A Guideline to Facilitate Over the Air Communication in a Disaster Scenario

by

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Abstract

During and directly following a disaster information is key. Not only getting information to the people that are in crisis but also getting data and reports out of the affected area so that relief agencies can act as quickly and effectively as possible is necessary. With the wide use of smartphones and mobile computing a unique opportunity has presented itself, more information can be collected by individuals that ever before. The challenge following a disaster is to re-establish over the air connection so that people can send and receive crucial information. Another challenge is making sure these handheld devices that serve as a life-line remain charged and operable.

Through the use of wireless technology and self-generating power sources a network could be set up quickly to address the needs of the survivors on the ground. By establishing a guideline that brings together technology, durability, and design, appropriate design strategies can be created to meet the needs of both relief agencies and the people on the ground.

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Chapter 1: Introduction

1.1 Problem Statement

During a disaster all lines of communication can be disrupted leaving the victims, relief workers, and outside world cut off from one another. In a disaster, timely communication is not only crucial, but it can be a matter of life and death. More robust solutions must be created that address the loss of connection between individuals and relief organizations. By collecting more data, relief organizations can respond in a quicker and more informed manner.

1.2 Need for this project

The reestablishment of communications following a disaster needs to happen as soon as possible. Disasters in themselves are unique and dynamic. No one tornado, hurricane, or earthquake is the same as another. Because of this, a guideline to assist in designing quickly deployable communication solutions is needed. Reestablishing communications not only allows victims and relief workers to pass vital information, but it would also allow for the survivors to contact loved ones giving them at least a small sense of comfort during a trying time.

1.3 Assumptions

This thesis project includes the following assumptions: a) the reliance of handheld devices as the primary and in most cases only source of communication will continue to increase; b) companies involved with developing or manufacturing communication equipment will be interested in this guideline; c) disasters will continue to happen.

1.4 Scope

The scope of this project is to research and develop a guideline that would assist manufacturers and companies that produce communication equipment interested in designing communication solutions that would be used in disaster preparation, mitigation, and relief. This study is focused on disaster relief in the U.S. but could conceivably be deployed anywhere around the world. By using real communication technology and platforms as a basis the design solutions will be as applicable to the real world as possible.

1.5 Methodology

The goal of this study is to develop a set of guidelines for designing solutions to re-establish over the air communications following a disaster. The focus of the study is dealing with disaster relief in the U.S. and will:

- Investigate Internet sources and literature on disaster causes and outcomes
- Identify and evaluate current failings in communication infrastructure
- Study current communication technology
- Study current self-generating power sources
- Research the use of social media during disaster situations
- Research the flow of information during a crisis or disaster scenario
- Research commonly used apps and programs that help people communicate in a disaster scenario.

1.6 Contribution

The contribution of this project is to assist companies interested in reducing the impacts of a disaster in a certain area. Through the use of the guideline and background research, companies can design equipment that will be deployed to create communication networks over the air. By establishing communication with relief and rescue organizations, loss of life can be reduced. Also by having these design solutions available before a disaster strikes, the time it will take to re-establish communications will be greatly reduced.

Chapter 2: Literature Review and Research

2.1 Literature Review

In 2007 the iPhone was introduced, and it changed the way cellphones were used and seen. At the unveiling of the iPhone Steve Jobs had said that Apple was going to reinvent the phone. With its all touchscreen interface and applications that could perform various functions, it certainly did change the way people saw and interacted with their phones and has become the standard of what we think a phone is today.

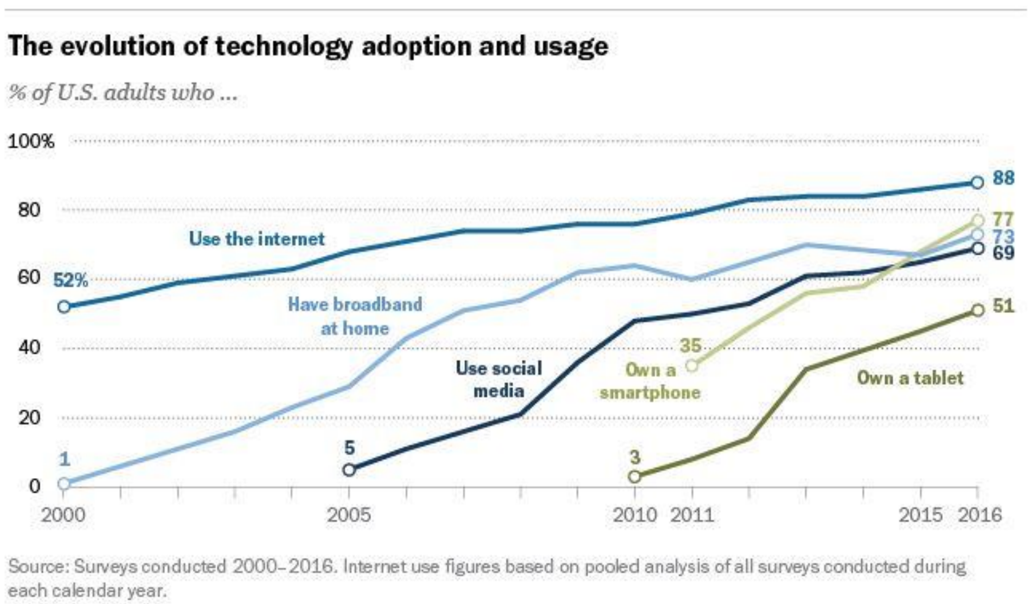


Figure 1: Handheld Device Adoption

Many access the internet through handheld devices. According to Pew Research in 2016, 77% of adults in the US had smartphones and 51% owned tablet computers (Smith, 2017). As mobile computing rises so will the reliance on Wi-Fi and other over the air connections to gain access to information and to communicate with one another.

The first website that was an early version of a social media site was called “Six Degrees” and allowed people to create profiles and friend one another to build connections (Hale, 2015). The site lasted from 1997-2001 and set the stage for what was to follow. In 2004 “TheFacebook.com” was launched by Mark Zuckerberg on Harvard’s campus. The site grew in popularity, changed its name to just “Facebook”, and was expanded to other educational institutions before being opened to the public in 2006. Facebook currently has 2 billion active monthly users making it the largest social media site in the world by far.

Twitter was established in 2006 by a team of coders that were inspired by SMS texting. They were using an early prototype of the platform shared between friends when an earthquake struck San Francisco. The early Twitter lit up with messages. It was at that moment that the developers knew they had something interesting on their hands (Carlson, 2011). They had developed a platform that could allow people to connect with one another in new and interesting ways.

Social media use is becoming more and more involved in people’s lives. When surveyed by the Pew Research Center, most Americans said that they got their news from social media. Half of the respondents indicated that that they learned about the 2016 presidential election through social media. Of the 88% of American adults that use the internet 79% use Facebook, 24% use Twitter, 31% use Instagram, and 29% use LinkedIn (Greenwood, Perrin, & Duggan, 2016). Worldwide, social media is widely used as well. Facebook has 2 billion users, YouTube has 1.5 billon users, WhatsApp has 1.2 billon users, Facebook Messenger has 1.2 billion users, WeChat has 889 million users, Instagram has 700 million users, Twitter has 328 million users, and Snapchat has 255 million users. The number of people that use social media rises each year, increasing the ways people connect to one another and how information is passed between them.

People that use social media are more likely to turn to that platform during times of crisis. During a disaster people turn to social media for a variety of reasons, including getting relevant updates, news from family and friends, and information about relief efforts (Olteanu, Vieweg, & Castillo, 2015). While they look for hard facts like road closures, damage reports and weather conditions, they also share personal information about their safety status and how they are feeling. According to a study conducted by the Red Cross in 2012, three out of four Americans (76 percent) expect help in less than three hours after posting a request on social media and forty percent of those surveyed said they would use social media to tell others they are safe.

The survey also identified a subsection of the population deemed *emergency social users* who are the most dedicated users of social media during emergencies. These users are likely to take a safety or preparedness action based on the information they see in their social networks. Three out of four users say they've contacted friends and family to see if they were safe and more than a third say social information has motivated them to gather supplies or seek safe shelter (American Red Cross, 2012).

With all of this data and information coming from social media, Castillo (2016) points out an interesting problem with the extensive amounts of data that is collected:

> Preliminary assessment and resource allocation is often done based on incomplete and often contradicting pieces of evidence. Background knowledge, such as census data or historical data from similar situations in the past, usually forms the basis for this preliminary assessment.

> A data gathering exercise aimed at understanding the "big picture" uses social media messages as a basis to create high-level summaries that speak about the situation as a whole, and not about specific requests for help or other individual messages.

The American Red Cross has been looking towards collecting and interpreting social media data over the last few years. In 2012 they partnered with Dell to establish their Digital Operations Center in Washington D.C. Specifically, the center will help the Red Cross source information from affected areas, spot trends to better anticipate people's needs, and to connect people with the resources they need, like food, water, shelter or even emotional support.

In conjunction with the Digital Operations Center, the Red Cross has been recruiting digital volunteers from across the country. Their responsibilities include monitoring online conversations for disaster-affected people, sharing important disaster updates and resources through their own social media accounts, and to offer a compassionate voice to people who have been impacted. They work in shifts of four hours at a time from their own homes. To become a volunteer they register online, take a social media basics course, and email the social engagement team to express interest in volunteering.

The Red Cross has also introduced apps for shelter locations, first aid tips, instructions, and hurricane preparedness. They also have several apps for specific disaster response and preparedness including Emergency, Tornado, Hurricane, Earthquake, and Flood. These apps will update the user about possible weather events in their area and have the function to monitor different locations throughout the country. The apps also include a flashlight feature as well as one-touch "I'm safe" messaging that connects directly to the users' social media accounts.

Use of social media is more than just a way to gather or report information; it is a place that people can turn to for emotional support. According to Wendy Harman, the director of social strategy for the Red Cross (2012), in disaster situations people are stressed out, scared and seeking information. Social media and apps become a way to reach out to them with emotional support and tips on staying safe.

While the Red Cross has been focusing on collecting more data and using digital platforms, during a disaster information flow between aid agencies and individuals is often over looked (UN OCHA, 2012). Part of the reason for this is it is difficult to get information to where it needs to be. Another piece of the puzzle is poorly managed information has hampered relief efforts and cost lives.

As the UN OCHA put it in their report (2012):

> They need to find ways to work with new data sources, to collaborate with a wider range of partners, and to understand that information in itself is a life-saving need for people in crisis. It is as important as water, food, and shelter. (p. 3)

Relief organizations can talk to the people on the ground to get a clearer picture of the realities that they are facing. By utilizing the concepts of crowdsourcing, crowd-mapping, and crowd-seeding, more pertinent and accurate data can be collected. Crowdsourcing is a sourcing model that uses direct input from individuals to make decisions or obtain new ideas. These decisions can be more informed and timely in a disaster situation. With crowd-mapping, inputs from text messages and social media are connected to the geographical location they are sent from. If properly collected and understood, crowd-mapping can bring a level of transparency to fast-moving events that are difficult to cover in real-time. It also allows for longer term analysis of trends that may be difficult to identify through individual reports. Another way to gather information in a timely manner is to use the emerging concept of crowd-seeding. This concept is centered around identifying key individuals that can communicate accurate and truthful information about an event while it is happening. Instead of looking at the overall crowd, those specific individuals are relied on to deliver accurate timely information of what is currently happening to and around them. Because they can provide near-real-time information about things that are happening, the amount of pertinent information that is created can be huge.

Utilizing crowd information through social media can also be thought of as distributed cognition, a mechanism for understanding spread across many minds (Hutchins, 1995). By networking people together with their handheld devices, a deeper understanding of what is currently happening on the ground can be understood to a greater degree.

Different uses of social media during a disaster are citizen to citizen, citizen to organization, and organization to organization communication. An example of citizen to citizen was described by Wilensky (2014) with stranded commuters using social media after the Great East Japan Earthquake in 2011 to determine how to get home or to find shelter. While citizen to citizen communication is decentralized, it can be misleading or pass along errors because it is not originating from an official source. It is however one of the quickest ways to get information on the ground during a disaster.

A compelling case of citizen to citizen social media use in action was in the response of the volunteer organization that calls itself the Cajun Navy. This group was formed in the aftermath of Hurricane Katrina and was reactivated in response to floods in Louisiana in 2016 and Hurricane Harvey in 2017. The group uses their own private water craft to rescue people by traversing flooded streets that are no longer passable by any other vehicles. They are outside of the formal relief agency and organization hierarchy, using instead apps and other forms of over the air communication to coordinate rescues. Two apps that are widely used by the group is the GPS app Glympse and Zello (Morris, 2016). Glympse allows users of the app to send or request real-time locations using their phones' GPS. The user can also set the amount of time that someone can view their location to limit the exposure to people knowing where they are at all times (Glympse, n.d.). Zello is a walkie-talkie style app that uses 3G,4G, and Wi-Fi to connect smartphones, tablets, and PCs. It uses a push to talk button like on regular walkie-talkies, but a useful feature is that conversations can be replayed and stored for reference (Zello, n.d.).

Citizen to organization or organization to citizen is seen by most emergency response organizations as a one-way form of communication. Rather than listening and responding to individual posts, they push information out to the public. For many organizations they are not prepared to handle the public's use of social media during emergencies.

During Hurricane Harvey the U.S. Coast Guard asked people to call 911 instead of posting on social media. In a tweet during the storm the Coast Guard said that if callers got a busy signal that they should keep trying. Some responders to the post pointed out that people could not stay on the phone waiting for someone to answer as their phone batteries were dying (Shu, 2017). Over Twitter, people that were out of harm's way were asking people to send them their address and details, so they could contact the Coast Guard and other emergency services for them.

Organization to organization communications through social media are not usually used because of the myriad of ways organizations already communicate. This may change in the future as more organizations establish a greater presence on social media platforms.

A huge drawback of the reliance on social media and wireless communication is that following a disaster communication can be disrupted. Failure of communication networks is common during disasters. As Richards (2015) writes:

> The failure of communications networks is a common occurrence during many disaster scenarios, and yet we have continued to see this preventable sequence of events play out time after time with deadly, expensive, and potentially preventable consequences.

Disruptions to communication networks caused by physical damage have the potential to be incredibly costly and time consuming to restore. They may require maintenance or sometimes replacement of complex network hardware to re-establish communications. This can be especially problematic if a major structure such as cell towers or fiber-optic cables are involved. If a cell tower is severely damaged or knocked down, it not only causes major disruptions in the area's wireless communications, but it is extremely expensive to replace and will remain a significant problem until the service provider is able to get a repair crew into the area (Richards, 2015).

Whether these systems are completely or just partially disabled, communications systems during a natural disaster can be the difference between life and death for those affected. Locating those who are trapped or injured becomes nearly impossible for emergency responders, and rescue efforts become further complicated if the ability to coordinate is hampered by the lack of established forms of communication.

Immediately following a disaster, the top priority for emergency responders is to prevent any further loss of life, and if possible, mitigate damage to property and public infrastructure.

Much of this information is time sensitive and must be communicated quickly to those who are in need of the information.

During many disasters emergency workers and people on the ground are forced to turn to alternative forms of communication to stay in contact with one another. After Hurricane Maria struck Puerto Rico electric, land-line, cellular, even the radio networks used by police and fire were disabled and showed no signs of being reestablished in a timely fashion. That is when the Red Cross put the call out that they needed 50 ham (short for amateur) radio operators to come to the island to assist with communications. Answering the call was the American Radio Relay League, a group that has existed for more than a century (Murphy & Krupa, 2017).

The volunteers quickly spread out across the island and set up remote communication operations using voice, Morse code, and other methods over a wide range of frequencies above the AM broadcasting band. Ham operators were also critical in facilitating rescue operations after 9/11 and Hurricane Katrina. These volunteers helped share critical information about diabetics nearing the end of their insulin reserves, babies threatened by dehydration, and families rationing crackers (Murphy & Krupa, 2017).

Quickly the ham operators realized their messages were the only ones getting off the island. They conscripted anyone with enough skills to run the radio equipment and put them into service. These operators worked with public safety and utility officials to transmit information to other ham operators working in the field. For weeks ham operators were riding with police to broadcast calls to other operators at command centers with officers who could respond with orders. This was necessary because before Hurricane Maria the police's wireless communication systems relied on computers and power sources that were knocked out by the storm.

Another problem may be arising from the modernizing of the telephone and cellular networks. After Hurricane Katrina, Bellsouth used the opportunity to modernize their cable plants and installed more fiber optic cables connected to remote terminals (RTs). However, RTs require local power and in many instances, it is too complicated to provide long term power backup at these sites. With fiber optic cable the chance of loss of service of land-line phones is greatly increased compared with the use of traditional telephone architecture (Kwaninski, 2012).

One important issue in the operation of communication networks following Hurricane Sandy was also associated with the extensive power outages caused by the storm. A huge need that was uncovered was for charging stations for cell phone and other personal devices. Verizon and AT&T set up some charging stations around the city, but it is unknown how many people were helped by that and how many people were unable to communicate due to dead batteries. Hurricane Sandy's aftermath highlighted an increasing vulnerability of communication networks as they are more distributed and more reliant on power from an electrical grid. Exacerbating this weakness at the end user level is that their main access to the network can only remain operational as long as the device has a charge. When the power is out, keeping these devices charged can be very difficult to nearly impossible.

Following the tragic events of September 11, 2001, the 9/11 Commission recommended the establishment of a nationwide, interoperable public safety communications network to resolve the communication challenge faced by emergency responders nationwide. The development of high-speed wireless communication technology presents a way to enhance information sharing and communications during emergencies (Essid, 2012). The ability to access videos, download floor plans of a burning building, or to be able to connect with other personnel from other communities led to the interest in creating a nationwide safety network.

On February 22, 2012, President Obama signed into law H.R. 3630, the Middle-Class Tax Relief and Job Creation Act of 2012, which included provisions to fund and govern a Nationwide Public Safety Broadband Network. This network will provide a secure, reliable nationwide network for emergency responders to communicate during an emergency. The network will operate on 20 MHz of spectrum solely dedicated to be used by emergency responders and will ensure that they have adequate network access. Having a separate system allows the emergency workers to have an open line of communication that will not become congested during an emergency situation.

While this proposed network has experienced delays, and would only be open to emergency workers, it does point to the rising need for wireless communication between organizations that can transmit data, video, and images.

Project Loon is an experimental project that is focused on providing internet service to areas that have no existing infrastructure. The project's goal is to maintain a fleet of balloons that will provide internet coverage to people on the ground. The balloons carry transceivers connected to solar panels 20 km up into the stratosphere. The solar panels are large enough to keep the transceiver running during the day and to charge the battery to keep everything running at night. The transceivers transmit connectivity from the ground stations, across the balloons, and back down to users' LTE phones. Each balloon has a coverage area of 5000 square kilometers. Every balloon is tracked by GPS and when a balloon is ready to be taken out of service it can be landed in a targeted area to avoid collisions with aircraft and structures on the ground. A team then goes and collects the balloon and its hardware for reuse and recycling.

This project is ambitious and does expose the idea that some places on this planet are hard to get wireless signals to. However, with the use of constantly moving balloons and deployment structures it is hard to envision how this particular solution could provide long term wireless data connections.

Summary

Communication is crucial in a disaster not only between individuals but relief organizations as well. As more and more people use social media and handheld devices to communicate support for this kind of traffic needs to be increased. Through the use of wireless technologies more people can be reached, and information can be received from them allowing for a quicker and more appropriate response. While this technology is powerful, it also has some draw backs. During a disaster power service is often disrupted, causing wireless networks to fail and make it difficult for people to find ways to keep their devices charged.

2.2 Disasters

2.2.1 Introduction

The International Federation of the Red Cross and Red Crescent define a disaster as “a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community’s or society’s ability to cope using its own resources.”

They also have an equation to visualize the core components of a disaster:

(VULNERABILITY+ HAZARD) / CAPACITY = DISASTER.

Vulnerability is defined as individuals or communities’ inability to prevent or avoid exposure to risk. The most vulnerable people are usually those who are poorer or live further away from cities. Another component of vulnerability is the amount of preparedness that was done ahead of time.

Category	Subcategory	Examples
Natural	Meteorological	Tornado, hurricane
	Hydrological	Flood, tsunami
	Geophysical	Earthquake, volcano
	Climatological	Wildfire, heat/cold wave
	Biological	Epidemic, infestation
Anthropogenic (Human-Induced)	Sociological (intentional)	Shooting, bombing
	Technological (accidental)	Derailment, building collapse

Table 1: Hazard Categories

Hazards are broadly defined as the larger events that influence peoples' lives. According to Castillo (2016), hazards are broken down into two main categories: Natural and Anthropogenic. The Natural category consists of subcategories: Meteorological, Hydrological, Geophysical, Climatological, and Biological. The Anthropogenic subcategories are: Sociological (i.e. mass shooting, terrorism), and Technological (i.e. building collapse).

Capacity is the ability of the affected area and people to recover from the damage that has been sustained. The more prepared an area is and the easier it is to move materials in and out, the quicker an area can recover following an event.

In conclusion, in the presence of a hazard if vulnerability can be minimized and capacity maximized the effect of a disaster will be greatly reduced.

2.2.2 Natural Hazards

Natural hazards are caused by a severe natural event. Usually related to weather events, natural hazards can also include earthquakes, infestations, or other biological components. Some hazards can occur quickly or can develop over a long period of time.

2.2.2.1 Meteorological

The most severe examples of a meteorological hazard are hurricanes and tornadoes, but they also include hail, rain, lightning, etc. Hurricanes and tornadoes are perhaps the most hazardous of this category due to the amount of damage a single storm can cause in a certain area.

Tornadoes consist of a rotating column of air that is in contact with the ground. They are visible as a funnel cloud and are marked by high winds, as low as 67 mph to as high as 300 mph. Tornadoes on a local scale are the most intense of any spinning storm (NOAA, 2017). While they are only typically one mile or less in diameter their winds can be devastating. Their relatively small size and their tendency to form quickly makes predicting when and where a tornado will strike very difficult. Tornadoes develop over land and are most common in the Midwest region of the US but can develop anywhere in the country. They have also been documented on every continent but Antarctica.

It is nearly impossible to measure the actual wind speed inside tornadoes due to their unpredictability and intensity that would destroy regular weather instruments. Thus a system was created by Dr. Ted Fujita in 1971 to judge tornadoes intensity by the severity of damage produced. He came up with a Fujita Scale that had values from F0 to F5 that devised the approximate wind speed ranges for each damage category. The original Fujita scale was evaluated and updated over the years to become the current Enhanced Fujita Scale (NOAA, 2014). The values of the EF scale are:

EF-0 has wind speeds of 65-85 MPH and causes light damage such as the surface off peeling some roofs, some damage to gutters or siding, branches broken off trees, and shallow-rooted trees pushed over.

EF-1 has wind speeds of 86-110 MPH and causes moderate damage such as roofs severely stripped, mobile homes overturned or badly damaged, loss of exterior doors, windows and other glass broken.

EF-2 has wind speeds of 111-135 MPH and causes considerable damage such as roofs torn off well-constructed houses, foundations of frame homes shifted, mobile homes completely destroyed, large trees snapped or uprooted, light-object missiles generated, and cars lifted off the ground.

EF-3 has wind speeds of 136-165 MPH and causes severe damage such as entire stories of well-constructed houses destroyed, severe damage to large buildings such as shopping malls, trains overturned, trees debarked, heavy cars lifted off the ground and thrown, and structures with weak foundations blown away some distance.

EF-4 has wind speeds of 166-200 MPH and causes devastating damage such as whole frame houses and well-constructed houses being completely leveled, cars thrown, and small missiles generated.

EF-5 has wind speeds of 200+ MPH and causes incredible damage such as strong frame houses leveled off foundations and swept away, automobile-sized missiles fly through the air in excess of 300 feet, high-rise buildings have significant structural deformation, and incredible phenomena will occur.

Joplin Missouri, was hit by an EF-5 tornado in the late afternoon on Sunday May 22, 2011. It was part of a larger system and reached nearly a mile wide. It tore through the southern part of the city and rapidly intensified and tracked eastward across the city. The tornado killed 161 people, injured 1,000 others, and caused damages amounting to a total of $2.8 billion (Gounley, 2016). It is ranked as the costliest tornado in U.S. history. The civil defense sirens sounded 20 minutes before the tornado struck but many residents did not hear it.

The tornado also highlighted the use of social media in conjunction with disaster response. News outlets began aggregating images and video from eyewitnesses shared through social media (Stephens, 2011). As part of the response, a Joplin Tornado Info Facebook group and website were created to help coordinate information, needs, and offers. The results were so positive that the project was a finalist for the 2011 Mashable Awards for Best Social Good Cause Campaign (Haberman, 2011).

A hurricane, or more broadly a tropical cyclone, is a rotating low-pressure system that consists of organized thunderstorms but has no separating front (NOAA, n.d.). All tropical cyclones begin as tropical depressions which are designated by having winds under 39 mph. Once the winds are over 39 mph the designation changes to a tropical storm. Only when a tropical storm's sustained wind speed reaches 75 mph is it called a hurricane. Hurricanes are measured using the Saffir-Simpson Hurricane Wind Scale which divides storms into five categories with one being the least severe and five being the most. From the NOAA website the categories are:

A category one hurricane has sustained winds of 74-95 mph. The winds are very dangerous and can damage the roofs of homes as well as cause power outages that can last a few days.

A category two hurricane has sustained winds of 96-110 mph. The winds are extremely dangerous and may cause extensive damage. Many trees with shallow roots will be blown down and houses will incur major roof damage. Power loss is expected to last several days to weeks.

A category three hurricane has winds from 111-129 mph. The winds are devastating and many houses will have major damage to roof decking and can lose parts of the roof structure. Many trees will be uprooted or blown down, blocking roads, and access to electricity and water may be unavailable for several days to weeks.

A category four hurricane has winds of 130-156 mph and will cause catastrophic damage. Houses will lose most of their roof structure and possibly exterior walls. Most trees and power poles will be blown down, blocking roads, and cutting off power for weeks to months. Most of the area will be uninhabitable for a week or months.

A category five hurricane has wind speeds of 157 mph and higher. Most homes will be completely destroyed, causing roofs and walls to collapse. Power and water will be out for weeks to months and the area will uninhabitable for an extended period.

Hurricane Sandy became the largest recorded Atlantic hurricane with a measured diameter of 1,100 miles. Damages from the storm have been assessed to be about $75 billion and 233 people died in the eight countries that were in the path of the storm. In the United States Hurricane Sandy affected 24 states and was particularly destructive in New Jersey and New York. Its storm surge hit New York on October 29, 2012, flooding streets, tunnels and subway lines, and cutting power in and around the city. Damage in the U.S. amounted to $71.4 billion.

Hurricane Sandy caused power outages and disrupted telecommunications across Northeastern states. This resulted in spotty coverage for cellphones, television, home telephones, and Internet services. People lined up at pay-phones in at least one New York neighborhood because their phones had either lost coverage or had run out of battery. New York-based Verizon said the storm caused flooding at three Verizon central offices that hold telecom equipment in Lower Manhattan as well as sites in Queens and on Long Island.

Verizon Wireless, AT&T, Sprint Nextel, and T-Mobile all lost service coverage around New York City.

According to Kwaninski (2012) in his report:

> One important issue in the operation of communication networks after Sandy that was also associated to the extensive power outages caused by the storm was the need for charging stations for cell phones and other personal communication devices. That is, Hurricane Sandy's aftermath highlighted an increasing vulnerability of communication networks as their architectures are more distributed and more relying on power from the grid, particularly at the end user level. (p. 4)

During Hurricane Sandy, FEMA asked residents to use social media to update their status to avoid overloading phone channels (Ludwig, Reuter, & Pipek, 2015).

2.2.2.2 Hydrological

Examples of hydrological hazards are floods or landslides. Any hazard involving water would be considered hydrological. Most flooding occurs due to rainfall but there is a distinct role people and the structures they build play into it (Bolt, Horn, Macdonlad, & Scott, 1977). Flooding takes on two forms: there is the runoff from rain that runs from high ground to low ground and there is coastal flooding that usually involves water being blown onto land by a storm. Some flooding occurs in certain regions annually and is relatively easy to predict. The quick floods are harder to anticipate and can cause greater damage and loss of life.

A tsunami is a large seismic sea wave that is generated by displacement on the sea floor. The most common cause of tsunamis is impatient displacement along a submerged fault, associated with an earthquake (Bolt et al., 1977). On March 11, 2011 a magnitude-9 earthquake shook northeastern Japan and caused a huge tsunami. The earthquake was centered on the sea floor 45 miles east of Tohoku, Japan. The shaking lasted about six minutes. Residents of Tokyo received a warning one minute before the earth started shaking. People all over Japan also received text alerts of earthquake and tsunami warnings on their cellphones.

Less than an hour after the earthquake, the first tsunami wave hit Japan. The tsunami waves reached a recorded run-up height (a measure of how far inland a wave surge reaches) at 128 feet at Miyako city and traveled 6 miles inland in Sendal. The tsunami flooded approximately 217 square miles of Japan.

The number of confirmed deaths is 15,894 and more than 2,500 people that are still missing. There were 150,000 people who lost their homes, 50,000 of which are still living in temporary housing six years later. Over one million structures were destroyed or damaged in the island chain. The estimated cost of the disaster is estimated to be about $200 billion but the World Bank has estimated that the total economic cost could reach $235 billion, making it the costliest natural disaster in world history (Oskin, 2017).

2.2.2.3 Geophysical

A Geophysical hazard is any change or deformation of the earth's surface. The major examples of these hazards are earthquakes and volcanoes. Earthquakes are defined as deformations in the Earth's crust. The releasing of strain in the Earth's surface is what is felt as an earthquake. Earthquakes are caused when faults in the Earth's crust slip, dip, or spread apart

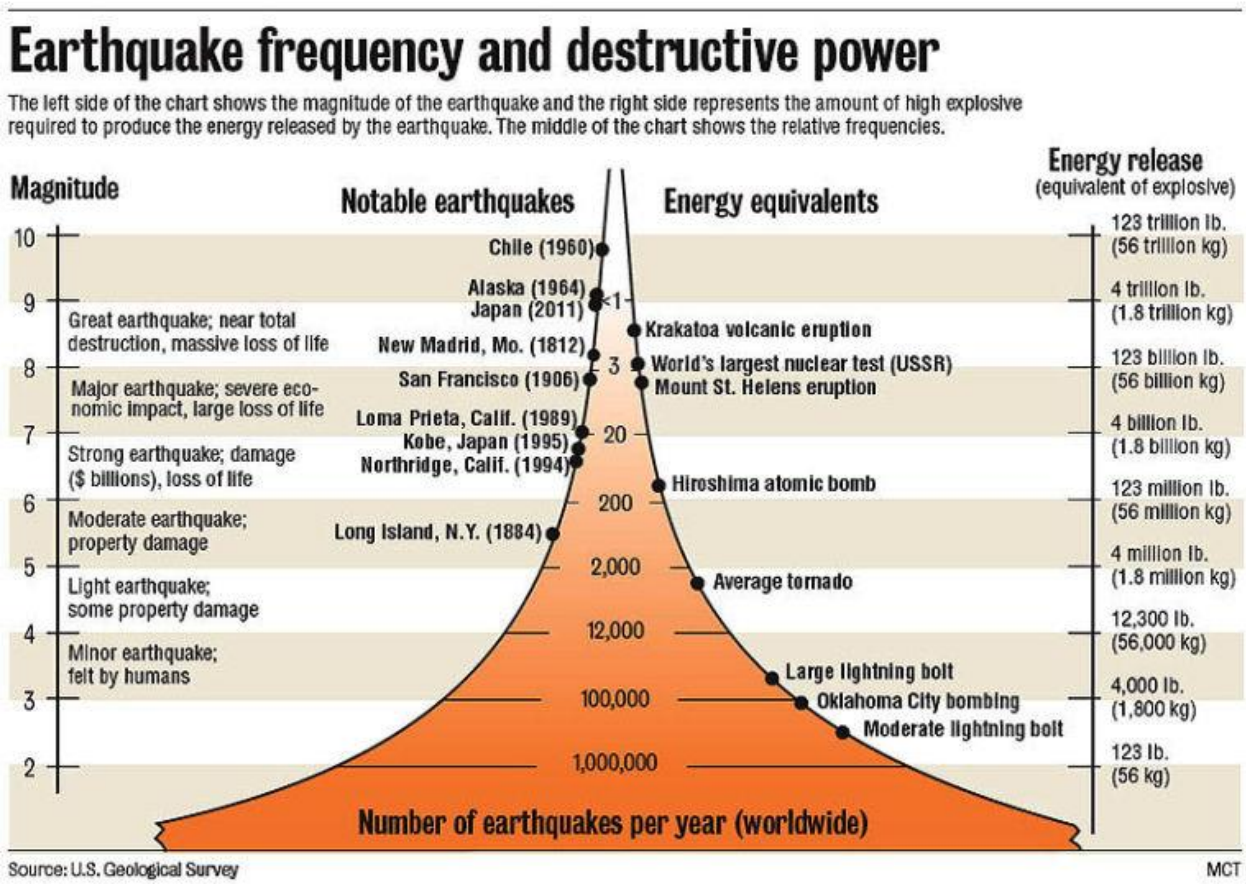


Figure 2: Earthquake Frequency and Destructive Power

(Bolt et al., 1977). They are the most common in areas that have great geological change, like mountains, and at the edge of the tectonic plates that are always moving below the surface. Earthquakes are measured on the Richter Scale:

1.0 – 1.9, Micro, microearthquakes are not usually felt but are recorded by seismographs, these occur continually/several million times per year

2.0 – 2.9, Minor, felt slightly by some people and no damage to buildings, over one million times per year

3.0 – 3.9, Minor, often felt by people but very rarely causes damage, 100,000 times per year

4.0 – 4.9, Light, noticeable shaking of indoor objects and rattling noises, felt by most people in affected area, generally causes minimal to no damage, 10,000 to 15,000 per year

5.0 – 5.9, Moderate, causes none to slight damage to all well-constructed buildings, felt by everyone, 1,000 to 1,500 per year

6.0 – 6.9, Strong, strong to violent shaking at epicenter, damage to a moderate number of well-built buildings, felt in wider areas, up to hundreds of miles from the epicenter, 100 to 150 per year

7.0 – 7.9, Major, causes damage to most buildings, felt across great distances with major damage limited to 150 miles from epicenter

8.0 – 8.9, Great, major damage to buildings, structures likely destroyed, felt in extremely large regions

9.0 and greater, Great, at or near total destruction, collapse or severe damage to all buildings, felt in distant locations, permanent changes to ground topography

2.2.2.4 Climatological

Examples of climatological hazards are wildfire, extreme heat or extreme cold. Wildfire, also known as wilderness fires and forest fires burn four to five million acres of land every year in the U.S. Wildfires move at 14 miles an hour and consume everything in their path from trees, brush, to houses, and even human beings. Wildfires need the presence of three things to start:

fuel, oxygen, and a heat source. Fuel is anything that can burn, like dry grass, trees, brush, and human built structures. The greater the available fuel the larger and more intense the fire. Oxygen is in the ambient air and the greater its presence the hotter the fire. This is why wind plays such a large factor in the way fire spreads and the direction it takes. While four out of five wildfires are caused by humans a heat source can come from lightening, campfires, hot winds, and even the sun.

While wildfires occur regularly in most of the 50 states, the hardest hit states are: Oregon, Idaho, Wyoming, Montana, Washington, Colorado, and California. California is especially susceptible to fire because of the hot and dry Santa Ana winds. According to the National Weather Service glossary, the Santa Ana winds are caused by weather that blows the hot dusty air from the internal desert region into southern California (NOAA, 2009).

2.2.2.5 Biological

Biological hazards are epidemics, infestation, and disease. With a biological hazard, communication can help to stem the spread of disease by disseminating information in more complex ways then word of mouth or radio broadcasts. While internet and cell services would not be disrupted by the hazard itself, cell phone and internet usage could spike as people try to contact one another and search for possible contagions online.

2.2.3 Anthropogenic

Anthropogenic hazards are anything that is caused by human beings. This hazard can be caused either intentionally or unintentionally. The devastation of this hazard largely stems from the fact that it so unpredictable. Whether it is an act of terrorism or a massive accident such as a train derailment, these events are nearly impossible to plan for.

2.2.3.1 Sociological

Sociological hazards are intentionally caused by an individual or a group of people. Examples of this are terrorism, mass shooting, war, and forced displacement of people. In the U.S. the most severe example of a sociological hazard was the terror attacks on September 11, 2001. When two planes were flown into the World Trade towers, communication in and out of the affected areas were extremely difficult. At the time cell phone usage was not as high as it is today, and it was before the first smart phone was released, but people resorted to physically posting pictures in efforts to locate loved ones. Also as reports of the planes hitting the towers came in all air travel in the U.S. was grounded and even the New York Stock Exchange was closed for a number of days. In attacks like this timely information is vital. In sociological hazards, decisions need to be made quickly and many lives may depend on how fast information can be transmitted.

During sociological hazards, many times utilities like power, water, and internet are not disrupted but the shear amount of cell phone calls and internet usage can clog and crash networks. Following the Boston bombing in 2013, the cell phone networks were totally overwhelmed. Cell phone service outages were reported not just at the location of the bombing but in the surrounding area as well. Emergency responders are given priority in emergency situations and no disruption in their communication capacity was reported, but many people were unable to make or receive calls.

2.2.3.2 Technological

Technological hazards are unintentional and are defined as accidents like train derailment, building collapse, and large vehicle accidents.

At 1:15 am on July 6, 2014 a train caring highly volatile crude oil derailed and burst into flames in the small Quebec town of Lac-Mégantic. The train had been parked outside of town, but a small fire had weakened the air brakes and when they failed an improperly set hand brake allowed the train to roll down the hill and explode into flames in the town's center killing 47 people. From the ruptured train cars 1.5 million gallons of oil spilled and fed the intense flames for hours.

This accident, while not being huge was devastating for the small town of 6000. 2000 people were forced to leave their homes and destroyed much of the downtown. Like most technological hazards, this derailment could have been avoided. There were 18 different safety systems that either failed or were not properly engaged. The small rail company that owned that section of track were known to cut corners and skirt safety regulations (Hasley, 2014).

2.3 Research

2.3.1 Introduction

Designing a solution for communication following a disaster contains many variables and technical components. In this section the components and pertinent information will be presented. In the following chapter the guideline to assist in decision making and help with creating a design solution will be presented and will be used in conjunction with the following information.

2.3.2 Disaster Management Cycle

Disaster management is defined as the organization and management of resources and responsibilities for dealing with the aspects of a disaster to reduce its impact. Formatting it as a cycle alludes to the fact that reducing the impacts of a disaster is a continuous process. It is important to take into account all four main phases of the disaster management cycle. While it is crucial to facilitate response and recovery following a disaster, attention to the mitigation and preparation must also be a key focus of any successful design. For recurring disasters (like seasonal flooding) a design solution could also be created to mitigate and prepare for future hazards. The cycle is broken down into four major phases:

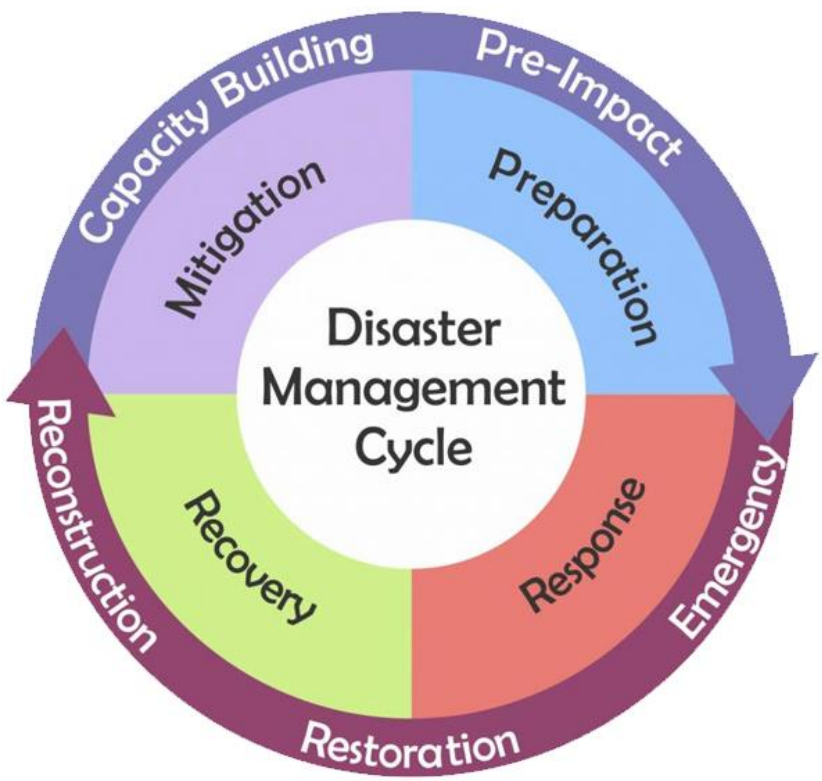


Figure 3: Disaster Management Cycle (2016)

Mitigation: Measures that prevent or reduce the impact of disasters. This could be thought of as properly constructed buildings, appropriate evacuation routes, etc.

Preparation: Planning, training, and educational activities for things that cannot be mitigated. This could include readiness kits; resources may be placed directly before a predicted disaster hits.

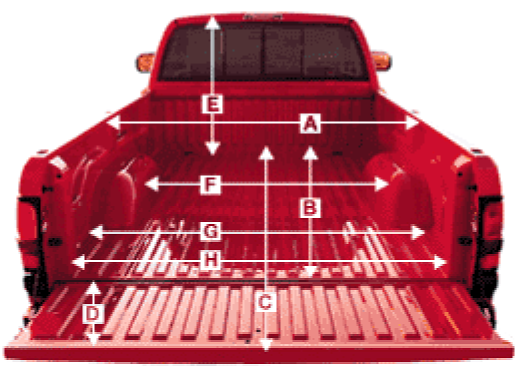
Response: Immediately after a disaster when time and communication is paramount. This phase is most focused on preventing as much loss of life and destruction as possible.

Recovery: The long-term aftermath of a disaster, when restoration efforts are in addition to regular services. This phase could take years to accomplish.

2.3.3 Transportation

Moving the design to site can be different based on the type of vehicles and conditions on the ground. With transportation where the design is produced or where it needs to be moved to can be a factor.

- **Light Truck**



		6.5' Box	8' Box
A	Maximum Width At Outside Of Fender	78.0	78.0 (1)
B	Overall Length Of Box	82.1	101.2
C	Front Of Box To End Of Open Tailgate	98.6	118.4
D	Tailgate Height	17.0	17.0
E	Box Floor To Top Of Cab	42.5	42.5
F	Width Between Wheelhouses	49.3	49.3
G	Maximum Width At Floor	64.3	64.3
H	Maximum Width Opening	63.2	63.2

All dimensions in inches unless otherwise noted.
(1) 93.8" with dual rear wheels.

Figure 4: Light Truck Bed Size

The average size of a light truck bed is listed in the table above. Every make a model of this type of truck is different. If there is a specific truck that will be used, the bed should be measured before designing anything that will have to fit within its dimensions. The figure is from a 2001 Dodge Ram pickup but can be used as a guide for measuring a specific truck bed if one is to be used.

- **Heavy Truck**

Heavy trucks are used for transporting large equipment usually across great distance. These types of trucks are usually loaded with machinery like forklifts but can be loaded by hand with significant physical effort. Due to the deck height a loading dock or some sort of platform at height must be used for loading and unloading. The used of semi-trailers would be best used for designs that need to be moved from state to state or across the country.

Semi-Trailer Dimensions											
	Length	Inside Width	Inside Height Rear	Inside Height Center	Inside Height Front	Door Opening Width	Door Opening Height	Rear Floor Height	Cubic Capacity	Overall Width	Overall Height
28' High Cube	27'3"	100"	110"	109"	107"	93"	104"	47-1/2"	2029 cft	102"	13'6"
45' Wedge	44' 1-1/2"	93"	112"	109"	106"	87"	105-1/2"	50"	3083 cft	96"	13'6"
48' Wedge	47'3"	99"	112-1/2"	110-1/2"	108-1/2"	93"	105"	48-1/2"	3566 cft	102"	13'6"
53' Wedge	52'	99"	111"	110-1/2"	110"	93"	105"	49"	4050 cft	102"	13'6"
53'	52'	99"	110-1/4"	110-1/4"	110-1/4"	93"	105"	49"	4050 cft	102"	13'6"

Figure 5: Heavy Truck Cargo Dimensions

2.3.3.1 Modular Design

Due to the dynamic nature of disaster relief, a modular design approach should be used. Modular design is an approach that subdivides a system into smaller parts called modules that can be independently created and then used in different systems. Modularity in products are products that fulfill various functions through a combination of modules. The benefits of this approach allow for flexibility, ease of transportation, serviceability, and a greater life span of a design because parts can be changed or replaced as needed (Kamrani & Salhieh, 2000).

Product modularity can be represented based on types of combinations between modules. Combinations between modules are based on the types of interactions between the different modules. There are four categories of modularity:

- **Component-Swapping Modularity**

Component-swapping allows different modules to be changed out to repair, improve or change the functioning of the system. An example of component-swapping modularity in the computer industry is illustrated by matching different types of CD-ROMs, monitors, and keyboards with the same motherboard. This allows for different models of computers to be implemented.

- **Component-Sharing Modularity**

Component-sharing and component-swapping modularity are identical except that swapping involves the same basic product using different components and sharing involves the same basic product using the same component. An example of this kind of modularity in the computer industry is represented by the use of the same power cord, monitor, or microprocessor in different computers.

- **Fabricate-to-Fit Modularity**

In fabricate-to-fit one or more components are used with one or more variable additional components. Variation is usually associated with physical dimensions that can be modified. An example of this kind of modularity is cable assemblies in which two standard connectors can be used with a different length of cable.

- **Bus Architecture Modularity**

This modularity occurs when a module can be matched with any number of basic components. Bus modularity allows the number and location of components in a product to vary. An example of this kind of modularity is a computer where different input and output units, in addition to different types of mice, RAMs, and hard drives, can exist and vary in both their location and number.

2.3.3.2 National Institute for Occupational Safety and Health (NIOSH) Lifting Equation

NIOSH has a lifting equation for calculating a recommended weight limit for one person. The lifting equation establishes a maximum load of 51 pounds, which is then adjusted to account for how often you are lifting, twisting of your back during lifting, the vertical distance the load is lifted, the distance of the load from your body, the distance you move while lifting the load, and how easy it is to hold onto the load.

The difficulty with assessing risks associated with lifting is that weight alone does not determine the risk for back injury. Other factors include:

- How often you are lifting something
- Whether you bend or twist while lifting
- How high an object is lifted
- Where the origin of the lift occurs; specifically, whether it is below knuckle height
- Whether you hold the object away from you while lifting
- How long you lift or hold the object

2.3.4 Environment

2.3.4.1 Type of Disaster

To create an appropriate design solution the type of disaster or disasters must be taken into account. Depending on the kind of disaster that has occurred, there are different considerations to keep in mind. Presented below is a short description of each category of the different hazards with regards to how they can affect the communication and power networks.

- **Meteorological**

In the case of severe hurricanes and tornadoes, massive damage to the power and communication infrastructure can occur, taking weeks to months to be restored. Tornadoes generally cause less damage than hurricanes. Hurricanes often leave flooding in their wake that can last for days.

- **Hydrological**

Structurally the electric and communication grids are usually left relatively intact. Substations and transformers may become flooded, which can disable power and communication for days to weeks.

- **Geophysical**

Deformations of the earth can cause disruptions in electrical and communication service but are not usually widespread outside of the epicenter.

- **Climatological**

In the case of wildfire or forest fires power and communication infrastructure is destroyed and must be built form the ground up. Survivors of severe fires often have no home or even community to return to.

- **Biological**

During this hazard, power and communication infrastructure is not damaged but telephone and internet usage can spike, causing the networks to slow and potentially fail.

- **Sociological**

Depending on the severity of the event, power and communication infrastructure may not be interrupted but the spike in phone and online traffic may choke networks, resulting in loss of connection.

- **Technological**

During this hazard, power and communication infrastructure may not be interrupted but telephone and internet usage can spike, causing the networks to slow and potentially fail.

2.3.4.2 Environmental Standards

Based on where the disaster happened, there are other environmental conditions to take into consideration. It is important to understand some of the environmental strains that will be placed on a design in a certain area. For example, if placing electronic devices in a tropical area heat gain must be mitigated to maintain function.

- **MIL-STD-210**

The table below represents what the U.S. military considers extreme temperatures in different areas of the world, including storage and inside and outside operation.

		Area	Low Extreme	High Extreme
Non-operating and storage		All Area	-62^{0}C (-80^{0}F)	$+71^{0}$C ($+160^{0}$F)
Operating	Outdoor	Cold Weather	-54^{0}C (-65^{0+}F)	$+52^{0}$C ($+125^{0}$F)
		Desert and Tropical	0^{0}C ($+32^{0}$F)	$+71^{0}$C ($+160^{0}$F)
	Indoor	All Areas	0^{0}C ($+32^{0}$F)	$+52^{0}$C ($+125^{0}$F)

Table 2: MIL-STD-210

- **IP standards**

The International Protection Marking (IP code), sometimes referred to as the Ingress Protection Marking, classifies and rates degree of protection provided against intrusions like dust, hands and fingers, accidental contact, and water. The standard aims to provide more detailed information than vague terms such as *waterproof*. For example, a cell phone rated at IP58 is dust resistant and can be immersed in 1.5 meters of freshwater for up to 30 mins. Another example is IP22, which is the typical minimal requirement for electrical outlets. This means the openings are too small for a finger to be inserted and it protects against vertically dripping water.

Depending on where the design solution is placed, the designer must consider how much water and solid interference is to be allowed. An example is a design that is intended to be outside for an extended period of time must be waterproof and at least dust resistant. However, if the design solution is going to be inside short term the amount of resistance to liquid and solids may be less important.

Number	Solids	Water
1	Protect against solid objects greater than 50mm such as a hand	Protected against vertically falling drops of water. Limited ingress permitted
2	Protected against a solid object greater than 12.5mm such as a finger	Protected against vertically falling drops of water with enclosure tilted up to 15 degrees form the vertical. Limited ingress permitted
3	Protect against a solid object greater than 2.5mm such as a screw driver	Protected against sprays of water up to 60 degrees from the vertical. Limited ingress permitted
4	Protected against a solid object greater than 1mm such as a wire	Protected from water splashes in all directions. Limited ingress permitted
5	Dust protected. Limited ingress of dust. Will not interfere with the operation of the equipment. Two to eight hours	Projected against jets of water. Limited ingress permitted
6	Dust tight. No ingress of dust. Two to eight hours	Water from heavy seas of water projected shall not enter the enclosure in harmful amounts
7	Not used for solids	Protected against the effects of immersion in water between 15mm and 1m for 15 minutes
8	Not used for solids	Protected against the effects of immersion in water under pressure for extended periods of time

Table 3: IP Standards

- **MIL-STD-810**

This is a U.S. Military standard that emphasizes tailoring an equipment's design and test limits to the conditions that it will experience throughout its service life, and establishing chamber test methods that replicate the effects of environments on the equipment rather than the environments themselves. Although prepared specifically for military applications, the standard is often used for commercial products as well. Depending on the length of storage or deployment this standard should be used accordingly.

The standard's guidance and test methods are intended to:

- define environmental stress sequences, durations, and levels of equipment life cycles

- be used to develop analysis and test criteria tailored to the equipment and its environmental life cycle

- evaluate equipment's performance when exposed to a life cycle of environmental stress

- identify deficiencies, shortcomings, and defects in equipment design, materials, manufacturing process, packaging techniques, and maintenance methods

- demonstrate compliance with contractual requirements

2.3.5 Power

If there is no available power source one must be provided. The designer should make sure to determine the electrical load of the design so that the chosen power source is large enough to fully power everything needed.

To figure out the power needed for a design, the designer should add up all the electric draw from the different equipment used in the design.

Type of power	Pros	Cons
Solar	Self-generating power Low maintenance No noise	Only works while sun is shinning Must be paired with battery backup to capture excess power to be used at night
Wind	Self-generating power Quiet	Only works while wind is blowing Is mechanically complicated and may require maintenance Must be placed on a mast or some high place to capture as much wind as possible Must be paired with battery to capture excess power to be used when wind is not blowing
Generator	Easy set up Constant power generation	Requires fuel source Requires regular maintenance to keep functioning Can be loud when running
Batteries	Can be recharged by any power source No noise	Short term operation Reliant on a form of recharging to continue operation beyond short term Depending on type and size of battery can be hard to lift or move

Table 4: Pros and Cons of Power Sources

2.3.5.1 Solar Panels

Solar panels consist of Photovoltaic (PV) cells that are arranged side by side and are connected to one another to create panels. When the panels are struck by sunlight they generate a direct current (DC) electric charge. If the other components use alternating current (AC) for power than an inverter must be used to convert the DC produced by the solar panels to AC that can be used the other equipment. One of the limitations of solar panels are that they only generate power while the sun is shining. The maximum efficiency for PV panels is about 20%. That efficiency drops as the amount of direct sunlight is reduced as on a cloudy day or if the panels are shaded.

Solar is a good option for remote or sites that are hard to get to. To effectively generate power the panels must be able to be adjusted, unshaded, and have to point due south in the northern hemisphere and due north in the southern hemisphere. For optimum power generation, solar panels must be adjusted each season. To determine the best angle for the winter months, take the latitude, multiply by 0.9, and add 29 degrees. To determine the best angle for the summer months, take the latitude, multiply by 0.9, and subtract 23.5 degrees. For the best tilt in the fall and spring subtract 2.5 degrees form the latitude.

- **Sizing Solar System**

  Based on the amount of electricity the design needs, a solar panel or number of solar panels must be used that will fulfill the power requirements.

Solar panels vary in size from manufacturer to manufacturer and depending on how much power they need to generate. Some of the most common sizes are listed below.

100watts 26”x40” 18lbs 18volts 5.56amps

180watts 26”x58” 26.5lbs 19.5volts 9.24amps

265watts 39”x65” 40lbs 30.96volts 8.56amps

- **Peak Solar Map**

Peak Solar refers specifically to how much solar energy is available in an area during a typical day. A peak sun-hour is an hour in which the suns intensity is 1,000 watts per square meter. Peak solar radiation occurs at solar noon, when the sun is the highest in the sky. The intensity of the sun varies based on the season and geography. Solar energy is more intense near the equator because it is closer to the sun (Baker, 2016).

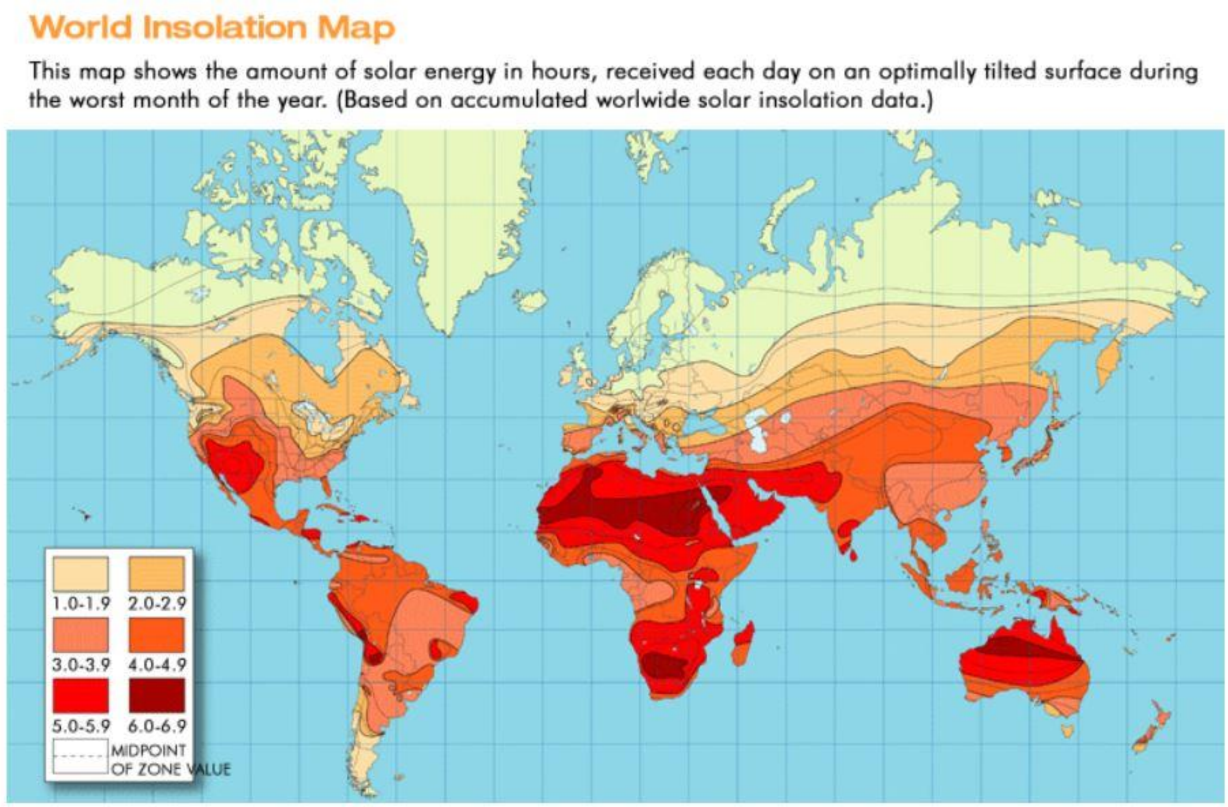


Figure 6: Peak Solar Map

2.3.5.2 Wind

Wind power uses the flow of air through wind turbines to mechanically power generators to produce electric power. Wind power gives variable power and may be less useful in some areas rather than others because it is only generating power while the wind is blowing. In many cases wind power is used to augment or accompany another form of power generation.

Modern wind turbines fall into two groups:

1) horizontal-axis wind turbines are the more traditional kind of wind turbine. They are used in the majority of the wind industry due to its ability to produce more energy from a given amount of wind. They are, however, heavier and are not necessarily the best choice for use in smaller scale power generation scenarios. Another disadvantage of a horizontal wind turbine is that they do not produce well in turbulent winds.

2) vertical-axis wind turbines have its axis perpendicular to the ground. This kind of turbine is used primarily in small wind projects and residential applications. These turbines are able to generate wind coming from any direction and some turbines are even powered when the wind blows straight up or straight down. Because of this versatility, vertical axis turbines are ideal for installations where wind conditions are not consistent or due to installation restrictions the turbine cannot be placed high enough to benefit from steady winds.

2.3.5.3 Generator

A generator is a device that converts mechanical energy into electric energy. The most common type of generator runs off gasoline but there are generators that run off propane, natural gas, and diesel. In a disaster situation ensuring there is enough available fuel may be difficult. If there is no available fuel, a person should bring a supply to keep your generator running. Generators range in size from smaller more portable generators that weigh about 50 pounds up to generators that are carried on trucks.

- **Portable**

Portable generators are commonly used to power a small appliance or two for a short term. Depending on the size and energy output gas generators can be different sizes and weights. Because this kind of generator is powered by an internal combustion engine it must be fueled and to prevent carbon monoxide poisoning it must be run outside and away from any open doors and windows.

- **Stand-by**

Stand-by generators are larger than portable generators and are installed to be a backup if the power goes out. These generators usually run on propane or natural gas and automatically come on when a loss in power is detected.

2.3.5.4 Rechargeable Batteries

A rechargeable battery can be charged, discharged, and recharged many times. These batteries are composed of one or more electrochemical cells. They are produced in a number of shapes and sizes. Several different combinations of electrode materials and electrolytes are used, including lead-acid, nickel-metal hydride (NiMH), lithium-ion (Li-ion), and lithium-ion polymer (Li-ion polymer).

Standalone battery systems are to be used for very short-term deployment. Batteries can be charged and operated independent of other power sources. However, without recharging them their power generation is limited. A larger battery or assembly of batteries can be used to store charges from power sources, i.e. solar or wind power.

- **Lead-acid**

  Lead-acid batteries are the oldest type of rechargeable battery. It has a very low energy-to-weight and a low energy-to-volume ratio, but it has a relatively large power-to-weight ratio. These batteries can supply high surge currents, which make them useful for use in automobile engines. Standard car batteries weigh 40-60 pounds and produces a 12-volt DC charge. These batteries can be reconfigured to give greater or lesser electrical load.

- **Nickel-Metal Hydride (NiMH)**

  Nickel-Metal Hydride batteries use a nickel oxide hydroxide positive electrode and a hydrogen-absorbing alloy for the negative electrode. A NiMH battery can have two to three times the capacity of an equivalent size nickel-cadmium (NiCd) battery, and its energy density can approach that of a lithium-ion battery. These batteries are often used in digital cameras, hybrid batteries, and other high-drain devices.

- **Lithium-ion (Li-ion)**

  Lithium-ion batteries generate a charge by moving lithium ions from the negative electrode to the positive electrode and back when charging. These batteries have a high energy density, tiny memory effect, and low self-discharge. They are also relatively light weight compared to lead-acid batteries. These batteries are commonly used in home electronics, portable electronics, electric vehicles, and are used in military and aerospace applications. These batteries can be very expensive depending on size and configuration.

- **Lithium-ion Polymer (Li-ion polymer)**

  Lithium-ion polymer batteries use lithium-ion technology but use a polymer electrode instead of a liquid one that is in standard lithium-ion batteries. These batteries provide a higher specific energy than other types of lithium-batteries. They are used in applications where weight is a critical factor like tablet computers, cellular telephones, or radio-controlled aircraft.

2.3.5.5 Device Charging

In a power outage, keeping ones' devices charged becomes a paramount concern. Any design solution that is responding to this condition must include some sort of device charging.

Device	Electric Draw	Watts
Cell phone	1.2 Amps @ 5 Volts	6
Tablet	2 Amps @ 5 Volts	10
Laptop	3 Amps @ 10 Volts	30

Table 5: Device Power Draw

2.3.6 Communication

2.3.6.1 Type of Internet Connections

- **Local area network (LAN) Connection**

LAN connection is the standard terrestrial connection for accessing the internet. This requires either a computer terminal to be physically connected by using an ethernet cable or wirelessly connected to a local network of other computers or to a router that connects to the internet.

- **Broadband Global Area Network (BGAN) Connection**

BGAN is a global network that uses portable terminals to connect with satellites in geostationary orbit. Terminals are normally used to connect a laptop to broadband internet in remoter locations, although if line-of-site to the satellite exists the terminal can be used anywhere on the planet. The BGAN network is comprised of three geostationary satellites that are owned by the Inmarsat company. This form of satellite connection uses smaller terminals (about the size of a laptop) as well as larger dishes to connect to their satellites.

- **Satellite Internet**

Satellite provided internet has been available since 2004. There are a few companies in the U.S. that provide this service. It is only until recently that download and upload speeds have become fast enough to rival terrestrial broadband internet. The system relies on satellites in geosynchronous orbit to bounce a signal from a dish on the ground to a relay station in another location on the earth. This takes a few seconds, which can make this kind of connection lag somewhat in comparison to non-satellite based internet connections.

2.3.6.2 Type of Networks

- **Wireless Mesh Network**

Wireless mesh network is a fully connected network where each node is connected to all the other nodes on the network. This network has a fixed topology and relatively slow or infrequent mobility making it less likely to encounter breaking of links with devices.

- **Ad Hoc Network**

An ad hoc network is best used for quickly establishing a network “on-the-fly”. Because the network is decentralized it can be hard to manage and maintain connection from node to node. The strength of an ad hoc network is it can use any number of devices that have the ability to connect to one another.

Mobile ad hoc networks (MANETs) is a continuously self-configuring, self-organizing, infrastructure-less network of mobile devices connected wirelessly. It is sometimes known as “on-the-fly” networks or “spontaneous networks”.

Smart phone ad hoc network (SPANs) uses existing hardware (primarily Wi-Fi and Bluetooth) and software (protocols) in commercially available smartphones to create peer-to-peer networks without relying on cellular carrier networks, wireless access points, or traditional network infrastructure. Apples iPhone 7 iOS and higher have been enabled with multi-peer ad hoc mesh networking capability.

2.3.6.3 Type of Wireless Communication

- **Wi-Fi**

Wi-Fi antennas can cover a wide range depending on their size and power. The best way to figure out how much area needs to be covered is to draw on a map of the area to help understand what distances need to be covered and how large of an area it truly is. Also, the higher a Wi-Fi antenna is the better the reception

Wi-Fi wireless networking works by sending radio transmissions on specific frequencies to other listening devices that can receive them. The connection range of a Wi-Fi antenna or device depends on its power gain. A numeric quantity measured in relative decibels (dB), gain represents the maximum effectiveness of an antenna compared to a standard reference antenna. Antennas are rated on their dBi (decibels relative to an ideal reference antenna) gain to communicate their power and range. Higher dBi indicate an antenna capable of working at higher levels of power, which usually results in greater range. Also, the higher the dBi gain of an antenna the more focused it is. Thus, making less focused antennas having lower dBi gain and consequently shorter range.

Omni directional antennas

Omni directional antennas broadcast Wi-Fi signal in a 360-degree radius. These antennas are ideal for providing multiple connections but can have limited range. They are ideal for mesh networking or providing an access point to connect to the internet.

A drawback of the higher powered omni-directional antenna is the higher the power the flatter the coverage bubble. So, if using a higher gain antenna, there may be little to no reception close to the antenna. In this case, a secondary antenna should be used to maintain Wi-Fi connection.

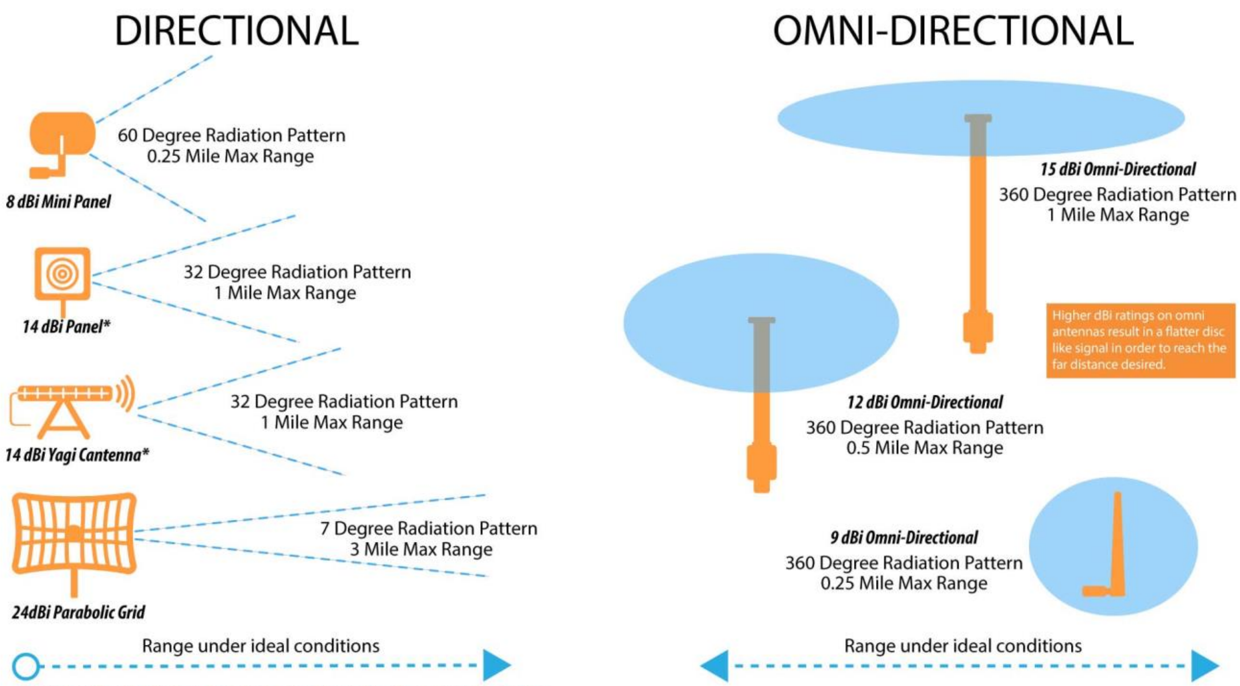


Figure 7: Types of Wi-Fi Antennas

Directional antennas

Directional antennas are typically used to extend the range of a Wi-Fi network into hard to reach corners of buildings or other specific situations where 360-degree coverage is not needed.

With directional antennas the longer the range the narrower the signal beam. So if trying to transmit a Wi-Fi signal a long distance it must be precisely aligned to ensure that a good connection is transmitted to the area wanted.

- **Cellular**

When a person makes a phone call, a signal is sent from the phone's antenna to the nearest base station antenna. The base station responds to this signal by assigning it an available radiofrequency channel. RF waves transfer the voice information to the base station. The voice signals are then sent to a switching center, which transfers the call to its destination. Voice signals are then relayed back and forth during the call.

Each connection, or conversation, requires its own dedicated frequency, and the total number of available frequencies is about 1,000. To support more than 1,000 simultaneous conversations, cellular systems allocate a set number of frequencies for each cell. Two cells can use the same frequency for different conversations so long as the cells are not adjacent to each other (Beal, n.d.).

- **Ham (Amateur) Radio**

All Amateur Radio operators have a basic knowledge of radio technology, operating principles, and pass a Federal Communications Commission (FCC) examination to be licensed to operate on the Amateur Band radio frequencies (ARRL, n.d.). They operate frequencies above the AM radio band to the microwave region. These bands are often referred to as short-wave bands. These short-wave signals can be bounced off the ionosphere to reach great distances for transmission.

- **Bluetooth**

Bluetooth is a low-power wireless connectivity technology that is used to broadcast between devices. There are two kinds of Bluetooth technology: Basic Rate/Enhanced Data Rate (BR/EDR) and Low Energy (LE). Bluetooth BR/EDR is a continuous point-to-point wireless connection that enables devices to talk to one another, used mostly for wireless speakers, headsets, and hands-free-in-car radio. Bluetooth LE enables short-burst wireless connections and uses multiple network topologies, including point-to-point, broadcast, and mesh.

Bluetooth has three device classes that are delineated by transmitting power and range. Class two is mostly used in cell phones and other small electronic devices.

Device Class	Transmit Power	Intended Range
Class 3	1 mW	~ 3 ft
Class 2	2.5 mW	~ 33 ft
Class 1	100 mW	~ 328 ft

Table 6: Bluetooth Range

- **Citizens Band (CB) Radio**

CB radio does not require a license to operate and can be used for business or personal communications. It is a simplex device that can communicate with other radios on the same frequency, allowing only one person to talk at a time. A CB transmitter can cover about 5 miles using a 5-watt transmitter. A CB radio has 40 channels that it can transmit through.

2.3.6.4 Types of Wireless Coverage Area

Each type of wireless communication has a given coverage area based on antenna size, power, and radio frequency. Presented below is a general figure to show how the different communication ranges relate to one another.

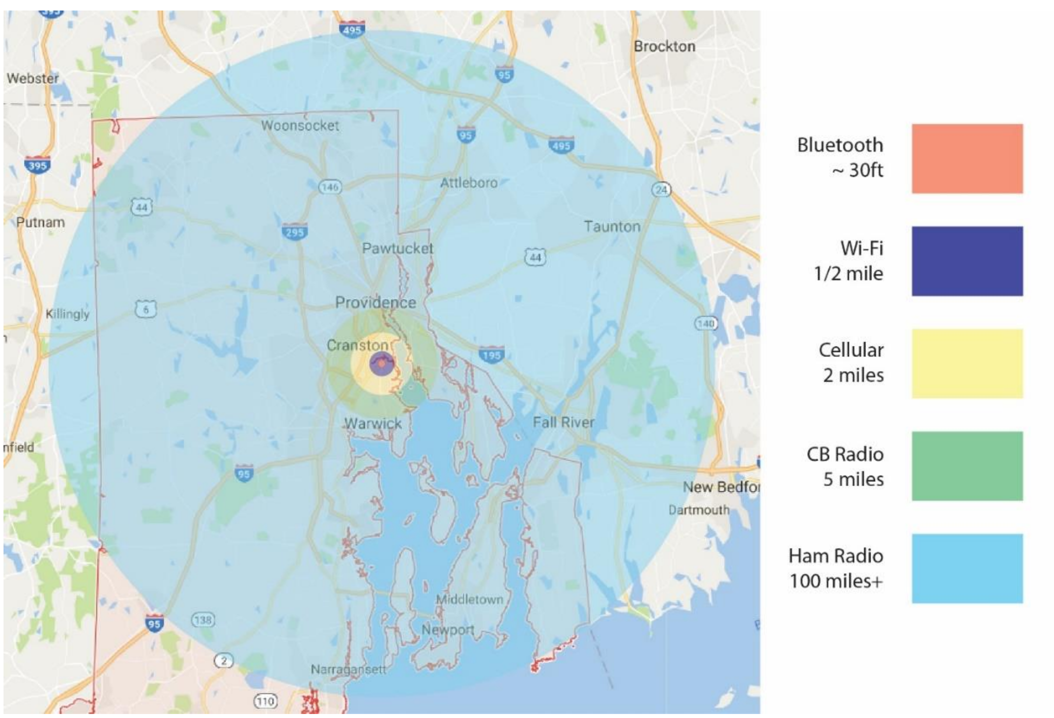


Figure 8: Coverage Area of Different Wireless Communications

Chapter 3: Design Guideline

3.1 Introduction

Designing a solution for establishing communication following a disaster contains many variables and technical components. In this chapter to assist in the creation of a design solution, a simple design process will be outlined that the design guideline will fit into. The guideline which is presented below will assist in decision making and help with creating a design solution.

3.2 Design Process

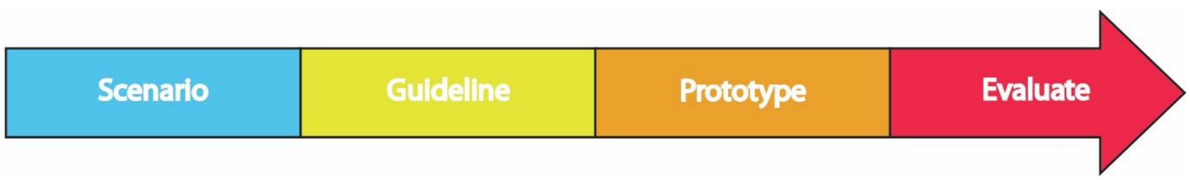


Figure 9: Design Process

Scenario

The specific type of disaster and place that the design solution will be in needs to be defined. These defined needs and goals become the inputs for the guideline. Every scenario is different and specific needs and conditions will vary from situation to situation. The more inputs from the scenario the more focused the design solution will be.

Staging the inputs as a series of questions makes for clearer, more understandable goals. The questions are based on the 5 w's of who, what, where, why, when, and how. The specific questions will be different for different scenarios but the general questions to ask are listed below.

Who may be installing or delivering the design solution?

Who are the intended users of the design solution?

What kind of disaster is the design solution responding to?

What might be a good choice for communication?

What would be a good choice for power generation?

Where is a good place for the design solution (inside/outside)?

What environment will the design solution be in?

How long is the design solution intended to be in use?

How might the design solution be installed?

How might the design solution be delivered?

Guideline

Once the inputs are defined and understood they can be entered into the guideline to assist in making the best choices for each problem that must be solved. By using the guideline presented below, important decisions will be identified and be assisted by referring to specific research presented in the previous section.

Prototype

Prototyping can be conducted in many different ways. The creation of a prototype helps to understand what the output of the design guideline is, and it will provide an object or solution that can be evaluated to see if it is an acceptable solution.

Evaluate

It is important to evaluate the design outcome. Sometimes it is discovered that the design outcome is lacking in some respect so that one will have to go back into the design process to identify what was missing in the initial design. By referring back to the inputs defined in the design scenario parameters can be set to judge whether the design solution is acceptable or if it succeeds at solving the problem.

Degrees of success/acceptability?

3.3 Design Guideline

A guideline is defined by Merriam-Webster as 1) a cord or rope to aid a passer over a difficult point or to permit retracing a course or 2) an indication or outline of policy or conduct. This guideline is closer to the second definition, but the image of a rope aiding in the passing of a difficult point is rather apt as well. This guideline has been established to help companies interested in creating communication solutions understand and organize all the components in designing different solutions to reestablishing communications following a disaster. The guideline is broken down into four major considerations with more detail and guidance in each section. This organization allows for an easier way to understand the inputs that are required to create an appropriate design solution.

Research

Before starting with the guideline, it is important to understand the background context that is being the design solution will be in. This could include the type of disaster that is common for a certain area, population data, etc. Each disaster has its own unique set of circumstances. Refer to literature on disasters in section 2.2 to collect pertinent information about the specific disaster that the design solution is intended to address.

An example of how this research information could be used is in tornadoes and hurricanes high winds can mean that structures and vertical structures will most likely be blown over or destroyed limiting the amount of high places to put antennas or satellite dishes.

Disaster management cycle

To help in understanding what problems the design needs to solve it is good to reference the disaster management cycle to determine what phase the design will be responding to. While response and recovery are crucial phases to address, the most robust solution will also take into account aspects of the mitigation and preparation phases.

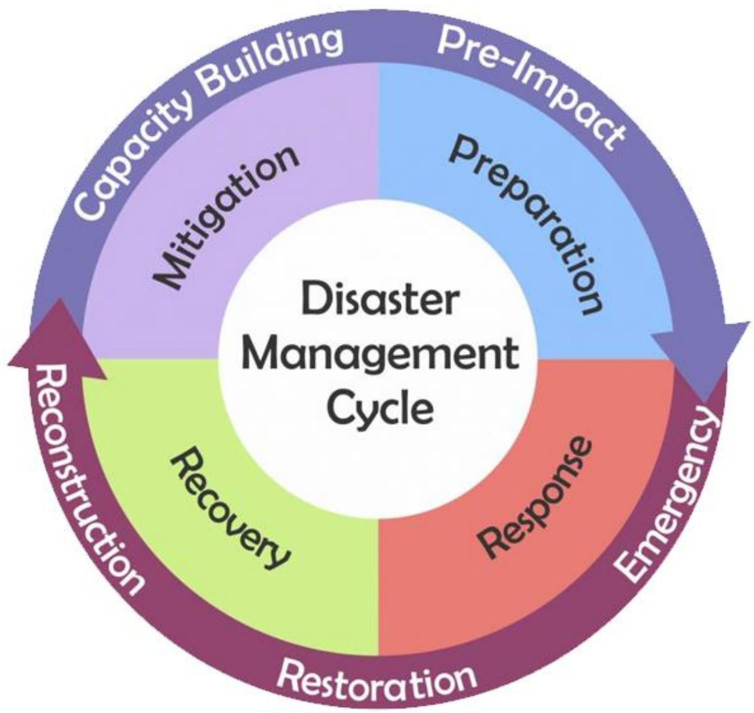


Figure 10: Disaster Management Cycle (2016)

The cycle is broken down into four main phases:

Mitigation – measures that prevent or reduce impact of disaster

Preparation – planning, training, and educating for things that cannot be mitigated

Response – taking care of what needs to be directly after disaster

Recovery – getting everything back to normal

3.3.1 Transportation

Whatever the design solution is, it will need to be transported to site. To get an idea of how the design will be delivered, it is good to know what kind of transportation will be used. There are a few factors that go into making the decision about what the best way to transport the design solution will be. Factors to consider are where does the design solution need to be delivered to and how accessible is that location. Who will be delivering and installing the design solution. The table below presents some of the pros and cons associated with the different forms of transportation.

Type	Pros	Cons
By hand	Can get to extremely remote locations	Slowest form of transport and requires to be carried by person, limited by the weight a person can carry
Light truck	Best for local, short distance, easy to come by	Small payload, can only get to areas reachable by roads
Heavy truck	Best for middle to long distance	Must have loading dock or platform to load/unload May require moving equipment

Table 7: Pros and Cons of Different Transportation Types

Implications:

By hand: This form of transportation may be the only way to get a device to a remote location. If roads are blocked or destroyed this may be the only way to deliver a device. If this method of transportation is used weight must be minimized and handles or straps must be added to allow of easier carrying.

Light truck: Many people have pickup trucks. In a disaster scenario this form of transportation may be easier to come by. This is a good option for moving items quickly over short distances. If this mode of transport is used, make sure that the design solution fits in the truck bed and can be loaded and unloaded by hand. This may require disassembly and reassembly of the design solution.

Heavy truck: This method is great for moving larger items that cannot fit on smaller modes of transport. Items can be stacked for more efficient packing and transport. These vehicles require licensed commercial drivers to operate which can limit the availability of these vehicles during a disaster.

3.3.2 Communication

Reestablishing or even establishing communication to areas hit by a disaster is a crucial goal of the design. To design an effective solution there are some decisions that must be made related to communication. Who needs to communicate? Who are they communicating with, other victims, relief workers, people outside of the affected area? What kind of information will be exchanged? To determine which kind of wireless communication is appropriate for a given scenario factors like the environment on the ground (forested, mountainous, etc.), number of people that need access, what kind of devices or technology is already on the ground, and what are some of the challenges of establishing the different forms of communication must be taken into consideration.

Use the table and implications below to help inform the decision about what forms of communication are best for the design solution.

Type	Coverage distance	Pros	Cons
Bluetooth	3-300 ft	Low power from device	Short range Not compatible with all devices
Wi-Fi	½-1 mile	Connects smartphones, computers, tablets	Not accessible to just cell phones Needs power and routers to enable communication
Cellular	2 miles	Connects all cell phones	Phones can only operate on their own specific networks Transmission towers need power to operate
CB	5 miles	Needs no established network	No connection to internet Voice only
Ham Radio	100+ miles	Needs no established network	No connection to internet Voice only Requires Licensed operator

Table 8: Pros and Cons of Different Wireless Connections

Implications:

Bluetooth: Is a great low power solution to connect devices but requires each device to have Bluetooth capability. It is a very short distance kind of communication, so it requires the device to be in close proximity to the broadcasting source. Bluetooth is used to transmit data between devices.

Wi-Fi: This form of communication requires a network to connect devices together. This connection can stand alone as a way to pass information between devices. If a connection to the internet is desired, then it must be provided by a ground link to the internet infrastructure or a satellite link if no ground link is available. This form of communication is great for allowing direct data transfer between computers and hand-held devices. It can also be networked wirelessly to cover a large area. A Wi-Fi signal is a broadcast at 2.4 of 5 MHz higher frequency making it ideal for applications that are closer to the ground (0-30 ft.) where it may encounter interference from buildings and trees. Newer cell phones can make voice calls using just a Wi-Fi connection. Voice over Internet Protocol (VoIP) uses a Wi-Fi connection to make and receive phone calls like a traditional landline phone.

There are two types of antennas that are used in Wi-Fi applications. They can be used independently or together depending on the requirements of the broadcast area. The two types to be considered are:

- Omni directional: Are antennas that broadcast a signal in all directions. The more powerful the antenna the less reception is available close to it. That means that if someone is standing directly under a higher-powered antenna they may have no reception. In this case a smaller secondary antenna would need to be added.
- Directional: Are antennas that broadcast a signal in a single direction. These antennas are great for sending a signal long distance. The more powerful the antenna the narrower the width of the signal is so great care must be taken in focusing the antenna to where you want the signal to go.

Cellular: Many people have cell phones. This option is great for connecting people that need to communicate over voice, text, or need to send images. Cellular networks require power and antennas to communicate. There is a limit to the amount of cellular phone calls that can occur simultaneously in a certain area. All the communication between devices is handled locally on the network but for remote calling outside of the network a satellite link must be used. A Cellular signal is broadcast at 800-900 MHz which enables the signal to travel farther than Wi-Fi, but the lower frequency makes it more susceptible to interference the closer it is to the ground. The ideal height for a Cellular antenna is 50-200 ft.

CB: Citizen Band radio is a one-way communication device. This form of communication transmits voice only between people. The person one end cannot talk until the person on the other end has finished. This form of communication does not need an independent network because the device itself broadcasts and receives radio signals. This form of communication allows people to connect with one another in a quicker more informal way.

Ham Radio: This form of communication can be broadcast great distances, depending on the size of the antenna, but it does require a FCC licensed operator. Ham radio supports voice communication only. While it does not require an outside network, it is reliant on the operator to transmit and understand the information that is being passed back and forth.

The figure below is a visualization of the range of different kinds of wireless communication laid over one another.

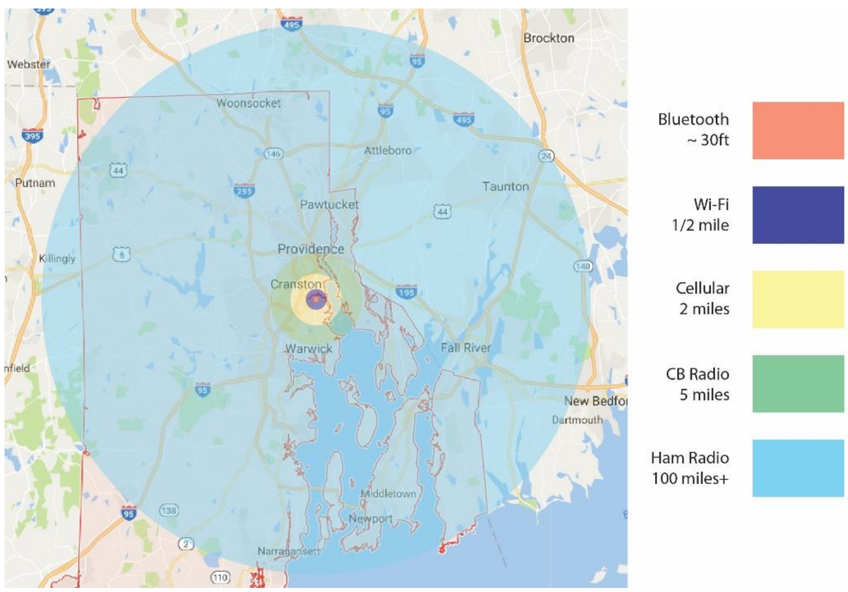


Figure 11: Coverage Area of Different Wireless Communications

3.3.3 Power

Power is crucial to run any kind of communication technology or device that is designed. Power generation is often disrupted following a disaster and is crucial to reestablish as soon as possible. If there is no power some sort of electricity generation must be provided. There are a number of ways to generate and store power but choosing the appropriate way of making that power can be difficult. Some of the factors to consider in choosing a power source are the environment the design solution will be in. Is it sunny, rainy, how far off the road is it, how easy will it be to transport fuel? These are all important questions to consider.

Refer to the table to weigh the pros and cons of each type of power generation.

Type of power	Pros	Cons
Solar	Low maintenance No noise Sun is free	Only works while sun is shinning Must be paired with battery backup to capture excess power to be used at night
Wind	Wind is free Relatively quiet	Only works while wind is blowing Is mechanically complicated and may require maintenance Must be placed on a mast or some high place to capture as much wind as possible Must be paired with battery to capture excess power to be used when wind is not blowing
Generator	Easy set up Constant power generation	Requires fuel source Requires regular maintenance to keep functioning Can be loud when running Produces exhaust that needs to be vented outside
Batteries	Can be recharged by any power source No noise	Short term operation Reliant on a form of power to recharge to continue operation beyond short term Depending on type and size of battery can be hard to lift or move

Table 9: Pros and Cons of Different Power Sources

Also take into account for device charging. If the power grid has failed, people will need a reliable way to charge their devices. Depending on the kind and number of devices that will be charged different amounts of power will be needed. Use the chart below to get an idea of how much power is needed for each device.

Device	Electric Draw	Watts
Cell phone	1.2 Amps @ 5 Volts	6
Tablet	2 Amps @ 5 Volts	10
Laptop	3 Amps @ 10 Volts	30

Table 10: Device Power Draw

For device charging laptops take the most power to charge. In comparison it takes five times the power to charge a laptop than to charge a cell phone and three time as much power to charge a laptop than a tablet computer. If less power is available cell phone or tablet charging should be supported over laptop charging.

Implications:

Solar: The sun is not always shinning. Even cloudy days can greatly diminish the power output of solar panels. The angle the panels are set to the sun affects the efficiency of the solar panels. The ideal angle to the sun varies depending where you are but for the northern hemisphere all solar panels need to be oriented to the south. Solar is a better option the closer to the equator because the change in daylight is less from spring to winter. To determine if solar is a good option refer to the map below. The less solar hours a day, the less power will be created. Areas with a small amount of solar energy should consider a different form of power generation.

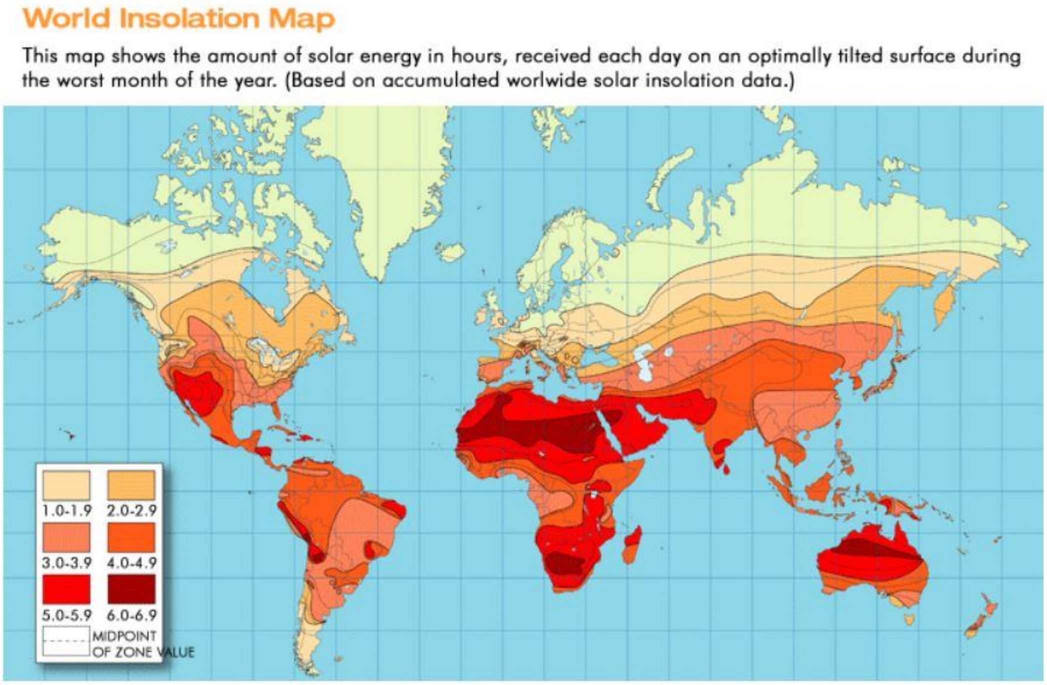


Figure 12: Peak Solar Map

Wind: The wind is not always blowing. For wind power to be usable a suitable location must be established. This is usually on the tops of tall buildings or the turbine can be placed on top of a mast to capture as much wind as possible. There are two kinds of wind turbines to consider. Both have their own advantages and disadvantages.

- Horizontal axis: is the more traditional kind of wind mill. It can generate more power but is larger and requires greater wind speeds to turn. This type needs large open spaces and is usually seated on tall towers
- Vertical axis: are smaller wind mills. They can generate power from wind with less speed but cannot produce power in high volume. They can also capture wind that is moving straight up or straight down making them ideal for instillation in urban areas. They are used primarily for generating smaller amount of power. They can be placed on building roofs or placed atop a pole.

Generator: They are great at producing sustained power no matter the weather outside. They do however make noise, produce exhaust fumes that needs to be dealt with, and need a constant fuel source. Also to be considered is the maintenance of the engine inside of the generator. It will need it's oil changed and other regular maintenance preformed from time to time which can cause down time when the generator is not producing any power. There are two types of generators to be considered:

- Portable: These types of generators are small, easy to move, and relatively cheap. They are best used when a small amount of power is need for keeping smaller devices running. They typically run on gasoline which will mean that they need to be refueled often or connected to a large fuel tank for longer operating time. They also produce noise and exhaust, so they must be placed outside at least 10 feet away from open doors and windows or be contained in their own housing that vents the exhaust to the outside.
- Standby: These types of generators are larger, expensive, fixed in place, and are wired into buildings subpanels to provide power automatically if power is interrupted. They are placed outside of buildings and run off of propane or natural gas so that constant refueling is not a concern.

Batteries: Batteries come in all shapes and sizes. Depending on the electrical load of the design the size and make up of the battery may vary. Three of the most common types of rechargeable batteries are:

- Lead acid: Have a large power to weight ratio and are best used when a large surge charge is needed. These types of batteries are commonly used in automobiles. These types of batteries have low energy density which allows them to keep a charge longer in a static state

- Nickel-Metal Hydride: Have a medium amount of energy density. These types of batteries are used in many devices that require recharging.
- Lithium-ion: These types of batteries have a high amount of energy density. They are light weight but can be expensive.

3.3.4 Environment

The environment plays a huge part in many of the decisions that have been made. For this section environment is thought of as where the design solution will be placed, for example is it indoors or outdoors? What are the extreme temperatures that the design will have to stand up to? The tables below outline some of the parameters that will need to be considered to create an appropriate design for a given environment.

		Area	Low Extreme	High Extreme
Non-operating and storage		All Area	-62^{0}C (-80^{0}F)	$+71^{0}$C ($+160^{0}$F)
Operating	Outdoor	Cold Weather	-54^{0}C (-65^{0+}F)	$+52^{0}$C ($+125^{0}$F)
		Desert and Tropical	0^{0}C ($+32^{0}$F)	$+71^{0}$C ($+160^{0}$F)
	Indoor	All Areas	0^{0}C ($+32^{0}$F)	$+52^{0}$C ($+125^{0}$F)

Table 11: MIL-STD-210

Placement	Pros	Cons
Indoor	Protected from the elements	Access may be limited Reliance on structure to be safe and dry
Outdoor	Allows unrestricted access	Must stand up to the elements Heat gain must be mitigated Cold temperatures must be insulated from

Table 12: Pros and Cons of Indoor and Outdoor Placement

Implications:

IP Standards: These standards are used to help to understand and communicate how much intrusion of solids or liquids should be allowed for a specific object. For devices placed outside the highest level of water resistance possible should be accounted for. If the device is placed inside water resistance is not as vital.

Number	Solids	Water
1	Protect against solid objects greater than 50mm such as a hand	Protected against vertically falling drops of water. Limited ingress permitted
2	Protected against a solid object greater than 12.5mm such as a finger	Protected against vertically falling drops of water with enclosure tilted up to 15 degrees form the vertical. Limited ingress permitted
3	Protect against a solid object greater than 2.5mm such as a screw driver	Protected against sprays of water up to 60 degrees from the vertical. Limited ingress permitted
4	Protected against a solid object greater than 1mm such as a wire	Protected from water splashes in all directions. Limited ingress permitted
5	Dust protected. Limited ingress of dust. Will not interfere with the operation of the equipment. Two to eight hours	Projected against jets of water. Limited ingress permitted
6	Dust tight. No ingress of dust. Two to eight hours	Water from heavy seas of water projected shall not enter the enclosure in harmful amounts
7		Protected against the effects of immersion in water between 15mm and 1m for 15 minutes
8		Protected against the effects of immersion in water under pressure for extended periods of time

Table 13: IP Standards

Outside: If a design solution is the be placed outside take into account the temperature range for the area it will be in. Electronics do not preform well in extreme heat or cold. For heat regulation fans and heatsinks should be used. Openings for fans will limit dust and water resistance. For extreme cold insulation or some sort of low level heating will need to be employed.

Inside: Objects that are placed indoors have less need for waterproofing and protection from extreme temperatures but will need extra protection from dust or other intrusions, especially if it will be sitting for an extended period of time.

3.4 Evaluate

Any design solution should be evaluated on how well it solves the problems that have been identified. For the purpose of this thesis the design solution will be judged on how successfully it addresses the specific inputs that were identified in the scenario.

By looking back to the initially defined inputs they can be brought in at the end to serve as the frame for the evaluation. For example, how many people will be covered by the design solution. Does that match the needs and expectations? If it does not how can the design be improved to meet the expectations? Are there other choices that could have been made in the guideline that would have been better suited for the design solution?

Chapter 4: Design Guideline Application

4.1 Introduction

Following the design process that was outlined in the previous chapter a scenario will be defined, the guideline will be used, a porotype will be produced, and it will be evaluated.

4.2 Scenario

A communication company wants to design a communication device that would be placed directly before or quickly after a hurricane. The focus for the design is the U.S. territories of Puerto Rico and the Virgin Islands. These islands present a unique challenge because moving materials to and from the islands can be expensive and time consuming. Due to the nature of the islands they are uniquely vulnerable to power and communication network failure if hit by a hurricane or other severe storm. Some of the specific questions related to this scenario are:

What type of disaster is the design intended to address?

Where would the design be constructed?

What environment could it be placed in?

Who might be installing or delivering the design solution?

How might the design solution be installed or delivered?

Who are the intended users of the design solution?

What could be a good choice for communication (network/no network)?

What would be a good choice for power generation?

Where is a good place for the design solution (inside/outside)?

How long is the design solution intended to be in use?

4.3 Design Guideline

4.3.1 Transportation

Where would the design be constructed?

Who might be installing or delivering the design solution?

How might the design solution be installed or delivered?

The design will be produced on the island, so it will not have to be moved long distances. To enable the design solution to be moved by the most types of transportation it will be able to fit in the back of a light truck. Based on the dimensions of an average light truck bed the components must be no longer than six feet or wider than five feet. Since it will be delivered by a light truck the components of the design must be no more than 51 pounds or required two people to lift them.

4.3.2 Communication

Who are the intended users of the design solution?

What could be a good choice for communication (network/no network)?

Emergency workers and victims of a disaster will need to communicate with one another. Another goal of the design solution is to support data transfer and access to the internet to allow information to be sent off the island. To connect the most amount of digital equipment establishing a Wi-Fi network is a good choice. To establish a Wi-Fi network a number of transmission points must be established to cover a wide area. Maximum coverage of a single Wi-Fi antenna is a half mile under ideal conditions. While cell phones are prevalent not all phones will be able to access the Wi-Fi network. Because of this to allow the greatest amount of access some accommodation should be made in the design to allow people to use the Wi-Fi without a device.

4.3.3 Power

What would be a good choice for power generation?

How long is the design solution intended to be in use?

For this scenario the power network is completely destroyed. Some sort of power generation must be established. Because the design will be in the Caribbean solar is a great option. From the Peak Solar map, the average peak sun hours are 5.6, allowing for great solar power generation. To extend the power generation after sunset a battery bank will have to be added. With unavailable power device charging is a must. Part of the design must provide charging for cell phones. The average draw for a cell phone is 6 watts.

For the solar panel a 100-watt panel at an average 5.6 hours would produce 560 watts per day in ideal conditions. This amount of power will be enough to run all the systems and provide device charging.

4.3.4 Environment

What environment could it be placed in?

Where is a good place for the design solution (inside/outside)?

The Caribbean is a tropical environment, so the heat gain of electrical devices needs to be mitigated. The design will also be placed outdoors to allow for the greatest distance of transmission. Because it will be outside it must be waterproof and as dust resistant as possible. According to MIL-STD-210 the extreme temperatures that need to be endured by the design are 32^0-165^0.

4.4 Prototype

For the prototype the design was separated into to two separate elements. The first element allows for device charging and independent access to the Wi-Fi network and the second allows for the maximum transmission of the Wi-Fi network. By separating the design into two elements it allows each to be placed independent of one another and to be where they need to be to perform their relative function.

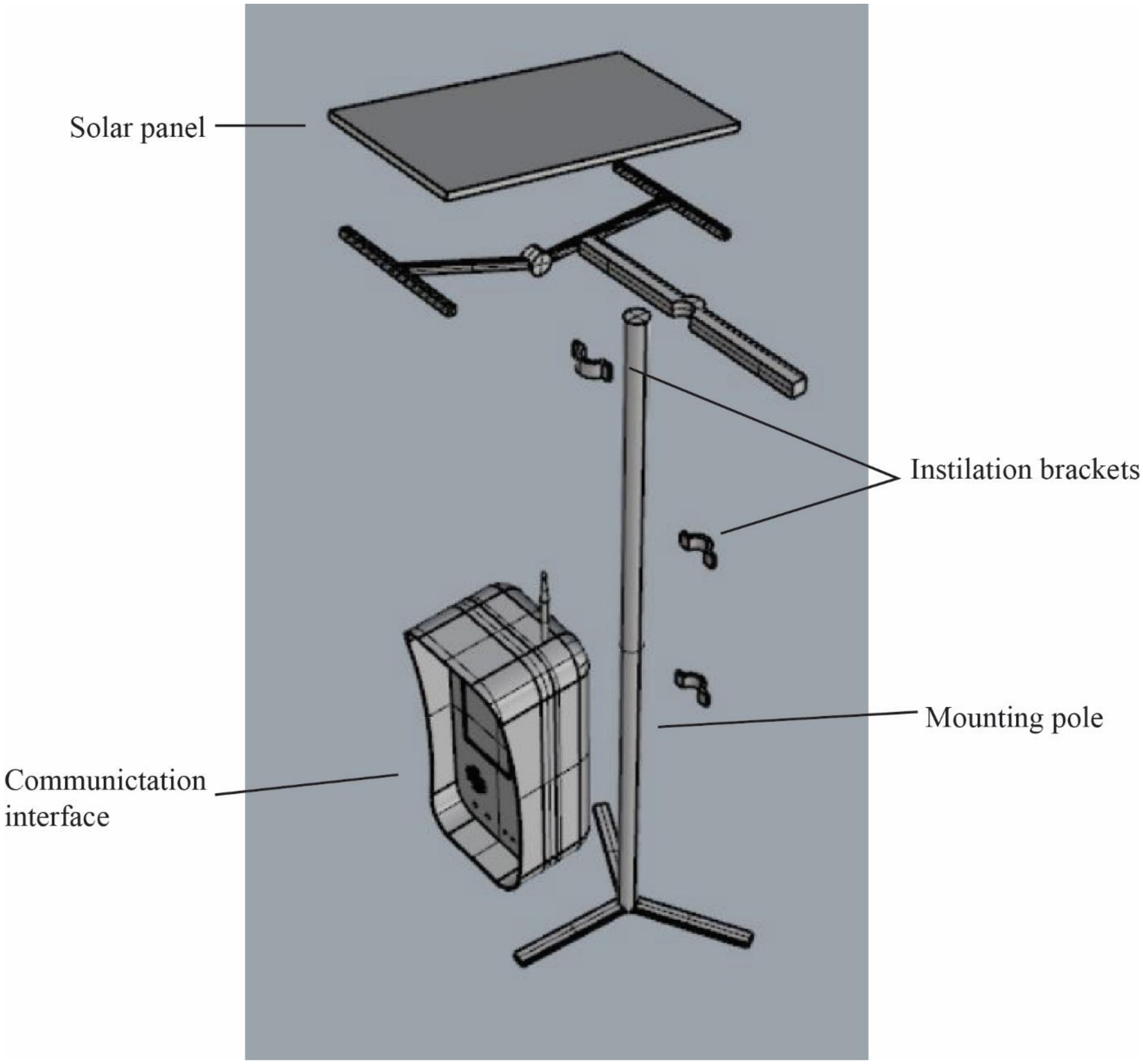


Figure 13: Prototype 1 Exploded

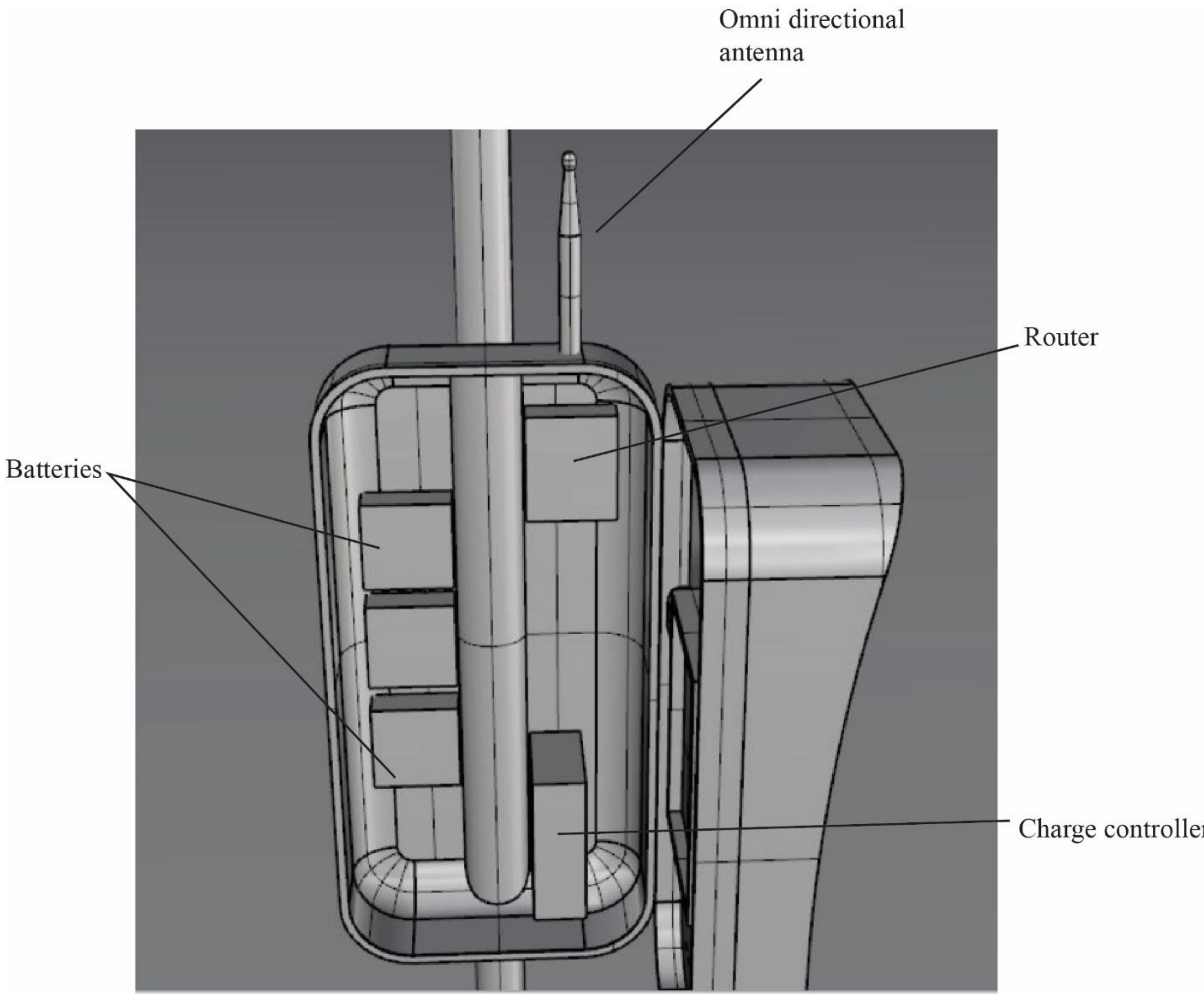


Figure 14: Prototype 1 Inside

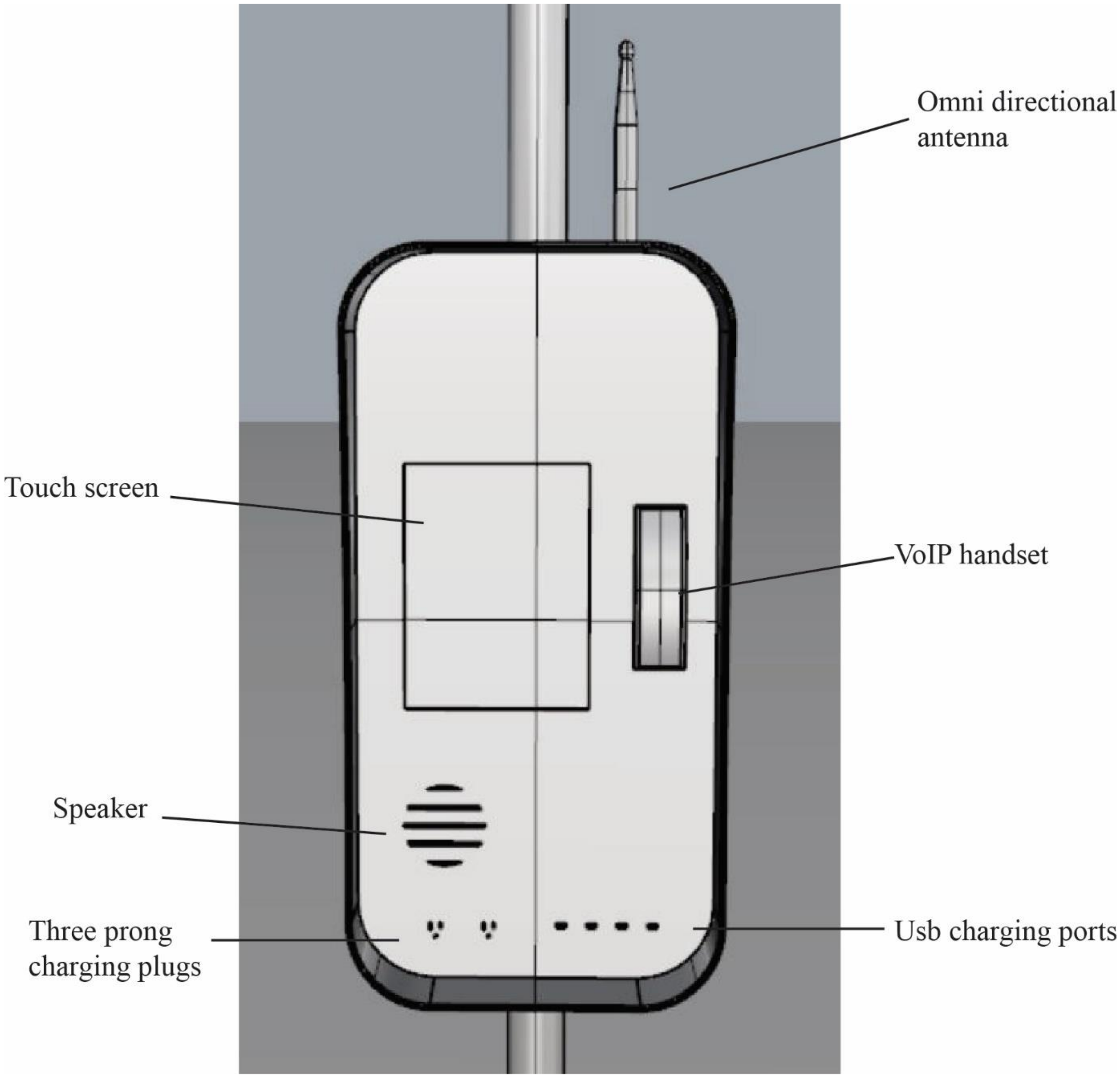


Figure 15: Prototype 1 Front

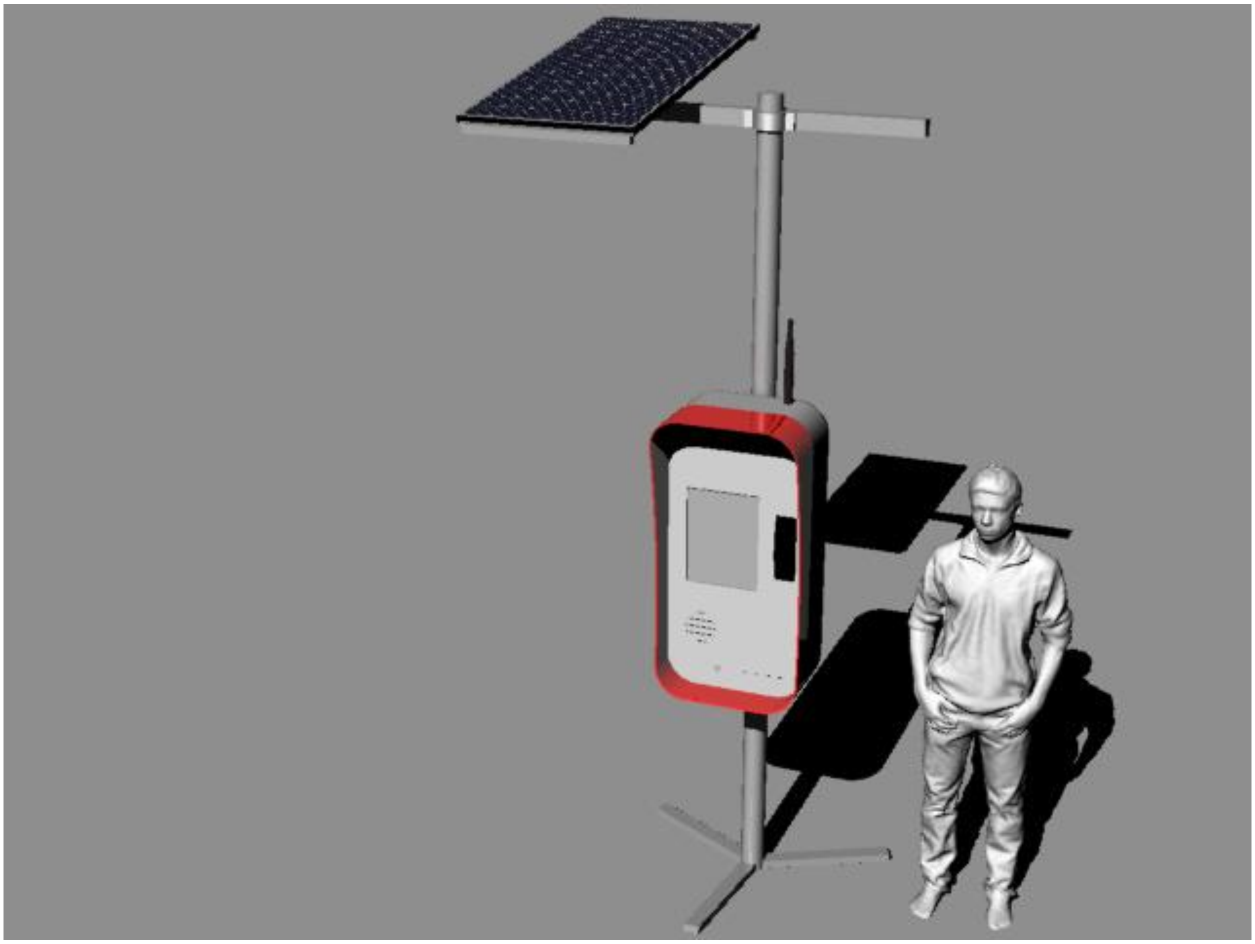


Figure 16: Prototype 1 Render 1

Figure 17: Prototype 1 Render 2

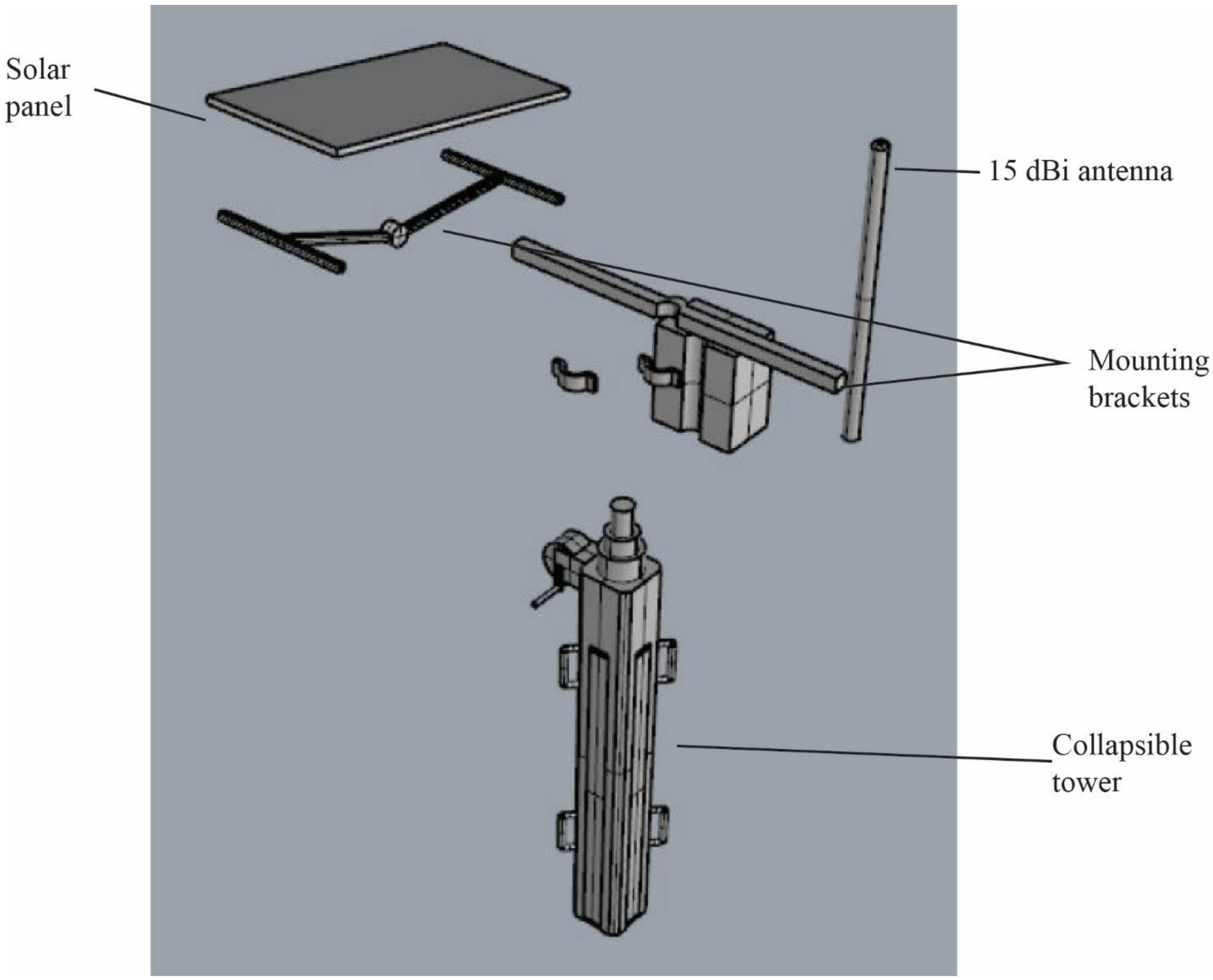


Figure 18: Prototype 2 Exploded

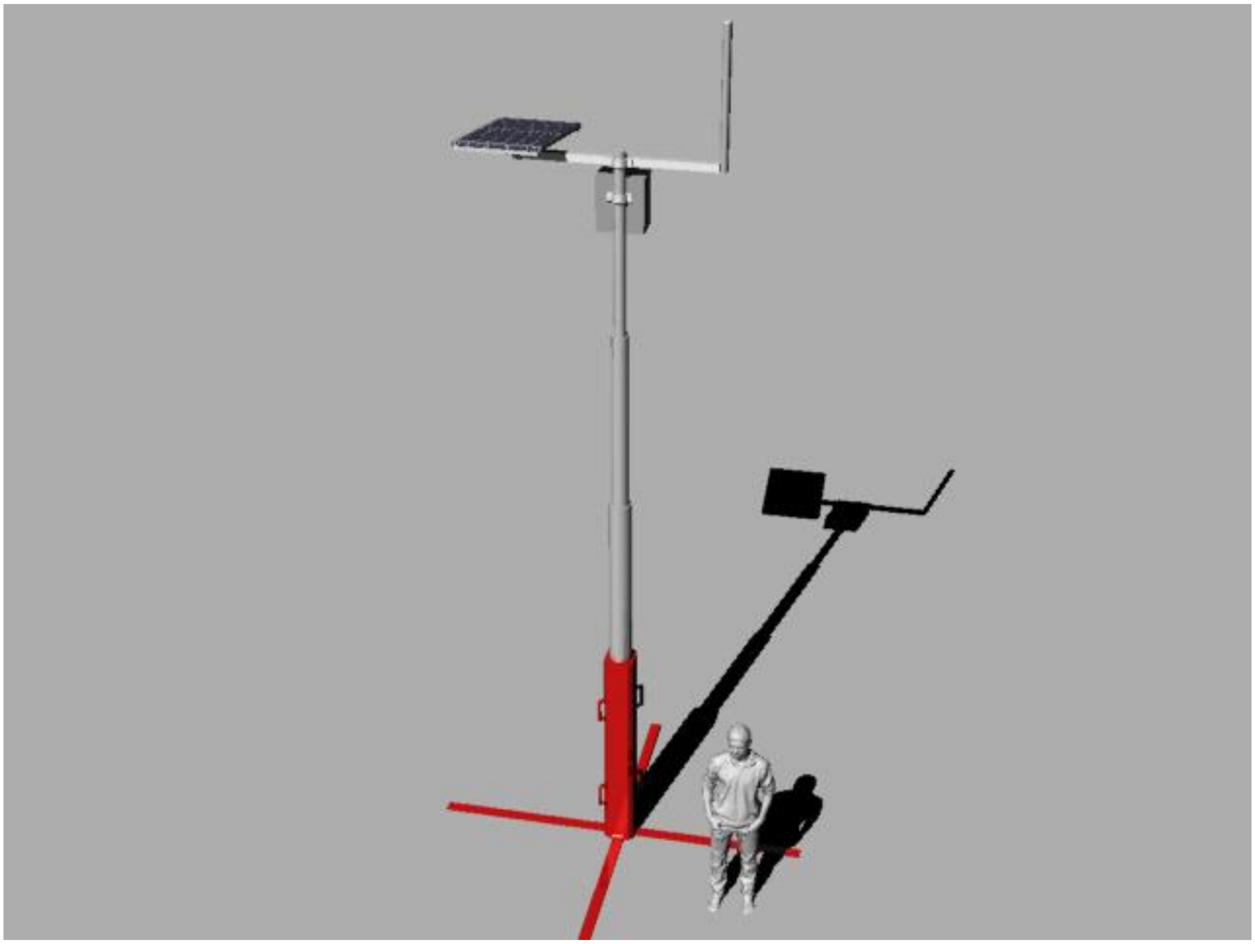


Figure 19: Prototype 2 Render

4.5 Evaluate

To evaluate how acceptable the design solution is it is helpful to look back to the questions that were asked in the scenario. By looking at these questions and how they were answered in the design will help in evaluating the design.

Where would the design be constructed?

Who might be installing or delivering the design solution?

How might the design solution be installed or delivered?

Who are the intended users of the design solution?

What could be a good choice for communication (network/no network)?

What would be a good choice for power generation?

How long is the design solution intended to be in use?

What environment could it be placed in?

Where is a good place for the design solution (inside/outside)?

By creating a design that has two parts the communication network will be more flexible and able to provide coverage for more people. This will also allow for easier transportation and delivery of the design elements to whatever sites they need to be placed at. This solution provides access to affected people in the community while also allowing emergency workers the ability to transmit data and other vital information to the outside world. Solar was chosen to be the power source for both design elements. However, it should be taken into account that while in ideal circumstances the panels would provide ample power larger batteries, or a small generator may have to be added where recharging demand is high or the panels under preform. With device charging available people will be able to keep their individual devices charged and usable. For those people without a personal device a VoIP handset is provided to enable access the network without having a personal device. Device charging will be a huge need of people that are living in areas without power for an extended period. By placing many the prototype 1's around a specific area device charging and access to the network will be addressed but it may not be enough. The addition of dedicated device charging stations may need to be established.

The design elements will be placed outside for an extended period of time. Due to this some of the parts are interchangeable between the two design elements making repair easier because less specific parts have to be on hand to make repairs. The designs will be placed outdoors to allow for the greatest transmission range of the Wi-Fi signal and to allow people the most access to device charging and independent access to the network. In a tropical environment heat and humidity is a factor. The design elements may need further cooling through the use of internal fans or some other method. They were left out of the prototype to maximize waterproofness and to prevent the intrusion of dust and other small objects. With testing it could be determined if some sort of cooling method would need to be employed.

In conclusion the design solution answers the questions that were presented in the scenario. While every question was addressed some may change over time or different solutions may arise that better address them. With all choices there are inherent tradeoffs but in this design solution the choices were made in an informed manner allowing for the benefits to outweigh the drawbacks. By developing a prototype, the effectiveness of the design solution can be established and better understood.

Chapter 5: Conclusions

In this thesis a guideline to assist in the development and design of communication was presented. With a foundation of research about specific disasters, background information about power generation, and communication technology, design solutions can be created to reduce the impact of disasters on the people and communities they strike. In a disaster scenario communication is often disrupted. This occurs because communication infrastructure is destroyed or the power to enable them to function has been disabled. Reestablishing communication between the victims and the emergency workers is not only important but can be a matter of life or death. By providing a design solution to address this communication disruption, rescues can be coordinated, maps can be updated, and help can get to where it is needed the most.

5.1 Opportunity for Future Study

To create more substantial design solutions better evaluation methods could be explored. With a more rigorous system, design solutions could be created that would potentially address problems and situations in a more through way.

Technology is always developing and changing. As different technology is developed in the future it will need to be incorporated into the research and guideline. By including this new information design solutions will be as relevant as possible.

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Appendix: Design Guideline Summary

Introduction

After a disaster has struck a populated area communication infrastructure is often disrupted or destroyed. Transmitting information to and from the affected area is not only important but it could be a matter of life and death. To address this problem a design solution can be created using the guideline below.

The audience for this design guideline are companies interested in designing solutions for specific disaster scenarios. These companies could be small tech companies, larger telecom companies, or a manufacturer of hardware that is interested in jumping into this area.

Research

Each disaster has its own unique set of circumstances. Refer to literature on disasters in section 2.2 to get an idea of what the specific disaster is and how it can affect communication.

Disaster management cycle

To help in understanding what problems the design needs to solve it is good to reference the disaster management cycle to determine what phase the design will be responding to. While response and recovery are crucial phases to address the most robust solution will also take into account aspects of the mitigation and preparation phases.

The cycle is broken down into four main phases:

Mitigation – measures that prevent or reduce impact of disaster

Preparation – planning, training, and educating for things that cannot be mitigated

Response – taking care of what needs to be directly after disaster

Recovery – getting everything back to normal

Transportation

How will the design be delivered?

How the design will be moved and transported will affect the design. If the design has to be moved by hand refer to the NIOSH lifting equation to determine safe weight of parts and pieces. Rule of thumb is nothing over 51 pounds should be lifted by an individual.

Types of transport

By hand – allows for a design to get to places that are inaccessible by vehicle. Handles and straps must be present to allow for easier carrying. The weight of the solution must be as light as possible

Light Truck – are relatively easy to access and anyone with a valid license can drive one. The smaller payload means that this vehicle can navigate narrower roads and passages but will limit the size that a design solution can be. This is a great option for short distances and moving items that are produced locally. Also with this mode of transport loading and unloading by hand is common so weight is also a concern.

Heavy Truck – are designed to move larger objects. This form of transport is limited by overhead height and width making some roads and bridges unpassable. A loading dock or some form of platform is needed to assist in the loading and unloading of the trailer. Machinery such as forklifts or pallet jacks may have to be used.

Communication

Who needs access to communication?

Victims of a disaster, rescue or aid workers, both. How many people will be covered. The more people that need to be covered the more access points will be needed.

Type of wireless communication needed

Wi-Fi – allows for many devices to talk to one another, smartphones, tablets, computers has a max range of ½ mile. Can be networked to cover large areas.

Cellular – can reach up to 2 miles depending on obstructions linking cell phones and other devices that have sim cards installed. Can be networked to cover large areas.

Bluetooth – short range communication that is primarily used to link to smartphones

CB – simplex communication method that uses voice handsets to talk to one another. Can reach about 5 miles.

Ham Radio – users need an FCC license to broadcast. Uses short wave radio to transmit voice over long distances.

Power

What kind of power generation is needed?

Solar – harnesses the power of the sun. On average only generates peak power for 4 hours during the day. If you want to have continuous power a battery bank must be used to provide power when the sun is not shinning. Setting up solar can be expensive initially but has the potential to be less labor intensive for up keep.

Battery – must be charged to operate. Can be used to power devices for short term. Size and kind of batteries differ depending on need of charge, weight, and usage. Batteries can heat up as they are charged and discharged so some form of venting of cooling must be employed.

Generator – many different kind and size of generators offer different power outputs. Generators can run on gas, diesel, natural gas. They can be noisy and need to be exhaust fumes outdoors. Because of noise and exhaust will need to be placed away from people or entrances.

Wind – harnesses the power of the wind. Needs to be put on a mast or an unobstructed space to catch the wind. Only works when the wind is blowing which is some areas may be unreliable. Must be attached to a battery bank to capture excess power generation. Can be married with solar to lengthen power generation after the sun sets.

Environment

Is the design inside or outside?

Refer to IP standards to determine how water and dust proof the design needs to be. If it is outside it should be as waterproof and dust proof as possible. If indoors the amount of water and dust resistance could be less.

What area will the design be in?

Refer to MIL-STD-210 to get an idea of the extreme temperatures that electronic equipment has to withstand to remain functional