree canopies encourage spotting, and dry ground fuels around a wildfire are especially vulnerable to ignition from firebrands. Spotting can create spot fires as hot embers and firebrands ignite fuels downwind from the fire. **In Australian bushfires, spot fires are known to occur as far as 20 kilometres (12 mi) from the fire front.**

Emissions

Wildfires release large amounts of carbon dioxide, black carbon, brown carbon, and ozone precursors into the atmosphere. These emissions affect radiation, clouds, and climate on regional and even global scales. Wildfires also emit substantial amounts of volatile and semi-volatile organic materials and nitrogen oxides that form ozone and organic particulate matter. **Direct emissions of toxic pollutants can affect first responders and local residents. In addition, the formation of the other pollutants as the air is transported can lead to harmful exposures for populations in regions far away from the wildfires**.

Airborne hazards

The most noticeable adverse effect of wildfires is the destruction of property. However, the release of hazardous chemicals from the burning of wildland fuels also significantly impacts health in humans.

Wildfire smoke is composed primarily of **carbon dioxide and water vapor (Eqn, (2))**. Other common smoke components present in **lower concentrations are carbon monoxide**, **formaldehyde, acrolein, polyaromatic hydrocarbons, and benzene**. Small particulates suspended in air which come in solid form or in liquid droplets are also present in smoke. **80 -90% of wildfire smoke, by mass, is within the fine particle size class of 2.5 micrometers in diameter or smaller**.

Despite carbon dioxide's high concentration in smoke, it poses a low health risk due to its low toxicity. Rather, carbon monoxide and **fine particulate matter, particularly 2.5 µm in diameter and smaller**, have been identified as the major health threats. Other chemicals are considered to be significant hazards but are found in concentrations that are too low to cause detectable health effects.

The degree of wildfire smoke exposure to an individual is dependent on the length, severity, duration, and proximity of the fire. People are exposed directly to smoke via the respiratory tract through inhalation of air pollutants. Indirectly, communities are exposed to wildfire debris that can contaminate soil and water supplies.

The U.S. Environmental Protection Agency (USEPA) developed the air quality index (AQI), a public resource that provides national air quality standard concentrations for common air pollutants. The public can use this index as a tool to determine their exposure to hazardous air pollutants based on visibility range.

Fire ecologist Leda Kobziar found that wildfire smoke distributes microbial life on a global level. She stated, "There are numerous allergens that we've found in the smoke. And so it may be that some people who are sensitive to smoke have that sensitivity, not only because of the particulate matter and the smoke but also because there are some biological organisms in it.

Post-fire risks

Figure 7 Charred shrubland in suburban Sydney (2019–20 Australian bushfires).

After a wildfire, hazards remain as shown in figure 7. Residents returning to **their homes may be at risk from falling fire-weakened trees**. **Humans and pets may also be harmed by falling into ash pits**.

Health effects

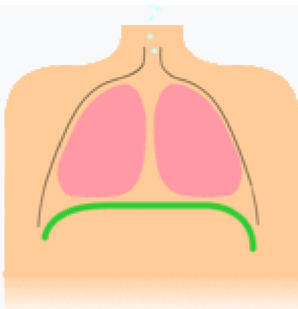


Figure 8 Animation of diaphragmatic breathing with the diaphragm shown in green

Wildfire smoke contains particulate matter that may have adverse effects upon the human respiratory system as shown in Figure 8. Evidence of the health effects of wildfire smoke should be relayed to the public so that exposure may be limited. Evidence of health effects can also be used to influence policy to promote positive health outcomes.

Inhalation of smoke from a wildfire can be a health hazard. Wildfire smoke is composed of combustion products i.e. carbon dioxide, carbon monoxide, water vapor, particulate matter, organic chemicals, nitrogen oxides and other compounds. The principal health concern is the inhalation of particulate **matter and carbon monoxide**.

Particulate matter (PM) is a type of air pollution made up of particles of dust and liquid droplets. They are characterized into three categories based on the diameter of the particle: coarse PM, fine PM, and ultrafine PM. **Coarse particles are between 2.5 micrometers and 10 micrometers, fine particles measure 0.1 to 2.5 micrometers**, and ultrafine particle are less than 0.1 micrometer. Each size can enter the body through inhalation, but the PM impact on the body varies by size. Coarse particles are filtered by the upper airways and these particles can accumulate and cause pulmonary inflammation. This can result in eye and sinus irritation as well as sore throat and coughing. Coarse PM is often composed of materials that are heavier and more toxic that lead to short-term effects with stronger impact.

Smaller particulate moves further into the respiratory system creating issues deep into the lungs and the **bloodstream**. **In asthma patients, $PM_{2.5}$ causes inflammation but also increases oxidative stress in the epithelial cells.** These particulates also cause **apoptosis and autophagy in lung epithelial cells**. Both processes cause the cells to be damaged and impacts the cell function. This damage impacts those with respiratory conditions such as asthma where the lung tissues and function are already compromised. The third PM type is ultra-fine PM (UFP). **UFP can enter the bloodstream like $PM_{2.5}$ however studies show that it works into the blood much quicker.** The inflammation and epithelial damage done by UFP has also shown to be much more severe. $PM_{2.5}$ is of the largest concern in regards to wildfire. This is particularly hazardous to the very young, elderly and those with chronic conditions such as asthma, chronic obstructive pulmonary disease (COPD), cystic fibrosis and cardiovascular conditions. The illnesses most commonly with exposure to the fine particles from wildfire smoke are bronchitis, exacerbation of asthma or COPD, and pneumonia. **Symptoms of these complications include wheezing and shortness of breath and cardiovascular symptoms include chest pain, rapid heart rate and fatigue.**

Carbon monoxide (CO) danger (poisoning)

Carbon monoxide (CO) is a colorless, odorless gas that can be found at the highest concentration close to a smoldering fire. For this reason, carbon monoxide inhalation is a serious threat to the health of **wildfire firefighters**. CO in smoke can be inhaled into the lungs where it is absorbed into the bloodstream and reduces oxygen delivery to the body's vital organs. At high concentrations, it can cause headaches, weakness, dizziness, confusion, nausea, disorientation, visual impairment, coma, and even death. However, even at lower concentrations, such as those found at wildfires, individuals with cardiovascular disease may experience chest pain and cardiac arrhythmia. A recent study tracking the number and cause of wildfire firefighter deaths from 1990–2006 found **that 21.9% of the deaths occurred from heart attacks.**

Another important and somewhat less obvious health effect of wildfires is psychiatric diseases and disorders. Both adults and children from countries ranging from the United States and Canada to Greece and Australia who were directly and indirectly affected by wildfires were found **by researchers to demonstrate several different mental conditions linked to their experience with the wildfires.** These include post-traumatic stress disorder (PTSD), depression, anxiety, and phobias.

In a another wildfire, **former uranium mining sites were burned over in the summer of 2012 near North Fork, Idaho** causing health effects. This prompted concern from area residents and Idaho State Department of Environmental Quality officials over the **potential spread of radiation in the resultant smoke,** since those sites had never been completely cleaned up from radioactive remains.

Epidemiology

Epidemiology is the **study** of diseases in populations of humans or other animals, **specifically how, when and where they occur.** Epidemiologists attempt to **determine what factors are associated with diseases (risk factors),** and what factors may protect people or animals against disease (protective factors).

The western US has seen an increase in both the frequency and intensity of wildfires over the last several decades. This increase has been attributed to the arid climate of the western US and the **effects of global warming**. An estimated 46 million people were exposed to wildfire smoke from 2004 to 2009 in the Western United States. Evidence has demonstrated that wildfire smoke can increase levels of particulate matter in the atmosphere.

The EPA has defined acceptable concentrations of particulate matter (PM) in the air, through the National Ambient Air Quality Standards **and monitoring of ambient air quality has been mandated.** Due to these monitoring programs and the incidence of several large wildfires near populated areas, epidemiological studies have been conducted and demonstrate an association between human health effects and an increase in fine particulate matter due to wildfire smoke.

The EPA has defined acceptable concentrations of particulate matter in the air. The National Ambient Air Quality Standards are part of the Clean Air Act and provide mandated guidelines for pollutant levels and the monitoring of ambient air quality. In addition to these monitoring programs, the increased incidence of wildfires near populated areas has precipitated several epidemiological studies. Such studies have demonstrated an association between negative human health effects and an increase in fine particulate matter due to wildfire smoke. **The size of the particulate matter is significant as smaller particulate matter (fine) is easily inhaled into the human respiratory tract**. Often, small particulate matter can be inhaled into deep lung tissue causing respiratory distress, illness, or disease.

Chronic obstructive pulmonary disease (**COPD**) is a lung disease characterized by chronic obstruction of lung airflow that interferes with normal breathing and is not fully reversible. The more familiar terms 'chronic bronchitis' and '**emphysema**' are no longer used, but are now included within the **COPD** diagnosis.

An increase in the smoke emitted from the Hayman fire in Colorado in June 2002, was associated with an increase in **respiratory symptoms in patients with COPD**. Looking at the wildfires in Southern California in October 2003 in a similar manner, investigators have shown an increase in hospital admissions due to asthma symptoms while being exposed to peak concentrations of PM in smoke.[243] Another epidemiological study found a 7.2% (95% confidence interval: 0.25%, 15%) increase in risk of respiratory related hospital admissions during smoke wave days with high wildfire-specific particulate matter 2.5 compared to matched non-smoke-wave days.

Children participating in the Children's Health Study were also found to have an increase in **eye and respiratory symptoms**, medication use and physician visits. Recently, it was demonstrated that mothers who were pregnant during the fires gave birth to babies with a slightly reduced average birth weight compared to those who were not exposed to wildfire during birth. **Suggesting that pregnant women may also be at greater risk to adverse effects from wildfire.** Worldwide it is estimated that **339,000 people die** due to the effects of wildfire smoke each year.

While the size of particulate matter is an important consideration for health effects, the chemical composition of **particulate matter ($PM_{2.5}$)** from wildfire smoke should also be considered. Antecedent studies have demonstrated that the chemical composition of $PM_{2.5}$ from wildfire smoke can yield different estimates of human health outcomes as compared to other sources of smoke.[226] health outcomes for people exposed to wildfire smoke may differ from those exposed to smoke from alternative sources such as solid fuels.

Wildfire and Fire protection

Wildfire prevention programs around the world may employ techniques such as wildland fire use and **prescribed or controlled burns**. Wildland fire use refers to any fire of natural causes that is monitored but allowed to burn. **Controlled burns are fires ignited by government agencies under less dangerous weather conditions**.

Monitoring

Satellite and aerial monitoring through the use of **planes, helicopter, or UAVs** can provide a wider view and may be sufficient to monitor very large, low risk areas. These more sophisticated systems employ GPS and aircraft-mounted infrared or high-resolution visible cameras to identify and target wildfires. Satellite-mounted sensors such as **Envisat's Advanced Along Track Scanning Radiometer** and **European Remote-Sensing Satellite's** Along-Track Scanning Radiometer can measure infrared radiation emitted by fires, identifying hot spots greater than 39 °C (102 °F). The National Oceanic and Atmospheric Administration's Hazard Mapping System combines remote-sensing data from satellite sources such as **Geostationary Operational Environmental Satellite (GOES)**, Moderate-Resolution Imaging Spectroradiometer (MODIS), and Advanced Very High Resolution Radiometer (AVHRR) for detection of fire and smoke plume locations as shown in Figure 9. **However, satellite detection is prone to offset errors, anywhere from 2 to 3 kilometers (1 to 2 mi) for MODIS and AVHRR data and up to 12 kilometers (7.5 mi) for GOES data**. Satellites in geostationary orbits may become disabled, and satellites in polar orbits are often limited by their short window of observation time. Cloud cover and image resolution may also limit the effectiveness of satellite imagery.

Satellites can be used to map the extent of a fire as shown in Figure 9 by observing the smoke plumes and identifying burn scars. **Thermal infrared sensors** can detect heat, thereby pinpointing the exact locations of fires and data acquired through the Charter may be passed on to **firefighters on the ground** within a matter of hours, providing helpful assistance for their efforts in locating and combating fires.

Figure 9 Satellite View of a Forest Wild Fire and Air Pollution

Since 2015 a new fire detection tool is in operation at the **U.S. Department of Agriculture (USDA). Forest Service (USFS)** uses data from the **Suomi National Polar-orbiting Partnership (NPP) satellite** to detect smaller fires in more detail than previous space-based products. The high-resolution data is used with a computer model to predict how a fire will change direction based on weather and land conditions. The active fire detection product using data from Suomi NPP's Visible Infrared Imaging Radiometer Suite (VIIRS) increases the resolution of fire observations to 1,230 feet (375 meters). Previous NASA satellite data products available since the early 2000s observed fires at 3,280 feet (1 kilometer) resolution. The data is one of the intelligence tools used by the USFS and Department of Interior agencies across the United States to guide resource allocation and strategic fire management decisions. The enhanced VIIRS fire product enables detection every 12 hours or less of much smaller fires and provides more detail and consistent tracking of fire lines during long-duration wildfires – capabilities critical for early warning systems and support of routine mapping of fire progression. Active fire locations are available to users within minutes from the satellite overpass through data processing facilities at the USFS Remote Sensing Applications Center, which uses technologies developed by the NASA Goddard Space Flight Center Direct Readout Laboratory in Greenbelt, Maryland. The model uses data on weather conditions and the land surrounding an active fire to predict 12–18 hours in advance whether a blaze will shift direction. The state of Colorado decided to incorporate the weather-fire model in its firefighting efforts beginning with the 2016 fire season.

The demand for timely, high-quality fire information has increased in recent years. Wildfires in the United States burn an average of 7 million acres of land each year. For the last 10 years, **the USFS and Department of Interior have spent a combined average of about $2–4 billion annually on wildfire suppression**.

Modeling

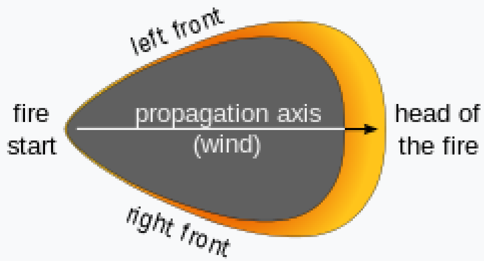


Figure 10 Fire Propagation Model

Wildfire modeling is concerned with numerical simulation of wildfires in order to comprehend and predict fire behavior. Wildfire modeling aims to aid wildfire suppression, increase the safety of firefighters and the public, and minimize damage. Using computational science, wildfire modeling involves the statistical analysis of past fire events to predict spotting risks and front behavior. Various wildfire propagation models have been proposed in the past, including simple ellipses and egg- and fan-shaped models. Early attempts to determine wildfire behavior assumed terrain and vegetation uniformity. However, the exact behavior of a wildfire's front is dependent on a variety of factors, including wind speed and slope steepness. Modern growth models utilize a combination of past ellipsoidal descriptions and Huygens' Principle to simulate fire growth as a continuously expanding polygon. Extreme value theory may also be used to predict the size of large wildfires. However, large fires that exceed suppression capabilities are often regarded as statistical outliers in standard analyses, even though fire policies are more influenced by large wildfires than by small fires.

Critical parameters

(1). Need to develop **protection systems** (external and internal) for all types of fire disasters with power failures.

(2). Identify the critical elements related to **maintaining and monitoring** of the fire 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 all types of fire disasters without and with multiple disasters.

Economic Impact of Fire Disasters

Even local fire disasters can impact 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. Fire 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 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 fire caused by natural or human based disasters. Also the fire 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:

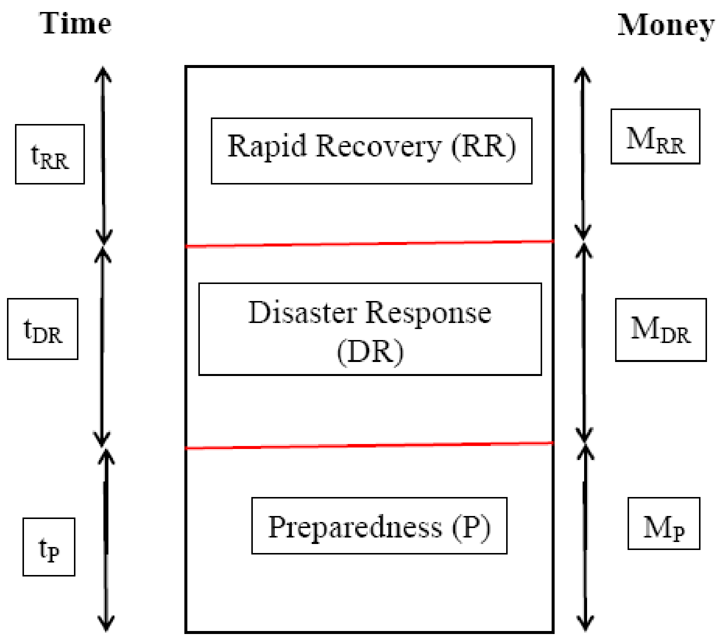


Figure 11 Phase Representation of Disaster Management and Rapid Recovery

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.

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

It is important to identify the critical parameters for preparedness for fire disasters 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 fire 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 reslilency. 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**.

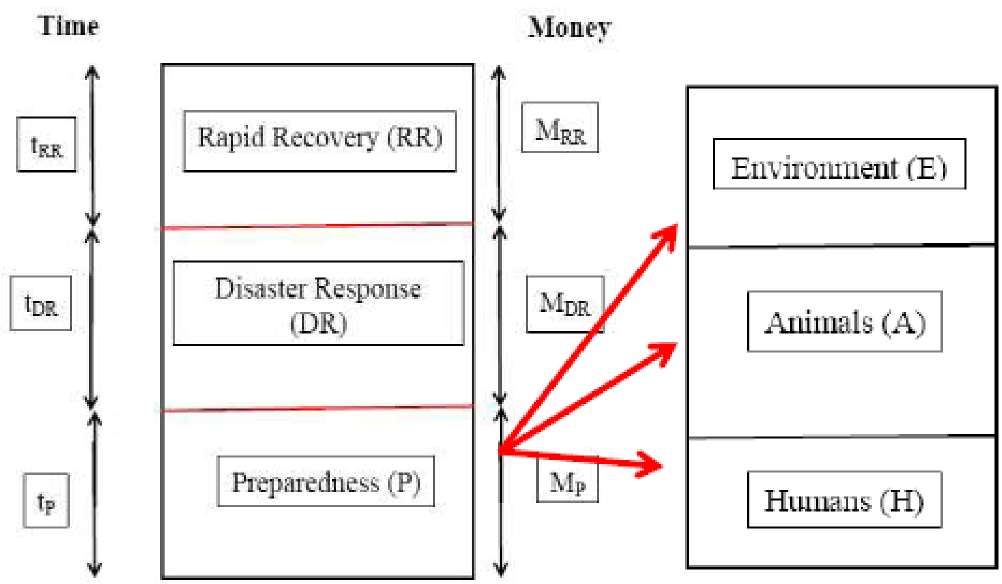


Figure 12 Parameters for Preparedness (P) (for you, family, team, city, country)

EVACUATION OBJECTIVES

Overall objective for **evacuation** due to fire 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 fire disasters** with the other potential natural, human made and virus for the **location of interest**. Based on fire 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 fire 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 **parameters time and money.**

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 fire 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 **over one (1) month** 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 fire 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 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 fire disaster 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).

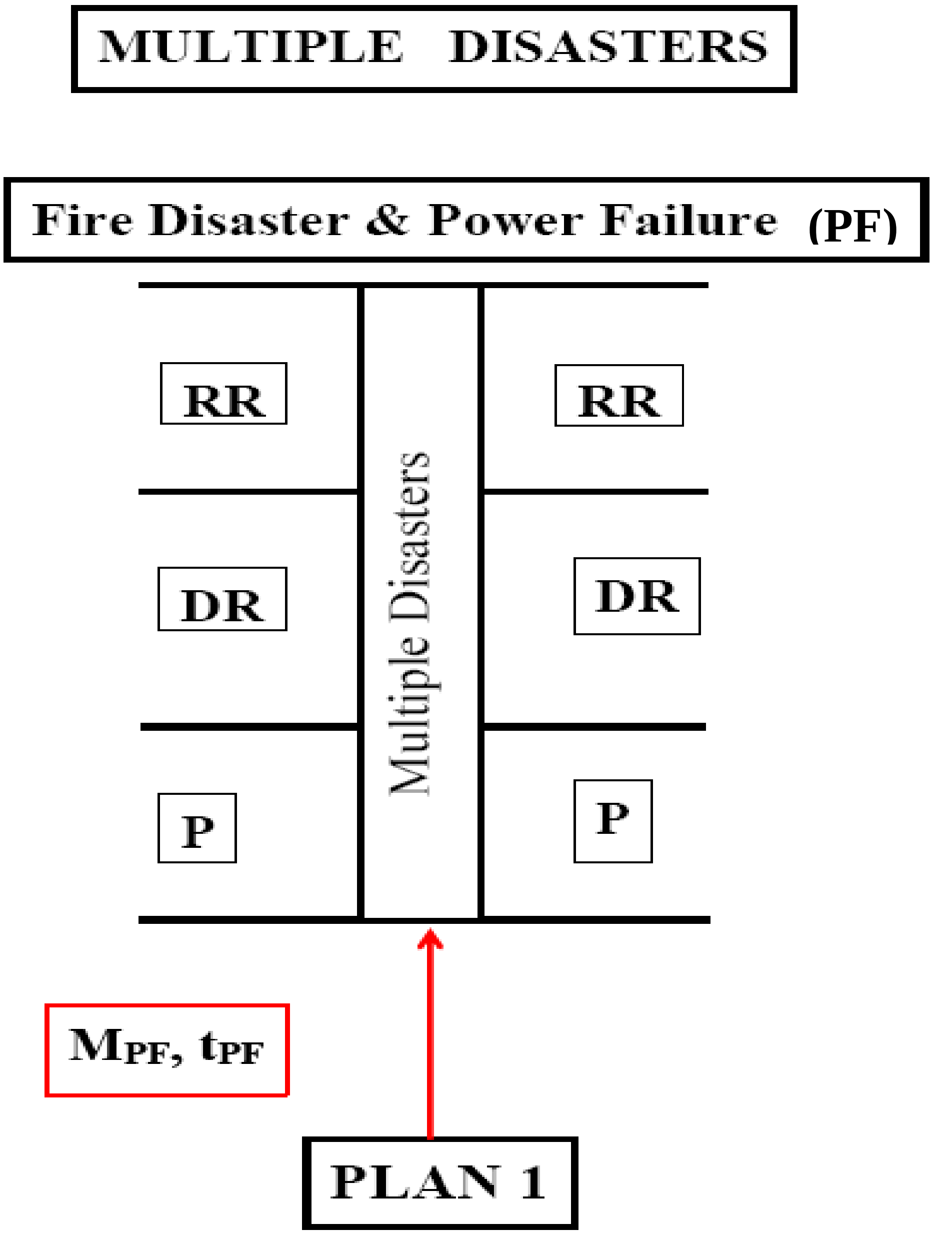
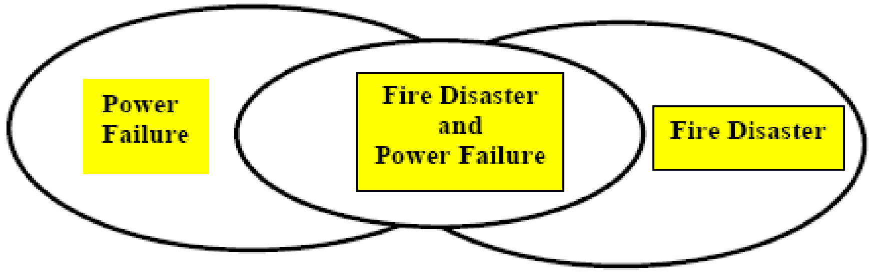


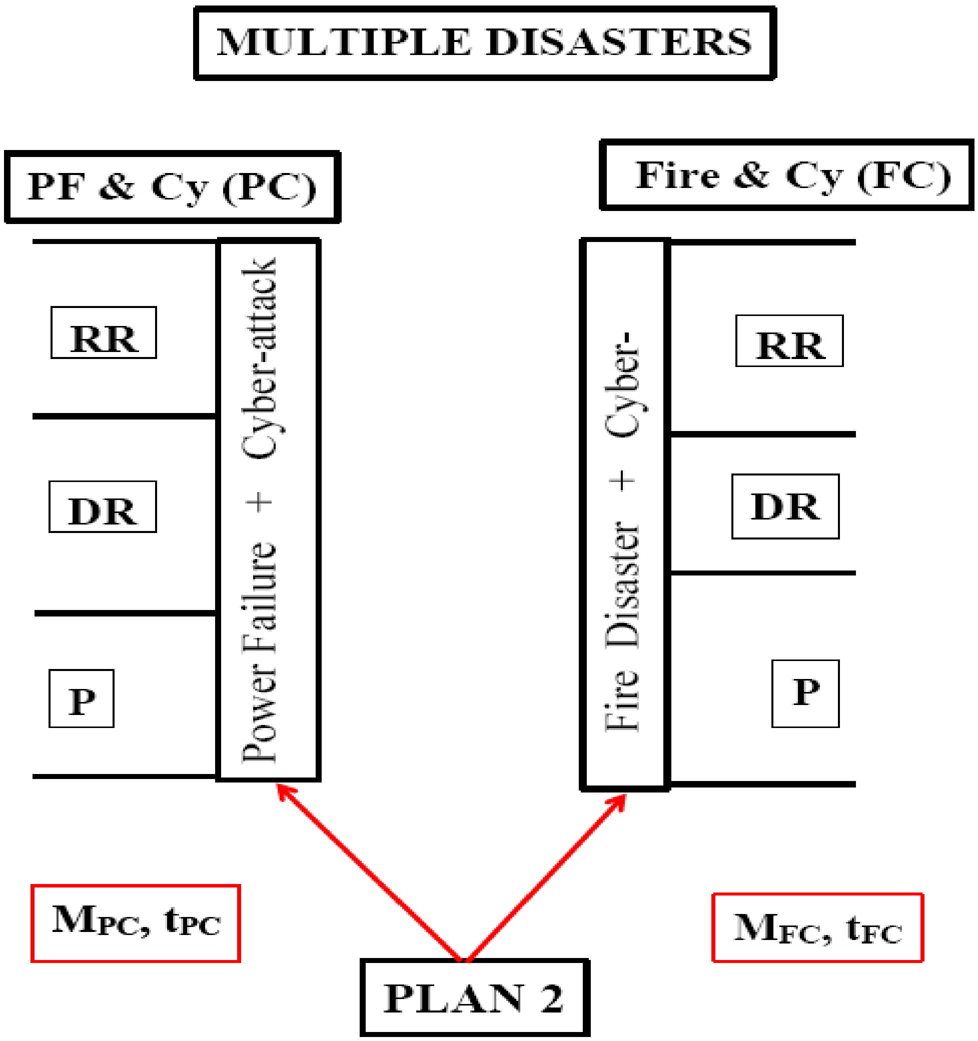
Figure 13 Multiple Disaster Plan 1 Combined Process

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 fire 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 fire 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 fire 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 local, onshore and offshore fire disasters, power failure, and cyber attacks Disaster Management and Rapid Recovery Plans (DMRRP) were developed Also data was collected on fire disasters, relevant electric power and also evaluated new technologies and following conclusions are advanced:

1. Fire 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 fire 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 fire, 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 fire, 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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