# From Space to Ground Zero: The Application of Geographic Information Systems and Rocket Cargo Transportation to Disaster Management Operations

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## Abstract

This paper provides an overview of the application of space-based technologies, specifically Geographic Information Systems (GIS) technology and rocket cargo launches, to disaster management operations. GIS links data from satellites, remote sensing, and other sources to dashboards, allowing relief teams to monitor relevant demographic, environmental, and disaster details. This information supports multiple aspects of planning and decision-making in the preparedness, response, and relief stages of the disaster management cycle. Rocket cargo transportation, an emerging method of shipping supplies, will allow for supplies to be shipped anywhere in the world in under twenty-four hours. This can be used in a future disaster relief scenario through the delivery of supplies in a timely manner. Both GIS and rocket cargo transportation are applied to a hypothetical flooding scenario, demonstrating how these technologies are and would be applied to three of the four disaster management cycle phases.

# From Space to Ground Zero: The Application of Geographic Information Systems and Rocket Cargo Transportation to Disaster Management Operations

Disaster management presents a unique set of challenges to disaster relief organizations. Upon the onset of disasters, some of which have little to no warning, relief teams are expected to deploy both manpower and supplies to unfamiliar areas as quickly as possible, establishing and executing multiple different faucets of relief and recovery to help the inhabitants affected. These tasks include evacuation, the provision of medical care and supplies, and the establishment of shelters for the displaced residents. As every disaster presents its own unique challenges, planning, initiating, and executing effective disaster relief responses are persistent challenges for humanitarian aid organizations. Coupled with rapidly changing situations and the necessity to act quickly, organizing disaster relief efforts proves to be a difficult task. To offset this, relief teams rely on many different kinds of tools to maximize their effectiveness, most of which incorporate modern-day technology. Therefore, understanding the different kinds of technologies that provide significant input into disaster relief decisions is essential to providing timely and effective responses to areas affected by disasters. One specific category of technology has risen in prominence and proven very effective in disaster relief efforts: space technology.

The use of technologies built for exploring and utilizing the final frontier goes beyond space exploration and corporate profit – it includes coordinating and monitoring disaster relief efforts. Space-based technologies that are used to support disaster relief include imagery satellites, remote sensing, atmospheric sounding, and radio communication (Tomaszewski et al., 2015). One of the most prominent ways these technologies are applied to the humanitarian sector is through geographic information systems (GIS), which utilizes the data provided by satellites and remote sensing to aid in disaster response. Another type of technology that is rapidly developing that can aid disaster relief efforts is rocket cargo transportation, through which humanitarian aid supplies will be transported in a rocket to anywhere in the world. Currently and futuristically, these technologies can and will drastically improve and expedite disaster relief responses worldwide. This paper will provide an overview of each technology, covering their current and future states as well as relevant financial and ethical considerations, and continue on to apply each one to a hypothetical flooding disaster scenario.

## Geographic Information Systems (GIS)

One of the primary applications of space technology in the humanitarian aid sector is satellite data processed by geographic information systems (GIS). Geographic information systems link geographically mapped data to user interfaces, allowing analysts to collect, analyze, and understand data collected from maps, remote sensing, GPS, and other technology (Thomas, 2017). This data is initially collected through satellites and other sources and transmitted to companies that hold the specific rights to that data. From there, GIS analysts organize the data into applicable dashboards, which can show information through different infographics and statistics. From there, GIS analysts can recommend disaster relief actions based on the GIS dashboards. Due to the ability of GIS to interpret and modify relationships between ecological conditions, physical factors pertaining to land qualities, and crises factors, it is uniquely suited for disaster relief and is widely used in the humanitarian aid community (Paul et al., 2020). Currently, GIS-based emergency decision support systems are the most used in the disaster relief sector (Zhou et al., 2018).

### Process of Data Collection/Use

In a disaster scenario, relief teams need to act quickly and wisely in deploying and monitoring their efforts. This is where GIS truly stands out compared to other technologies. The power behind GIS technologies is the speed and quality of data that can be used to make informed decisions.

Upon the onset of a disaster, disaster relief teams go through three stages in using GIS: collection, presentation, and application (Nagendra et al., 2020; Thomas, 2017). In the collection stage, companies with access to relevant data collection technologies (satellite imagery, remote sensing, etc.) gather this data and prepare it for GIS use. In the presentation stage, GIS analysts within relief organizations take the data and present relevant points in a GIS dashboard. Finally, in the application stage, disaster relief organizations utilize these dashboards to make data-driven decisions.

In this collection stage, there are many sources of data for disaster response users to draw from as well as software in which data can be compiled. One of the most popular GIS companies in today's market is Esri – a company that created a GIS (ArcGIS) for many different commercial uses (Maurya et al., 2015; Wang & Xie, 2018). One specific use for these dashboards is disaster relief, for which ArcGIS is already connected to associated data sources (impact locations, disaster intensity, weather-related sensors, etc.) that can be used to monitor disasters (*Esri disaster response program*, n.d.). Some examples of existing data that ArcGIS is connected to are already in ArcGIS Online or can be found in outside sources such as Living Atlas, which holds information from weather, traffic, hazards, infrastructure, and demographics to paint an accurate picture of current events (*Esri disaster response program*, n.d.). Beyond ArcGIS, other popular GIS programs are Google Earth Pro, Mapinfo Pro, Google Maps API, QGIS, OpenLayers, and BatchGeo (Abid et al., 2021; Tomaszweski et al., 2015).

The importance of GIS in disaster relief has become increasingly evident, which has prompted governments and organizations alike to provide free and low-cost data sources for organizations to use in times of disasters. An example of this is UNOSAT (UN Operational Satellite Applications Programme), which coordinates with other agencies to produce databases for humanitarian relief management (Ortiz, 2020). Another example is Relief Web – a site established by the UN OCHA (Office of Coordination or Humanitarian Affairs) to collect databases for decision-making support in humanitarian emergencies (Ortiz, 2020).

Beyond orbital and remote sensing satellite data, there are other sources of information that GIS dashboards can draw from. GIS is able to connect with the Internet of Things (IoT), which refers to everyday items (virtual devices, hardware, etc.) that can be connected to the internet (Tomaszerski, 2020). This allows GIS dashboards to compile real time, on-the-ground data that is relevant to a disaster. For instance, one study created a model that linked weather disaster monitoring systems to an AcGIS dashboard, allowing GIS analysts to visualize vulnerable regions according to relevant weather-related factors such as rainfall (Nabil et al., 2019). Another example of GIS and IoT being integrated is through fire evacuation systems, where smoke-related data from burning buildings are compiled through the IoT and utilized by GIS to assist in evacuations (Liu & Zhu, 2014).

To move on to the presentation stage, the data collected requires a partnership between disaster relief organizations and GIS companies, as these companies collect and hold the data while nonprofit organizations organize this data in accordance with their exact needs and preferences (*Esri disaster response program*, n.d.). For instance, if a disaster response team wanted to know the population density of disaster affected areas, the GIS teams in nonprofit organizations can alter their dashboards to show this.

However, this stage goes beyond presenting data in the form of a dashboard. It also involves communicating data in a meaningful way to others. At times, relief coordinators, who are already under pressure in their work environment due to rapidly changing scenarios and demanded delivery speed, are bombarded with data from these dashboards, which can greatly confuse their priorities (San Martin & Painho, 2019). As an alternative, information managers should both understand who they should communicate specific data points to (for instance, telling medical teams how many hospitals are in a certain area) as well as give context for why specific team members are being provided certain information, including how it is useful for their specific realm of responsibility (San Martin & Painho, 2019).

As evident by this discussion, satellites and other information sources have the ability to transmit many different types of data to user dashboards (Schumann et al., 2018; Tomaszerski, 2020; Zafar et al., 2019). However, the relevancy of data points changes depending on what kinds of relief teams are presented with it. Due to the extensive nature of all the different kinds of data available, it is essential for GIS analysts and disaster relief teams to understand what kinds of data they can view as well as how it can aid them in making quick and efficient management decisions.

### ***Types of Data Available***

The data available for disaster relief analysis includes environmental, demographics-related, and disaster-related data (Ortiz, 2020). Due to the wide range of available data, it is helpful to partition data points into relevant sections. Thus, data can be classified into one of four analytical categories: resource analysis, disaster analysis, environmental analysis, and urban analysis.

The first category of data, resource analysis, refers to the identification of areas that could provide helpful resources to populations affected by a disaster. Analyzing this data helps in identifying key locations in affected areas, allowing for a quicker allocation of resources. For instance, this data can help locate essential facilities, such as shelters, hospitals, water drains, and other relevant locations, which present locations for safe evacuation zones, medical facilities, and possible resource distribution centers (Emmanouli & Nikolaos, 2015). Furthermore, this data can identify resources currently located in particular zones, such as people, equipment, and supplies. For instance, analysts can identify safe hospitals in a particular region in order to locate medical equipment already within affected areas.

Next, disaster analysis refers to data that directly monitors both the disaster itself and high-risk areas affected by it. To monitor the status of disasters, GIS analysts find data points such as the direction, severity, and travel pattern of disasters themselves (Abid et al., 2021). Regarding high-risk areas, this type of data shows the physical areas most affected by disasters, which will help analysts identify locations deemed as high-risk (Chari & Novukela, 2023). These areas are then prioritized for response efforts.

A third type of data is environmental analysis, which refers to data relating to different aspects of environments affected by disasters. This differs from resource analysis in that environmental analysis does not focus on the resources in the environment, just the environment itself. This includes data concerning temperature, humidity, precipitation, wind speed, pollution, rainfall, weather, and other environmental factors (Ahasan et al., 2022; Paul et al., 2020). This also includes topography - land elevation, the quality of the ground, and other factors (Ortiz, 2020).

Finally, urban analysis focuses on populations and man-made infrastructure. Regarding population data, this includes population density and characteristics, such as the race/ethnicity of people in certain areas, their ages, their income, and other details (Thomas, 2017; Ahasan et al., 2022). Urban analysis also includes data relating to the infrastructure of the locations affected by disasters (Paul et al., 2020). This includes types of housing, roads, and city buildings in certain areas. This also slightly overlaps with the data found in resource analysis, as infrastructure data includes buildings such as hospitals and distribution centers.

## Data Applications

Transitioning to the application stage, many conclusions and recommendations can be drawn from the different types of data analyzed and processed by GIS. These different data types often overlap to draw essential conclusions and recommendations in a disaster relief scenario, as often two or more types of data are used to answer relevant questions. For instance, GIS technology has the capacity to identify the most efficient areas for distributions of supplies based on resource, disaster, environmental, and urban analysis (Paul et al., 2020). These decisions are drawn first from resource analysis, as GIS technologies can use this data to identify areas with established buildings or facilities already capable of holding supplies. Furthermore, the locations of tangible resources already in the country can be identified, allowing for disaster response teams to gather and utilize existing resources.

In addition to resource analysis, disaster analysis is used to analyze the present and historical path of a disaster, illuminating high-risk areas that may require more resource distribution than other areas. Next, environmental analysis is applied to identify safe areas for distribution centers as well as how disaster response teams can travel to these areas (Mukherjee & Singh, 2020; Seppänen & Virrantaus, 2010; Suwanno et al., 2023). For instance, in a flooding scenario, soil quality and areas at risk of landslides are essential considerations in deciding on distribution center locations.

Finally, urban analysis is used to identify and analyze populations and infrastructures in these areas. This can be used by first understanding the needs of the community based on their demographics. For example, distribution centers may need to be modified through hand-delivering supplies in areas with higher concentrations of elderly people. In addition, understanding the urban landscape of roads and buildings can help distribution teams determine safe routes and what areas are accessible to them when they are using vehicles.

As evident by the above examples, each type of data is required to be compiled and analyzed in order to answer disaster response questions. Other applications of GIS technologies in disaster relief scenarios include identifying areas to establish shelters and camps, resource management, collaborative communication between response teams, hazard mapping, assessing damage to infrastructure, coordinating search and rescue locations, and identifying the shortest and safest evacuation routes (Paul et al., 2020; Chari & Novukela, 2023).

## Current Limitations

While GIS is able to answer many questions during disaster relief scenarios, it is important to note that the quality of GIS is only as good as the software, data, and personnel being utilized in the analysis process (Tomaszewski, 2020). A challenge unique to the disaster relief sector is the limited amount of time and personnel available to understand, process, and handle new GIS data before and during a disaster (Schumann et al., 2018). Furthermore, organizations must consider the costs of implementing and sustaining GIS, as well as the cost of personnel hired to operate this technology. In addition, organizations must have established processes in place to ensure that the data from GIS is quickly transmitted to necessary users, which requires GIS analysts as well as each separate team using GIS dashboards to both accept and efficiently utilize quality transmission processes. Thus, organizations need to be aware of both the costliness of implementation and staffing as well as the needs for established processes to distribute quality GIS data in a timely manner.

In addition, without the proper intraorganizational infrastructure and knowledge in place, specifically regarding how end users effectively utilize the data, GIS implementation and use will not be successful. Thus, entire disaster relief units must be aware of GIS and understand how it is used to make decisions – something that takes time, training, and resources. While personnel must be in place to actually operate this technology, those who are using the GIS dashboards to make decisions need to have knowledge of GIS and its uses, requiring personnel to determine what information different disaster response workers need to know to fully utilize this technology. Thus, an additional challenge for organizations is establishing what specific relief teams need certain data in order to prevent overwhelming teams with too much data or passing on too little data.

## Ethical Concerns

Despite the life-saving nature of GIS in disaster relief, it does raise considerable ethical concerns. For instance, GIS has the capability to map the age, income, racial profile, and other personal aspects of people living within a certain area. For example, DICK’s Sporting Goods currently utilizes GIS location intelligence to plan ideal store locations based on the analysis of customer demographics and online spending trends (Sankary, 2021). Other types of data gathered by GIS technology are areas of high smartphone usage, spending habits in certain areas, and where potential customers live and work – all of which some consider to be a violation of privacy (Ball, 2022). While these kinds of data are not directly related to disaster response, it reveals how much data GIS technology has the capacity to detect, gather, and use, raising privacy concerns. Thus, it is essential that disaster response teams utilize this technology solely for its intended use and not for self-serving, privacy-violating operations.

## Future Outlook

One aspect of GIS that could change in the future is its ease of use. Currently, GIS users need to be sufficiently trained in order to use these programs, usually through specialized courses or by earning a degree (Zhu et al., 2020). However, GIS is difficult to master even after taking courses, as there are often gaps between course content, usually in which students follow step-by-step instructions, and applied learning, where students are required to understanding what they are doing, why they are doing it, and how to get to their desired solution (Whyatt et al., 2022). Thus, one of the primary challenges of GIS is the lack of user guidance and documentation within these programs, causing issues in locating wanted actions, understanding errors, and completing data retrievals (Unrau & Kray, 2018). Therefore, future GIS programs will likely improve their ease of usage to allow a wider range of users to engage with these programs.

In addition, the recent advances in AI will contribute to the evolution of GIS. Research has shown an increase in machine learning and AI models used for disaster management (Munawar, 2020). AI has the capability to predict natural disasters more accurately than traditional systems, drawing conclusions based on provided data rather than solely from patterns (Jung et al., 2020; Abid et al., 2023). In addition, AI will improve in its ability to gather data from more sources, such as news articles and social media, to provide a more comprehensive view of a disaster (Janowicz et al., 2019; Zhang et al., 2019). Furthermore, AI also has the potential to automate different functions related to analyzing data, making GIS easier to use and understand. Thus, through AI, larger amounts of data will be able to be processed at a faster rate and more tasks will be automated in GIS interfaces, allowing for better usability and quicker analyses of data.

## Joint Dashboard Partnership

In a disaster scenario, sharing information between organizations is one of the most important forms of collaboration (Liu & Shi, 2023). A lack of effective coordination inhibits disaster response efforts, resulting in an unnecessary lengthening of suffering for those impacted. An example of a disaster relief scenario that was inhibited by a lack of collaboration is when Hurricane Katrina hit the United States. During this disaster, there was a lack of central command and information structure, resulting in an inability for government agencies and nonprofit organizations to work together in a collaborative format (Boin & Bynander, 2015; Farazmand, 2007). This was primarily due to the unpreparedness of the government, as they did not provide a structure to coordinate all the organizations that responded to this disaster, nor did they provide consistent and accurate information regarding the present situation (Eikenberry et al., 2007). Therefore, the different organizations attempting to distribute aid were fragmented in their coordination strategies, each scrounging for information and resources concerning what was actually happening and what the greatest needs were. As a result, each organization distributed aid based on their own information sources and independent of other organizations, fostering a delayed and ineffective relief effort.

In order to increase the efficiency of disaster response, a useful tool would be a collaborative GIS dashboard shared and utilized among different disaster relief organizations responding to the same disaster. This type of partnership would allow for different organizations to contribute their data so each member can have a more complete picture of a disaster. Furthermore, this dashboard can help decision makers across partnered organizations coordinate their responses in a more effective manner, ensuring that efforts are not duplicated or that certain areas are “missed” due to miscommunication (Sun et al., 2020). Coordination between disaster relief agencies has proven to increase efficiency, and this can continue and improve through collaborative GIS dashboards (Coles et al., 2018).

Success stories concerning GIS dashboard partnerships arose during the COVID-19 pandemic. During the pandemic, GIS dashboards not only aided in informing the public of the current state of the pandemic, but also helped healthcare workers optimize resource allocation, plan interventions, and mitigate public health risks (Akindote et al., 2023). An example of this was when the Hong Kong Government, with the backing of a non-profit alliance called the Smart City Consortium, formed a partnership with different government bureaus and departments to combine their data into a single COVID-19 dashboard (Chun et al., 2021). This report included data concerning infected patients and their locations, the status of these patients, the number of patients hospitalized, and other information related to the disease. As a result of its usefulness, the dashboard reached over 40 million views as of October 2020, becoming popular among the public due to its ability to monitor the COVID-19 situation around their location.

Another example of the successful creation of a collaborative COVID-19 dashboard was a local partnership between the Columbia University Mailman School of Public Health and the Stamford Connecticut Department of Health (SDH). Through this partnership, the organizations developed COVID-19 dashboards to support local pandemic responses for smaller cities (Suri et al., 2022). Both organizations involved in this partnership were able to fill in knowledge gaps that the other one had and decide on the most important parameters to track in these dashboards. As a result, these dashboards allowed for stakeholders to see where patients were, how many patients were in different areas, and disparities in infection rates by race/ethnicity. As a result, the SDH was able to launch timely and targeted testing and vaccination campaigns, preventing further spread of the disease.

As the advantages of collaborative GIS dashboards became evident for coordination during COVID-19, applying the same principles to shared dashboards for disaster relief purposes would be strategic for interorganizational communication, asset allocation, and information sharing. These dashboards would be created through partnerships established before disasters strike, allowing for organizations to have formalized processes implemented so all parties understand how to use and apply these dashboards. During a disaster, organizations would be able to develop strategies based on these dashboards, monitoring where resources are being allocated, where each organizations' teams currently are, the amount of aid allocated to each region, and situation updates as they develop. In addition, teams on the ground can report sudden changes that GIS may be delayed in catching. For instance, a building being used as a shelter could collapse suddenly due to the aftereffects of a disaster. The team operating out of that facility would be able to report this to their GIS analysts, who can then instantly notify other organizations of the issue by putting it on the dashboard. Then, by being able to see the resources and teams from all the organizations, those teams that are the closest could be rerouted to the area. As illustrated by this example, everyone that has access to these dashboards would be able to work together to prevent the duplication of efforts, ensure that those who need aid are receiving it, and have constant eyewitness updates from multiple locations in the field.

## Rocket Cargo

In recent years, the supply chain world has experienced tremendous change. One specific advancement that is currently in development is reusable rockets that have the capability to transport cargo anywhere across the world. Compared to traditional modes of transportation, such as airplanes, rockets could potentially transport cargo to any destination around the globe within an hour, be offloaded, then return to its original or another destination. This newfound technology, commonly referred to as point-to-point rocket transportation, is still being developed by multiple high-profile companies. However, there are clear opportunities for speculation about how these programs could revolutionize the delivery of humanitarian aid.

## Current Contracts

In June of 2021, the United States's Department of the Air Force announced the Rocket Cargo Vanguard Program within their 2030 Science and Technology Strategy, demonstrating their intent to use rocket cargo for not only point-to-point defense transportation, but also for quick humanitarian aid response (*Department of the Air Force Announces*, 2021). The intention of this program is to not only develop rockets capable of point-to-point transportation, but to also be able to land rockets on non-traditional surfaces as well as near structures, establish logistics for rapid loading and unloading, and air drop cargo for use in situations where landing is not possible.

The goal of this project was not for the internal development of these rockets, but to employ commercial rockets, requiring the establishment of contracts with external organizations experienced in these areas (*Rocket Cargo for Agile Global Logistics*, 2021). In the beginning stages of this research, The United States Air Force observed the capabilities of several private companies to develop a rocket suitable for their intentions. Currently, there are multiple different rocket-producing companies that have signed contracts with the US military, some of which being Jeff Bezos' Blue Origin, Sierra Space, and Virgin Orbit National Systems. Each company is contracted to work on different aspects of the Vanguard program. For instance, Raytheon was offered an $8.7 million contract to develop a rocket cargo mission planning and command-to-control system, for which they are required to design processes, workflows, and interfaces related to rocket cargo missions (Sharma, 2023). In addition, in September of 2022, Rocket Lab announced the establishment of a Cooperative Research and Development Agreement in partnership with the United States Transportation Command, in which the company agreed to explore the viability of Rocket Lab's rockets, Neuron and Electron, for transporting cargo across the world (*Rocket lab signs agreement,* 2022).

However, SpaceX won the most substantial and publicized deal – a five-year, $102 million contract for the company to demonstrate their ability to create a rocket capable of point-to-point cargo transportation (Urban, 2022; Wattles, 2022). While a specific rocket within SpaceX's portfolio was not specifically mentioned in this contract, its intention is for the United States Air Force to collect data on SpaceX's commercial orbital launches and booster landings, along with cargo bay designs suitable for loading and unloading cargo. (Urban, 2022). Based upon their findings, the Air Force will decide upon the feasibility of rocket cargo transportation.

Despite not specifying the particular rocket being analyzed for the task, SpaceX's Starship rocket closely resembles the specifications that the Air Force laid out for their future rockets. Specifically, the military is looking at developing reusable private rockets that can carry between 30 and 100 tons of cargo, with the Starship being the only rocket in development that is both reusable and can potentially hold this much cargo (Sheetz, 2021). According to SpaceX, the Starship has a reusable payload capacity of up to 150 metric tons while being able to complete point-to-point transportation on Earth, making it a prime contender for the Vanguard program (*Starship,* n.d.).

## Financial Feasibility

When it comes to considering rockets as a mode of cargo transportation, it is essential to factor in the costs of launching rockets. Regarding SpaceX's Starship, the exact launch costs have not been released. However, in a recent press conference, Elon Musk, the founder and CEO of SpaceX, claimed that launching the Starship will cost less than $10 million within two to three years, with costs continuing to fall to as low as two million dollars in the future (Duffy, 2022; Smith, 2023). These price points have the power to destigmatize the high costs of rocket launches, making rocket cargo a feasible option for the government to consider. However, these numbers provided by Musk are estimations, and only time will tell if they come to fruition.

### Foreseen Limitations

Despite the perceived benefits of rocket cargo transportation, there are a few limitations that should be noted. First, while the predicted price point of a few million dollars per rocket launch is indeed small for the space industry, it is still a significant amount of money for the sake of transporting supplies. Thus, the justification for launching rocket cargo must be sound and significant, making this mode of transport for humanitarian purposes extremely rare.

Furthermore, it is unclear as to how rockets will be able to land on the earth's surface. In traditional take off and landing situations, rockets have a landing pad designed to withstand the heat and pressure put on it, allowing rockets to launch and land. However, in an emergency scenario, there will likely be unexpected debris on the surface, making it difficult to find clear places to land. Furthermore, even if the land is clear from debris, there is still an issue surrounding the earth not being able to withstand the pressure and heat of rocket launches and landings. Suggestions have been made for either developing transportable rocket launching pads or constructing rocket launching stations across the world, however both would impede the speed at which supplies could be delivered. An official conclusion as to what course of action the Air Force will take has not been released yet.

In addition, point-to-point rocket cargo transportation is obviously not feasible for humanitarian aid organizations. This is so due to the financial constraints around constructing and launching rockets, the logistical requirements for staff and supplies, and the regulations surrounding launching rockets. Thus, the primary contender for applying rocket cargo transportation in a humanitarian situation is the United States Air Force. However, it is unclear as to if they will consistently use rockets for humanitarian purposes. Thus, it is safe to assume that this mode of transporting cargo will only be used in unexpected disaster situations resulting in high casualties and requiring a significant amount of aid as soon as possible.

## Ethical Considerations

In addition to limitations, there is also an ethical component to rocket cargo transportation from the perspective of cost. For rocket cargo transportation, the Air Force must create standards of when it is necessary in light of how many lives the provided resources can save. As stated earlier, SpaceX claims that the cost of their Starship launching can eventually be brought to as low as two million dollars (Smith, 2023). With this high cost in mind, an ethical dilemma arises: how many lives must be in danger to justify launching a rocket with life-saving supplies to their location? In light of this project and the Air Force's budget, this will be an important consideration for the government as they decide how and when rockets launch depending on their budget, the number of rockets in commission, the viability of rockets within these situations, and the determined necessity of rapidly delivered supplies.

## Future Outlook

With SpaceX's contract with the Air Force ending in 2026, it is expected that the viability of the rocket cargo transportation program will be clear by that point. However, there are other stakeholders that expect a conclusion to become evident sooner rather than later. Greg Spanjers, the chief scientist of the Air Force Research Laboratory's Integrated Capabilities Directorate at Wright-Patterson Air Force Base, states that the Air Force wants flight data from Starship rockets going into orbit by the end of 2024 (Losey, 2023). Also in 2024, the Air Force plans to have a rocket cargo bay mockup built in Alliance, Ohio to practice and refine techniques for rapidly loading and unloading containers from a rocket (Losey, 2023). Finally, by 2026, the program is expected to be ready for use, from loading and unloading containers to launching rockets (Losey, 2023). Therefore, if all goes smoothly, the public can expect to see rocket cargo transportation actively being used by the Air Force in the next few years.

## Application to Flooding Disaster

In a natural disaster scenario, humanitarian aid groups need to work quickly, using tools such as GIS technology (and eventually rocket cargo transportation) to manage their relief efforts. This specific field is often classified as disaster management. The United Nations Office for Disaster Risk Reduction defines disaster management as groups organizing, planning, and executing measures and processes created to prepare for, respond to, and recover from disasters (*Disaster management*, 2017). From a practical perspective, disaster management is applied through the disaster management cycle framework.

This cycle has four stages: prevention/mitigation (reducing or eliminating the likelihood or consequences of a hazard), preparedness (equipping those who may be impacted and relief teams as well as minimizing other losses before a disaster), response (taking action to reduce or eliminate the impact of the occurring disaster), and recovery (returning victims' lives back to their previous state proceeding the disaster and its consequences) (Coppola, 2015). The mitigation and preparedness stages both happen before the disaster, as their purpose is to strategize how risks and damages caused by the upcoming disaster can be decreased or eliminated (Krishnamoorthi, 2016; Seppänen & Virrantaus, 2010). Specifically, mitigation refers to establishing plans and processes in case of a disaster, while preparedness refers to preparing for a predicted, impending disaster. The response phase is comprised of activities that happen during a disaster, including rescue efforts and relief distribution, while the recovery stage refers to activities that occur after a disaster. GIS technology and rocket cargo transportation have and will help in at least one stage of this cycle, aiding relief teams and those affected before, during, and after disasters. Due to the timing of the mitigation stage in comparison to when an actual disaster hits, the application section of this paper will focus on the remaining three stages, where relief is coordinated, delivered, and monitored.

Different kinds of natural disasters (earthquakes, tornadoes, etc.) combined with the various types of areas impacted requires flexible approaches to providing relief. One type of disaster that necessitates a unique relief approach is flooding. According to the World Health Organization, floods are the most frequent type of natural disaster, as they have affected more than 2 billion people worldwide from 1998-2017 (World Health Organization, n.d.). Furthermore, due to the effects of climate change, the global population impacted by floods is expected to increase by 24% to 30%, depending on a worldwide temperature increase of 1.5 to 2 degrees Celsius (Alves, 2023). Therefore, utilizing GIS and rocket cargo in a flooding disaster scenario is not only viable, but imminent.

Unlike other disasters, flooding can be difficult to predict and prepare for, as even when the likelihood of flooding is evident, the intensity and scale of floods are difficult to anticipate. However, the ability to predict floods has improved due to advances in machine learning and the increased availability of data related to floods (Ghorpade et al., 2021). Currently, humanitarian aid organizations use these advances to create predictive analytic models to forecast flood disasters, which can aid in both the mitigation and preparedness phases of the disaster management cycle.

## Preparedness

In preparing for the initial onset of a predicted flood, the first step is to construct flood risk maps using GIS. Flood risk is made up of three components – hazards (the flood itself, including its probability, magnitude, and impact to the areas affected), exposure (the value and people located in the threatened areas), and vulnerability (the likelihood of loss or damage caused by the flood and resulting threats) (Mishra & Sinha, 2020). Therefore, even if there is a low exposure in a certain area, the high vulnerability of that area could result in significant damage. Maps are created based on these three components to visualize affected areas by risk and help identify the most effective disaster response strategies.

Separating maps into hazard, exposure, and vulnerability allows GIS teams to break down the data for easier understanding of the current situation. First, hazard maps are created to visualize the extent and distribution of flood hazards to effectively identify areas endangered by flooding (Mudashiru et al., 2021; Sy et al., 2019). As there are many different kinds of hazards, they are usually compiled in a multi-layered map. In these maps, the hazard layers overlap to create a view of all the hazards in certain areas. Some examples of hazards that could be included in these maps are elevation, slope, drainage density, distance to a nearby water source, rainfall intensity, soil, geology, flow accumulation, and land use (urban, croplands, woodlands, etc.) (Ajjur & Mogheir, 2020; Osman & Das, 2023; Skilodimou et al., 2019). These factors are often visualized using hydraulic and hydrodynamic models. These models are created through software that is compatible with GIS, such as HEC-RAS and HEC-HMS, and provide an accurate view of how floods will move throughout a region (Kiba et al., 2023; Seenath et al., 2016). Currently, countries such as South Asia, Malaysia, Indonesia, and Thailand have used and are using HEC-RAS models for flood zoning and to mitigate flood hazards (Abid et al., 2021).

These hazard maps utilize criteria and ranking methods to determine the most at-risk areas. While there are multiple strategies in practice that do so, one of the most common is the multi-criteria analysis approach (MCA). Using MCA, specifically the analytic hierarchy process (AHP), has proven to be successful in developing and assessing flood hazard maps (Arya & Singh, 2021; Franci et al., 2016; Hagos et al., 2022; Mahmoody Vanolya & Jelokhani-Niaraki, 2019; Ouma & Tateishi, 2014). MCA provides a systematic framework to compare multiple criteria simultaneously, considering both qualitative and quantitative measures to evaluate and compare flood management alternatives (Das, 2020; Kumar et al., 2023) AHP is an extension of this, as it rates these criteria through subjective inputs based on large amounts of data (Das, 2020). The result is a flood hazard map that shows the most endangered areas based on the given data.

The two other elements of risk, exposure and vulnerability, tend to be combined in GIS maps due to their similar indicators and measurements. For instance, the demographics of people in affected areas (exposure) is directly correlated to the perceived loss of lives in those areas (vulnerability). These maps attempt to show the capability of people to deal with flood hazard based on measures such as social and economic statuses of the population (health, living standards, education, social equity, income, etc.), population density, distance to roads, and man-made settlements (Deepak et al., 2020; Osman & Das, 2023). While there are no set standards for elements that should be included in these maps, the contents are highly dependent on the cause of the flood, closeness to large bodies of water, population density, and other related considerations.

When hazard, exposure and vulnerability maps are combined in a multi-layered format, the areas most affected by floods as well as the vulnerability of the people in those areas overlap, allowing disaster relief teams to prioritize certain areas for relief. Furthermore, these teams can begin planning and organizing aid packages designed for specific areas based on population demographics, land quality, and other relevant factors. From a government perspective, this kind of map can also allow leaders to issue preparatory and evacuation orders to affected areas, given they have the technology to do so. Additionally, GIS teams can begin analyzing potential routes to and from areas that are expected to be highly vulnerable, ensuring that relief teams can get to these areas quickly and safely as well as retain the ability to evacuate residents.

In addition to these maps, GIS can also be used for analyzing the resources and essential facilities already in-country. These two are often tied together in analysis because resources are traditionally housed in essential facilities. These essential facilities include both those that would contain life-saving resources (hospitals, distribution centers, etc.) as well as buildings that serve as flood shelters or as potential safe points for people trying to stay above the water. By analyzing these points, GIS teams can identify both resources that can potentially be used due to the fact that they are already in-country as well as safe locations where they can evacuate residents to. Furthermore, mapping these areas allows disaster relief teams to view shortages for certain facilities (such as hospitals), which may impact the allocation of resources to certain areas (Abid et al., 2020).

Also, based on land and infrastructure analysis, GIS can identify hotspots for people that will need to be rescued. For instance, areas with poor infrastructure will likely require more search and rescue operations than compared to areas with stable buildings that can withstand flooding. In addition, these points can provide relief teams locations for where distribution and triage centers should be established based on area probabilities for injuries and the supplies available from the resource and facilities analysis.

If given enough time before flooding begins, aid packages could begin being prepared for transport. Once they are prepared based on the predicted needs of the population, they can begin to go on planes to be shipped to nearby airports or driven close to their intended destination. However, if the disaster is unexpected and there is a significant demand for immediate aid, rockets can begin to be outfitted by the United States Air Force with needed supplies for affected areas. However, it is important to note that these rockets will likely not be deployed for many humanitarian-related operations unless they are given unique sanctions by the United States government to do so due to international politics and high costs.

Despite the advances in predictive analytics used to forecast disasters, sometimes these situations develop quickly with little to no warning. As a result, GIS teams can have little to no time before disaster relief teams are deployed to areas requiring relief. Thus, the time frame available to complete the above preparedness processes may be long or short. This requires both GIS teams and those receiving their information (ex. relief teams) to be prepared for sudden changes and updates as situations during a disaster have the potential to change significantly in a short period of time.

## Response

The response phase, the most crucial of all the phases, includes actions that pertain to providing timely relief to those affected by disasters (Abdalla & Esmail, 2018). During this phase, GIS teams coordinate with relief teams on the ground as well as other humanitarian organizations to aid communities affected by disasters. In this phase, the initial relief strategies formulated during the preparedness phase are executed and constantly updated as new information is gathered.

In the preparedness phase, GIS teams created hazard, exposure, and vulnerability maps to identify high-risk community-based criteria such as population demographics, land analysis, infrastructure, and disaster intensity. Areas that are identified as high risk are prioritized for humanitarian response, prompting relief teams to focus on these areas for rescue efforts and relief distributions. Furthermore, based on the GIS maps, safe routes to and from these areas can be established. This ensures that relief teams are taking the safest and quickest routes available in order to delivery timely aid.

Tied with this concept of route planning is evacuation route planning. The process of planning evacuation routes is done in three steps: figuring out where people who need to be evacuated are located, determining safe areas for people to evacuate to, and deciding on the most efficient and safe route possible to get to and from these areas (Hasnat et al., 2018). These routes usually need to be more accessible than the routes that disaster relief teams take to get to a particular area. This is so because there could be a large number of people and/or vulnerable people such as the elderly and children who need to evacuate. To aid with evacuation planning, both the population demographics of certain areas as well as estimations of damage caused by flooding can be analyzed through GIS, allowing for GIS teams to estimate how accessible certain evacuation plans need to be depending on the severity of flood damage and the feasibility of possible routes.

Furthermore, GIS helps determine how aid should be allocated as well as the placement of shelter and distribution locations. The allocation of aid can be determined in a general sense through the identification of areas that are deemed as high priority for relief. The amount of aid can vary in specific locations based on headcounts as well as estimations of vulnerable and injured residents. In establishing exact points of distribution, and from there shelter locations, the ideal location contenders would be undamaged, structurally sound buildings with space available to house large groups of people. Some examples of these buildings would be hospitals and schools. They can be identified through GIS integration with IoT as well as orbital satellite images of buildings under examination. From there, building quality confirmation can be established through teams on the ground. If a building is not deemed to be structurally sound or there are no available buildings in the area, triage and shelter centers can be established based on current orbital satellite images, land quality (i.e. if land is safe enough for long-term use), closeness to affected areas, and whether other humanitarian aid organizations are already in the area.

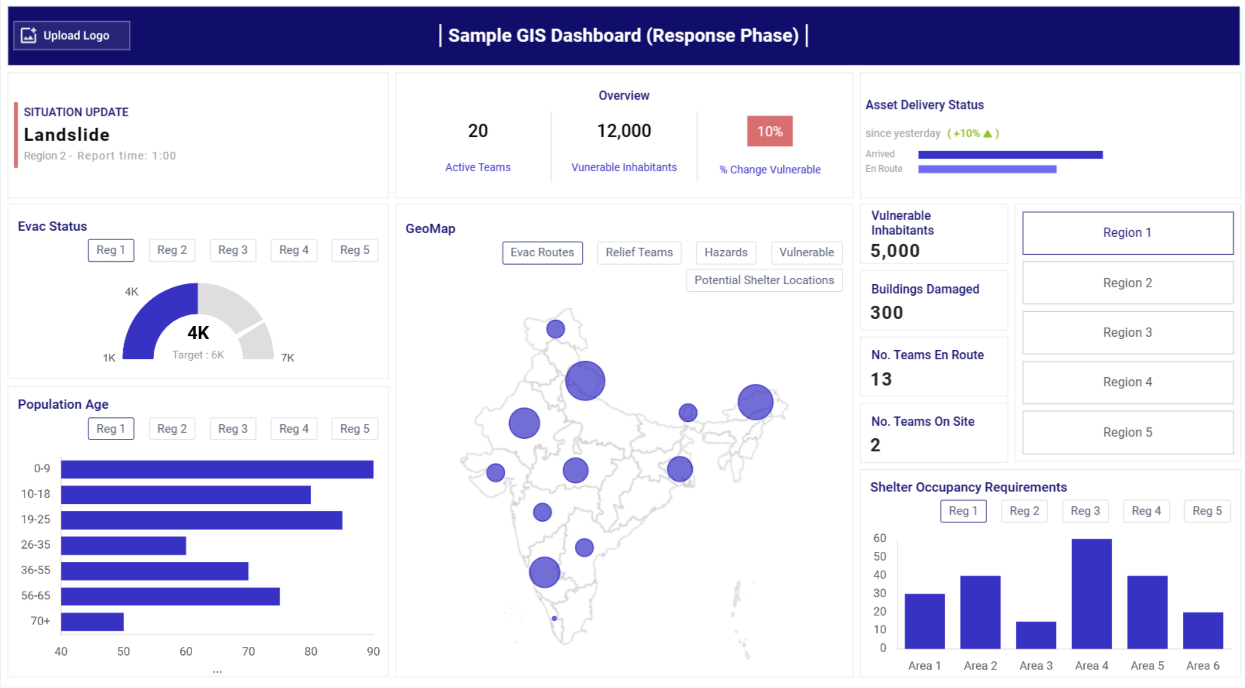
Based on the locations of established shelters and triage centers, logistics teams can coordinate where to land a rocket with cargo and supplies. The specifics of how this can be done, especially considering the landing pad requirement, are still uncertain. However, hypothetically, relief teams on the ground can analyze potential locations for a landing and determine the safest one, considering both the ability of the land to withstand the landing as well as the proximity to where the delivered supplies would be required to go. After establishing this location, the rocket would be able to be launched and arrive at its intended destination within an hour. From there, relief teams would need to unload the rocket in accordance with specific logistical processes and procedures. Once offloading is complete, the rocket would be launched back to its original destination or another facility either to reload supplies or to store for other missions.

While the hazard, exposure, and vulnerability maps created in the preparedness phase are inherently very useful, the time frame of which that data is relevant is short. Studies have found that the value of certain GIS-related data can be as short as 24 to 72 hours after collection, as the landscape and recovery situations change rapidly (for example, a building may collapse due to damaged infrastructure caused by the disaster) (Tomaszweski et al., 2015; Hodgson et al., 2009). Therefore, it is essential for GIS teams to constantly be analyzing their dashboards and uploading updates from relief teams and new GIS-related data. For instance, during and after a flood, high spatial resolution images from satellites can identify infrastructure damage through before and after images of affected areas (Franci et al., 2016). Once received, these updates can be uploaded to the hazard maps as well as be conveyed to disaster relief teams to notify them of unexpected hazards and new priorities for rescue efforts.

There are many different ways that these data points can be shown in a dashboard. An example of what this could look like is shown below.

**Figure 1**

*Sample GIS Dashboard – Response Phase*



*Note.* This is a sample of how a GIS dashboard could be constructed and what data points this could include for the response phase of disaster management.

This example demonstrates how data points relevant to the response phase can be compiled into a dashboard. Relevant points include situation updates, evacuation route statuses, population ages, estimated shelter occupancy requirements, asset delivery statuses, and associated statistics. Furthermore, each of these statistics can be narrowed down to reflect those of a specific region, as evident by the buttons in the graphs and next to the statistics. In addition, the map itself has several buttons that allow GIS analysts to view the locations of evacuation routes, relief teams, hazards, vulnerable inhabitants, and potential shelter locations throughout the country. This sample demonstrates the potential for dashboards to aid teams in the response phase, and GIS analysts can modify their own dashboards to reflect the statistics and graphs that are most helpful to them.

As these rescue and relief operations are being conducted, GIS dashboards can gather updates and present them through mobile apps to ensure that relief teams are notified continuously about unexpected situations in order to maximize their effectiveness. These apps provide relief managers with up-to-date visuals on hazard, exposure, and vulnerability areas as well as impending resource needs. In addition, data can be collected through these apps, increasing the accuracy of GIS dashboards in relation to current events. For example, certain emergency smart phone apps have the capability to send location information to GIS dashboards when people call emergency services (Sterk & Praprotnik, 2017). Furthermore, GIS mobile software allows for relief teams on the ground to input data on hazards and risks, giving GIS teams a clearer picture of current situations (Giardino et al., 2012). This is especially important since GIS data may not always capture data as quickly as compared to those on the scene. In addition, areas where relief teams are operating can be indicated in these apps, showing other relief teams where affected residents are already being served as well as areas where people still need aid (Sharma et al., 2020).

Furthermore, throughout this entire stage, GIS teams and relief managers on the ground need to have clear methods of communication established between them. This makes GIS-connected mobile apps extremely helpful, as both sides can see the same GIS dashboards. This ensures that everyone is on the same page as to what is currently happening as well as what needs to be done. Therefore, it is essential for GIS teams and disaster relief managers to collaborate through these apps, as the combined data from established GIS sources and eyewitnesses on the ground ensure that these dashboards are as accurate as possible.

### Recovery

The goal of the recovery stage is to aid communities affected by disasters in order to bring them back to the way things were before the disaster. This requires the continual support of GIS teams through the coordination of aid as well as the sharing of information about hazards as they become relevant. By this point, rocket cargo would no longer be necessary, as the need for immediate aid would have already been fulfilled in the relief stage. Thus, the transport of aid would be through airplanes, boats, or other modes of transport that would take longer but would be more cost-efficient and practical.

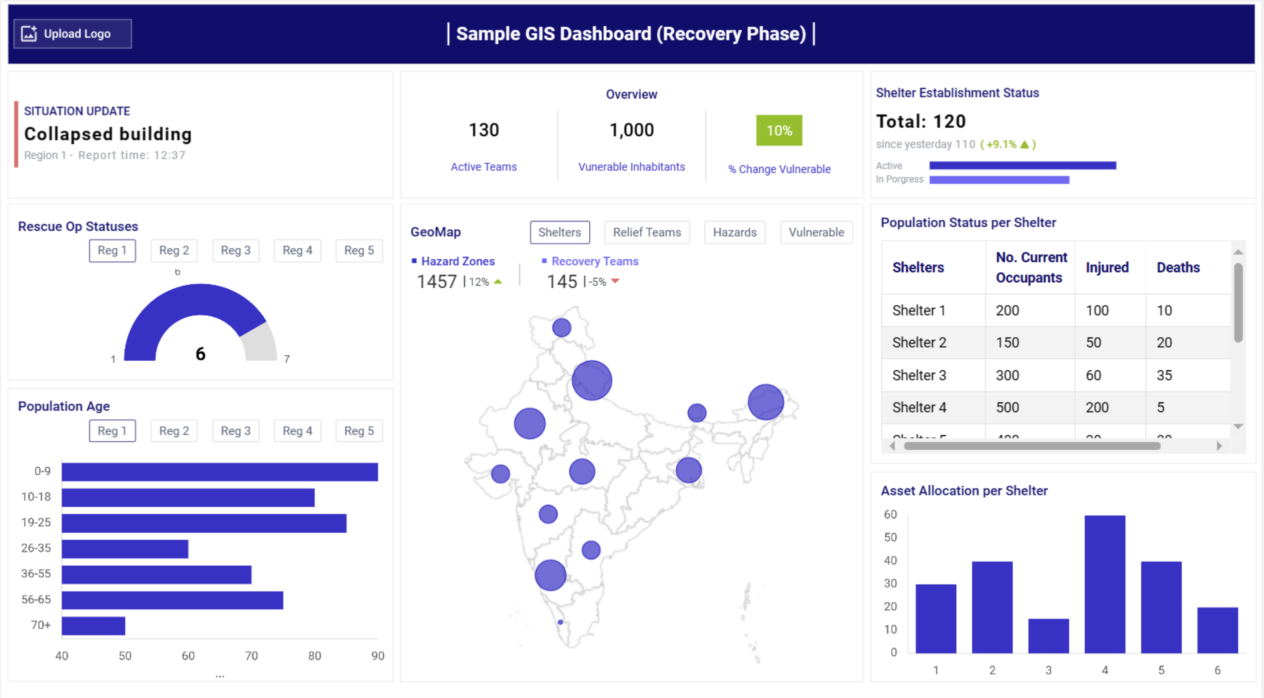
The GIS-related actions in this phase revolve around establishing post-disaster shelters and rebuilding. Regarding shelters, GIS can help identify the demographics of people in specific shelters. Based on this, analysts can determine locations to where people can be moved (Tomaszweski, 2020). Furthermore, remote sensing and orbital satellite data can identify damaged areas along with pre- and post- pictures of those areas, allowing relief teams to recommend priorities for rebuilding as well as giving GIS teams the ability to monitor the recovery process over time (Yu et al., 2018).

Another essential consideration in the recovery stage is the additional issues that can potentially arise due to floods. For instance, flooding can result in the spread of different infectious diseases, which is cause for concern as these diseases can spread rapidly in different shelters among people who are already vulnerable due to age or injuries (Abid et al., 2021). As proven through COVID-19 responses, GIS can visually present the locations of current diseases as well as the patterns causing these diseases to spread (Kamel Boulos & Geraghty, 2020). Through this information, relief managers can identify hotspots for these diseases in order to effectively stop them from spreading further. Also, based on this data, specific treatments can be allocated to areas where certain diseases are rampant.

Similar to the sample dashboard for the response phase, dashboards for the recovery phase require data to be displayed that are unique to that phase. While some data points from the response phase are still relevant, other data points can be added as they become available to GIS analysts. For instance, there would be more data pertaining to shelters as they are being established primarily in this phase. Below is an example of what a dashboard for the recovery phase could look like.

**Figure 2**

*Sample GIS Dashboard – Recovery Phase*



| Shelters | No. Current Occupants | Injured | Deaths |
|---|---|---|---|
| Shelter 1 | 200 | 100 | 10 |
| Shelter 2 | 150 | 50 | 20 |
| Shelter 3 | 300 | 60 | 35 |
| Shelter 4 | 500 | 200 | 5 |

*Note.* This is a sample of how a GIS dashboard could be constructed and what data points this could include for the recovery phase of disaster management.

In this dashboard, there are several data points that carry over from the response phase, such as situation updates; types of maps showing the locations of relief teams, hazards, and vulnerable inhabitants; and statistics such as population ages, active relief teams, and vulnerable inhabitants. However, there are new data points that become more relevant in this phase, such as the locations of shelters (as seen on the button in the map). Other relevant statistics that are included and pertain to shelters are the number of inhabitants per shelter as well as the number of injuries and deaths in those shelters. Furthermore, statistics can be added for rescue operation statuses and asset allocations per shelter. Similar to the response sample dashboard, this dashboard should be tailored to the planning and operational needs of each GIS team.

## Conclusion

The application of space-based technology to the humanitarian aid sector can and will continue to greatly impact the way these organizations conduct their disaster relief efforts, specifically pertaining to the preparedness, relief, and recovery stages of the disaster management cycle. GIS allows organizations to visualize areas impacted by disasters as well as provide relevant information in order to plan relief efforts. This information can be compiled into layered hazard, exposure, and vulnerability maps – all of which guide relief managers as to where they should focus their efforts in the safest and most efficient ways possible. In addition, the eventual incorporation of point-to-point rocket cargo transportation into disaster relief will quicken the delivery of aid to impacted communities. Furthermore, GIS technology helps in long-term disaster recovery, guiding managers as to where to focus their rebuilding efforts as well as preventing diseases from spreading. The analysis and application of GIS and rocket cargo transportation to disaster relief showcases their current and forecasted ability to improve the efficiency, timeliness, and coordination of disaster management, emphasizing the importance of disaster relief professionals understanding and utilizing these technologies at their disposal to save lives.

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