Collaborative Emergency Response Field Application GIS System Design

A GIS system that promotes collaboration between emergency response organizations with web and field-based applications

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Executive Summary

This report details the system design for a new web-based GIS application with offline capabilities that is focused on improving inter-organizational collaboration during emergency response. Currently emergency response organizations utilize a diverse array of GISystems that are poorly designed to interact with each other, hampering communication and coordination between the users in these organizations. The proposed system addresses the collaboration deficiency by using a single design that can be employed by any organization using their existing devices. Collaboration is further encouraged in the system design through a fully featured group function that enables sharing and structure through heirarchy and user permission levels. The application supports various users through a rich user profile that allows the user to modify components of their user interface within the application. The proposed system design can save money by eliminating the need for organizations to pay for expensive licensing and the improved coordination efficiency will support improved response and recovery times for emergency operations. The large scope of this application requires a collaborative effort from invested organizations during the design stages to ensure that the required capabilities are implemented. Any criticism of this design proposal is welcomed so that it may be further fine-tuned to meet requirements. The next step after approving this design proposal is to establish a working group composed of potential organizations to determine responsibility for the design and employ software designers to begin work on building prototypes of the application.

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Background

Despite the considerable progress in employing GIS in many emergency organizations, there is a significant hurdle faced by many organizations attempting to employ these systems. GIS systems tend to be designed with singular solutions in mind and the rapid utilization by many emergency organizations has led to a lack of standardization amongst them. When emergency organizations need to interact, there is no time available to make a new pipeline to connect the different GIS systems employed by organizations. To solve this problem a simple field-based system should be developed that allows any organization with any number or type of devices to connect and send required data and communications with each other. This application should be able to handle many typical GIS operations and analysis used for emergencies. Such a system would avoid issues where a specific GIS application is needed to handle a specific scenario or to access data.

Responding to emergencies efficiently is an extraordinarily complex task that requires communication and discipline from many trained individuals. Emergency responders cover a gambit of disciplines ranging from police officers to wildlife managers with supporting individuals from a likewise varied range of professionals. The precise nature of impending emergencies in each location is unpredictable, which means emergency professionals must always be ready for anything, an ambitious goal. Many emergency professionals and organizations have turned towards GIS to ensure readiness by providing awareness of their surrounding environment. In any given emergency it is the local environment that provides the most essential details, however, especially for large emergencies, national level organizations may become involved, necessitating cooperation between the various levels of organizations that often have slightly differing goals and objectives.

There has already been significant success in deploying GIS from local to international level organizations to solve some barriers of emergency situation resolution. An example of this can be found in Cairo where field-based GIS applications were employed to provide quick damage assessments (El-Gamily et al., 2010). Some applications for emergencies require significant involvement from professionals and have had GIS systems designed to handle specific emergency scenarios, such as chemical spills (Gui-Lian et al., 2000). Other, simpler, applications of GIS in emergency response involve using GIS tools, such as shortest-distance routing, to solve a specific problem in the emergency situation (NICOARĂ & HAIDU, 2014).

The realm of inter-organizational cooperation is a crucial factor in generating appropriate emergency response especially in large-scale or nuanced situations. The international collaboration of disaster recovery teams from Japan and the United States founded in GIS to build urban design (Tanaka et al., 2009) exemplifies how GIS systems can be used in large-scale operations to ease collaboration between organizations. In immediate response scenarios speed is of utmost consideration, which is where ad-hoc mobile systems can be employed to improve the communication of individuals from multiple organizations (Reuter et al., 2014). Taken to the extreme, collaboration with field systems can even begin in preparation stages by allowing infrastructure managers the opportunity to make resources available to first responders with a well-developed GIS system (Peña-Mora et al., 2010).

The current state of mobile technology offerings is perpetually short of an ideal system, wherein emergency response professionals would have any information they desired immediately available to them. Despite falling short of the ideal of instantaneous information, real-time GIS applications are being employed utilizing field sensors to provide quick information to responders in the field

(Mangiameli & Mussumeci, 2014). The data from such field sensors can be further utilized to aid in collaboration by distributing the data to disparate organizations that require it (Lagmay et al. 2017). A key aspect in delivering an actionable field GIS system is delivering optimized peer-to-peer networking system which falls into its own discipline of computer science (Tahir et al., 2021) and can involve techniques like search optimization to further optimize the system (Zhou & Meng, 2020).

Needs Assessment

The types of users that would utilize a standardized multi-organization GIS system fall into many broad categories, including first responders, field coordinators, operators, infrastructure managers, and data managers.

The first responder role encompasses many professions including the typical EMTs, Police Officers and Firefighters as well as some positions related to the emergency such as wildlife managers or explosives technicians. This role is primarily a user of the technology and wants access to the results of their queries in a timely manner and requires this information even if internet connections are not available.

The field coordinator role is made up of supervisors for first responder teams, often present in the field but not directly involved in the situation. Their main goal is to coordinate the actions of individuals with a birds-eye view of the entire situation. They will require access to more advanced analysis tools than first responders as they may be tasked with objectives like creating a cordon around a potentially dangerous situation. They also require effective communication tools as they serve as the focal point for communication to and from outside organizations and first responders.

The operator role is involved in coordinating emergency response personnel from a remote setting. They may be responsible for coordinating personnel from multiple organizations for multiple emergency situations across a vast area. Operators tend to have reliable connections and devices capable of performing more strenuous tasks, or they may be in direct communication with others that have those capabilities.

The infrastructure manager is not directly involved in emergency situations, rather their responsibilities come before and after emergencies. They are responsible for ensuring that information on buildings and utilities is placed into the GIS system so that they can be accessed by other emergency professionals. After emergencies they will be responsible for recovery operations in the event of damage, they may need to prioritize certain repairs first and getting a valuation on damage is important for ensuring that aid can come in a timely manner if needed.

The data manager is responsible for making sure that the entire system is working, and that the data is stored in interoperable formats that can be digested by the various organizations and types of users. They are also responsible for implementing solutions that improve the efficiency of the system by reducing data demand to only what is needed (while still ensuring that needed data is accessible). The data manager may also be responsible for performing data analysis that may reveal trends that will help to prevent or predict emergency situations before they occur.

All these professions are experts in their own domains that tend to operate in fast-paced high stress environments. This makes these user personas poor candidates for development from interviews or focus studies since their experiences of emergency situations overshadows the minutiae that GIS systems are focused on solving. It is, for example, not overly important to the first responder how a routing tool works, only that they are given optimal directions in a timely manner. The best ways to understand these users' needs is through direct observation, prototyping, and literature research.

Concepts Considered

The design requirements for this GIS system include handling distributed data, providing capabilities that are adaptable based on the resources from the client devices, working with data in both offline and online formats, two-way communication (and data pipelines) between devices from various organizations, and high scaling capacity to support surges from emergency disasters.

The first concept considered follows the current industry standard of ESRI products, specifically their collaborations model (ESRI, 2022) and its associated field applications. According to ESRI the distributed collaboration model allows the sharing of data between ArcGIS Enterprise organizations and ArcGIS Online. Under the collaborative model each organization controls access to their own data. The strong points for this concept are the well developed and tested field applications that are available for Android and IOS devices. Additionally, online support expands the reach to many other potential devices, while desktop users can still take advantage of robust desktop applications to access the same data. The major downside for this concept is cost, while ArcGIS Online capabilities tend to be free to the end user, applications and offline usage require licensing that would be prohibitive for collaboration with organizations that cannot afford the fees. Another minor downside to the model is the lack of collaborative data ownership options because data must be owned by an individual organization. It would introduce friction for data intended to be shared amongst multiple organizations. A final downside is that applications do not offer consistent interfaces and capabilities between each other, and that multiple applications may be required for a complete system.

The second concept considered looks to the world of open source and the emergent interoperability systems that are present there. Technical guidance from Open Geospatial Consortium suggests utilizing 3D modelling and game engines as a means of advancing interoperability (USGIF & OGC, 2021). This concept would involve creating multiple applications using new open-source technology so that all organizations could use it. The benefits to this concept include increased processing speed thanks to efficiency from game engines, likewise 3D capabilities can expand on the potential audience by being more relatable to users that may not have geospatial experience. Game engine-based applications have another advantage in being able to target multiple device platforms with a single application. The downsides for this concept are cost and time to implement applications, these types of applications are not cheap to produce and many open-source technologies still have room to improve. Another downside is that 3D technologies may be more difficult for some users to navigate, especially in time sensitive situations, and might require more data to be transmitted into the field.

A third concept for consideration is developing a specific application to be used by all organizations. This application would need to be developed for multiple target platforms, including all major mobile OSes and Windows Desktop at a minimum. The application would need to feature adaptable interfaces depending on the user. Finally, the application would need to implement a server solution for hosting and distributing necessary data. The main benefit to this approach would be in the ownership of the application once it is completed, major organizations can collaborate on the application as it is in development allowing their independent needs to be addressed. Another benefit is that all necessary platforms can be supported. Additionally, room for the future development of new features will always be available. A major downside is once again the time to implement as creating new applications is an intensive affair. There may also be some friction introduced as organizations need to determine who is responsible for contributing to the development and maintenance of the application. Another downside is that some organizations may not allow custom software to run on their networks.

A final concept that may be used to develop the proposed GIS system is a custom web-based offering. A browser-based application can be hosted on a web server and provide all necessary functionality to users. The major upside to this method is that it is accessible by most devices and does not run into issues with organizations needing approval to install an application on their devices. Another advantage to this method is that it provides a single format and code base for all users on any of their devices. The major downside for this concept is difficulty in creating offline capabilities for users. This major downside can be solved by using a new file access system API that is being implemented into modern browsers (File system access API - web apis: MDN). Another consideration that needs to be made is how users can keep the application itself on their devices, providing a simple html file or through a web bundler.

Concept Selection

Considering the potential of the various concepts, the browser-based JavaScript application has been selected as the best option currently available. The first determining factor for this decision is that a custom-built browser will be free to the end users, meaning that the potential for collaboration across organizations will not be limited by availability. Along this vein, browser-based applications will also work with any device meaning that potential adoption is even larger.

The needs assessment uncovered current issues with collaboration due to a lack of unified system design between organizations. This concept will address this issue by providing for a singular system that can be used by all participant organizations. Collaboration will also be further enhanced by making the development model be undertaken as a collaborative effort between invested organizations. This type of model helps to ensure that true collaboration can be achieved once the application is completed because all interested parties will have had an opportunity to voice their potential needs during development. The browser model is ideal for collaboration because the development is simplistic with a single target and the need to only create one codebase. Additionally, control is retained by invested organizations in the future development of the application, ensuring that it will continue to meet their needs.

Another issue from the needs assessment is that there will be diverse users each with their own requirements for capabilities and interface design. This concept meets individual users' needs by having a customizable interface facilitated by robust user profiles that can be tweaked for their use case. Groups can be made which users will be allocated to that determine what data the user will have access to and enable easy sharing between them. These user profiles can also help facilitate user tracking for various auditing purposes or enable micro analysis of emergency response.

A final deciding factor for the choice in browser applications is the seamless integration of multiple types of devices. Browser applications will behave the same regardless of the client device being used. At the same time, the client device's full power can be tapped from browser applications, including hardware acceleration. In combination with user profiles to determine the features present in the UI this means that one application can be employed to a user in the field that requires lightweight speed and simplicity, and the desktop analyst that requires a wide range of resources intensive features.

Offline capabilities, the main downside for this concept, can still be employed by the smart use of various tools. Offline data access can be facilitated by the file access system API, which will let users download data from the main server as needed or work with data stored only on the client device. Offline application usage can be enjoyed through a web application bundler (Gardon, 2022). A bundler can allow even complex web applications to run on client devices without an internet connection, potentially taking advantage of existing open-source geospatial APIs like Leaflet to reduce overhead development time.

This browser concept does not easily enable the creation of ad-hoc networks through the browser application; however, these can be created through hardware means. Mobile hotspots from cellular devices or mobile Wi-Fi access points are examples of hardware methods that could be employed by individual networks that could then interact with client devices. Overall, despite this disadvantage the browser application concept presents the most opportunities for collaboration between organizations.

Wireframe Design

This wireframe design captures the necessary elements to create a web application for emergency response organizations focused on introducing collaboration and distributed field capabilities. Upon opening the application, a user may find themselves on their User Profile page, seen in Figure 1, wherein they will be able to join groups and access their available maps. The maps are displayed within the map view pages, the classic view in Figure 2 for desktop users, and a mobile view in Figure 3 for users with compact screen devices. The map view allows users to access a variety of dialogs and buttons to adapt their experience to themselves, of particular importance is the user settings dialog in Figure 4 that allows the user to create and edit roles that changes the tools available, which would each have their own unique dialog as exemplified by a generic model in Figure 5. The primary collaboration means would be through groups managed on their group profile pages shown in Figure 6.

User Steps for Profile Page

1. Click on their avatar to upload a new picture for everyone to see.
2. Verify their user information is up to date and correct, send an email to an administrator to update their profile if not.
3. Create a new custom role for themselves by pressing the new button
4. Filter and assign the tools that they will need from a list of checkboxes that appear while the role is selected.

5. Use the import button to import a pre-configured role from default settings or that has been created by a group the user belongs to.
6. Click on a hyperlink to one of the group pages to go to its group profile page.
7. Press the back button on the browser and return to the user profile, search for a new group the user is not yet part of and request to join it.
8. Click on a hyperlink for a map that will take the user to the map view page

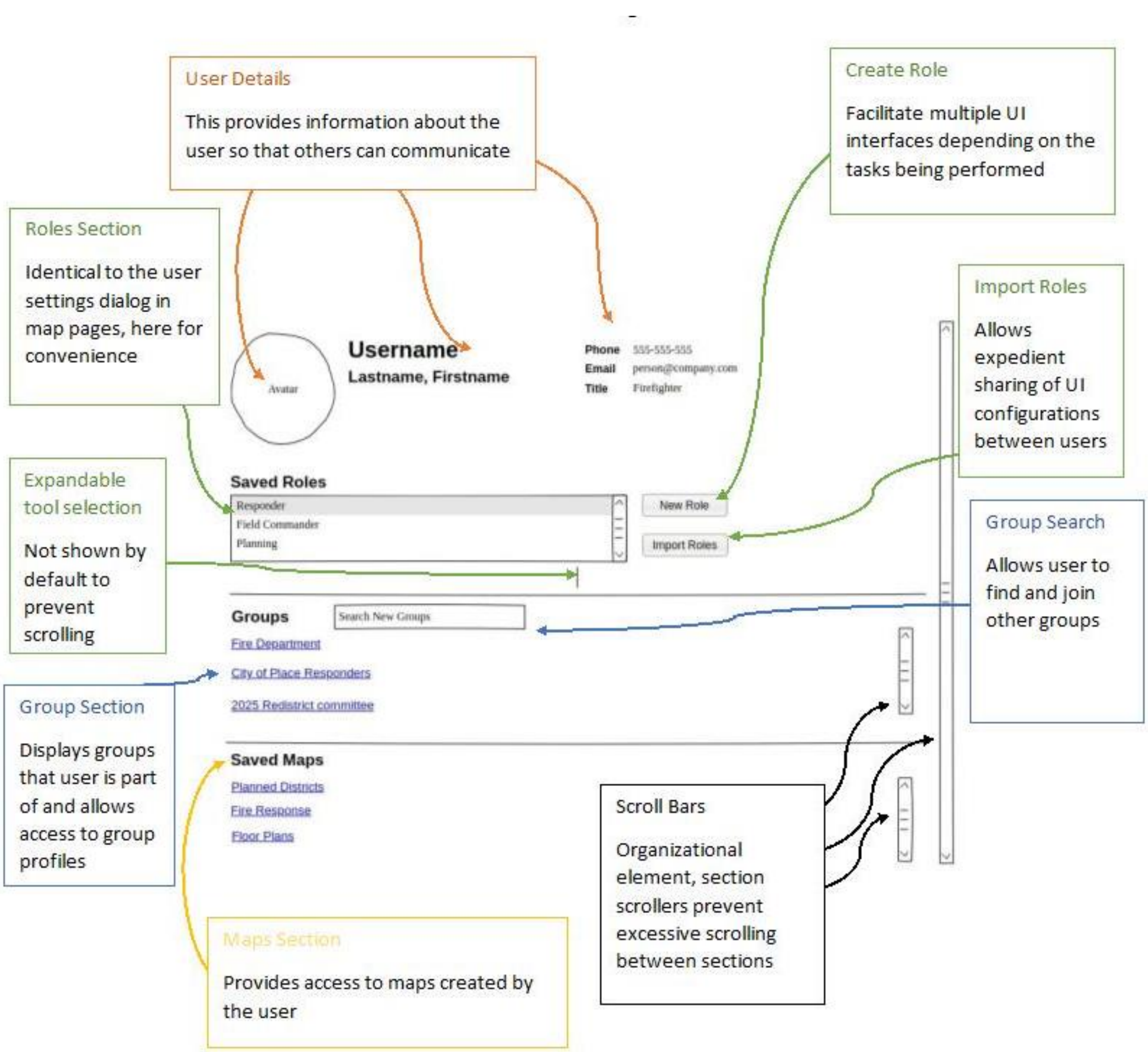

Figure 1. The user profile page. Provides details about the user. The saved roles section provides easy access to manipulate the UI that a user will have in map pages. The groups section shows what groups the user belongs to, providing access to group profiles. The group dynamic improves the inter-organizational collaboration capabilities of the application. Saved Maps provides access to map pages that the user has created or saved.

User Steps for Classic/Mobile Map View

1. Expand the map details panel in the top left so that it is visible.

2. Edit the title of the map because you can

3. Click on the info button to display details about the map and credits

4. Click on the help button to launch a tutorial walkthrough explaining necessary features or to access a knowledgebase on how to interact with the application

5. Click on the save button to create a copy of the map specific to the user

6. Click on share to decide on allowing public access, getting a shareable link, or sharing with specific users or groups

7. Open the layers button to add in a new road line data layer and remove unnecessary data layers, change the symbol for the road layer to reflect typical road symbology.

8. Collapse the map details pane

9. Expand the tool shelf in the top right corner of the page

10. Click on the user settings button to open the tool settings dialog

11. Use the role selection dropdown picking a planner role, changing the tools that are available

12. Select a “Create Route Network” tool that allows you configure the road layer as a network that can be used for routing in other tools

13. Notice that a message in the bottom left of the page has appeared saying that a user has edited a construction road closures layer that was already part of the map.

14. Click on the expand button in the message box to reveal more lines of text, showing that users from multiple groups have been chatting about various emergencies they have been responding to.

15. Click on the settings button to configure options for which groups and types of log messages will be displayed in the message box.

16. Collapse the message box.

17. Before going out into the field expand the connections panel in the bottom right of the page, click on the download data button to have a local copy of the map data and web application downloaded onto your device. Automatically the page should be redirected to the new local copy.

18. While out in the field meet with a professional from another organization that does not have the road data that you have. Use a mobile hotspot to connect your two devices together. Click on the Create local network button to create a password that will allow the other professional to access your map. The other professional makes some edits to the roads layer indicating that some roads will be closed in the near future. These edits are updated and reflected on your device.

19. Returning to the office, click the reconnect to live button that will synchronize the edits made in the field with the data that exists in the online version. This will also delete the data on the current device and redirect the user to the online version of the application.

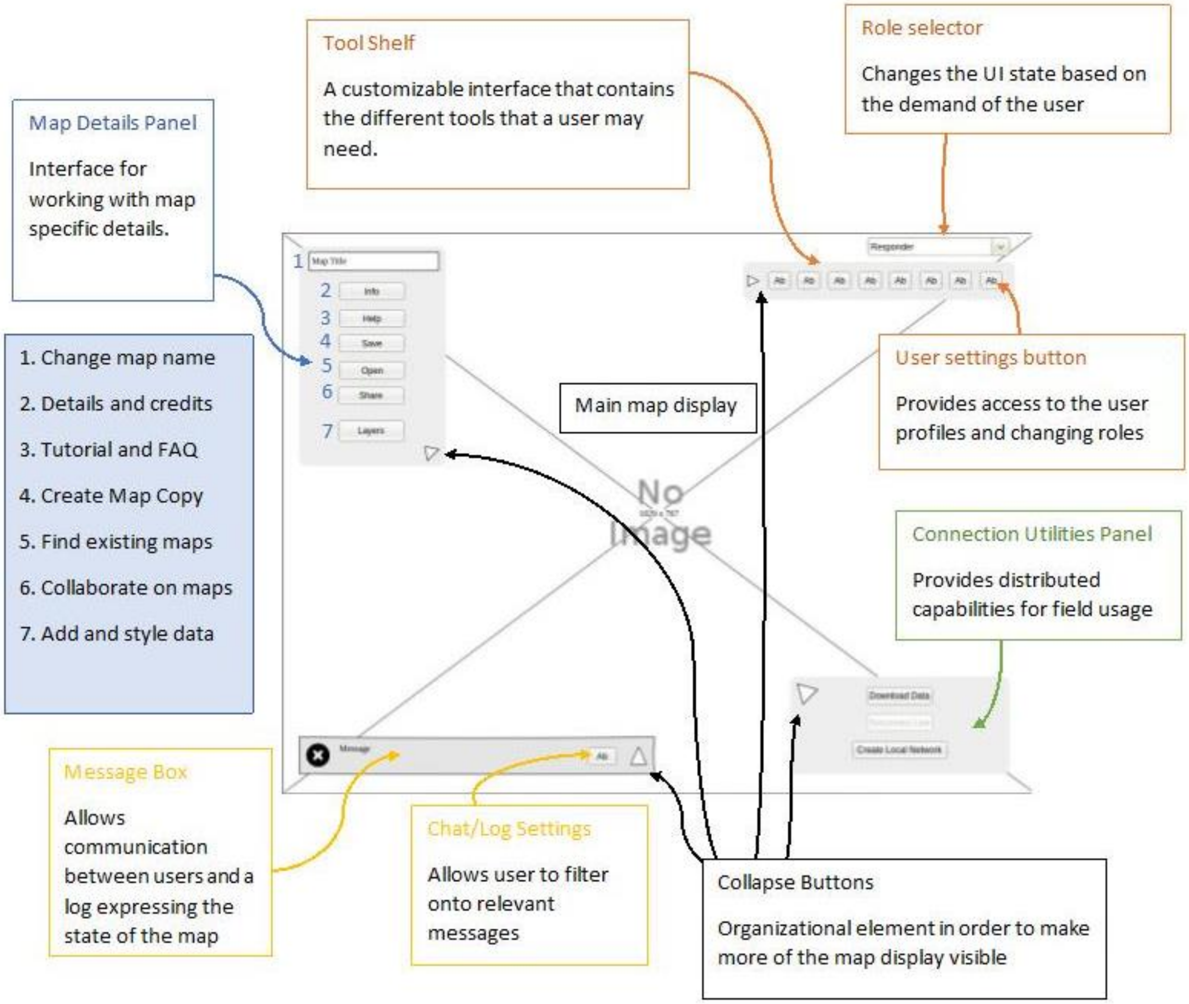

Figure 2. The classic map page for displaying maps on traditional screens. The page consists of four panels in each corner on top of the main map display that shows relevant map layers. The map page serves as the primary method for viewing and interacting with geospatial data in the web application.

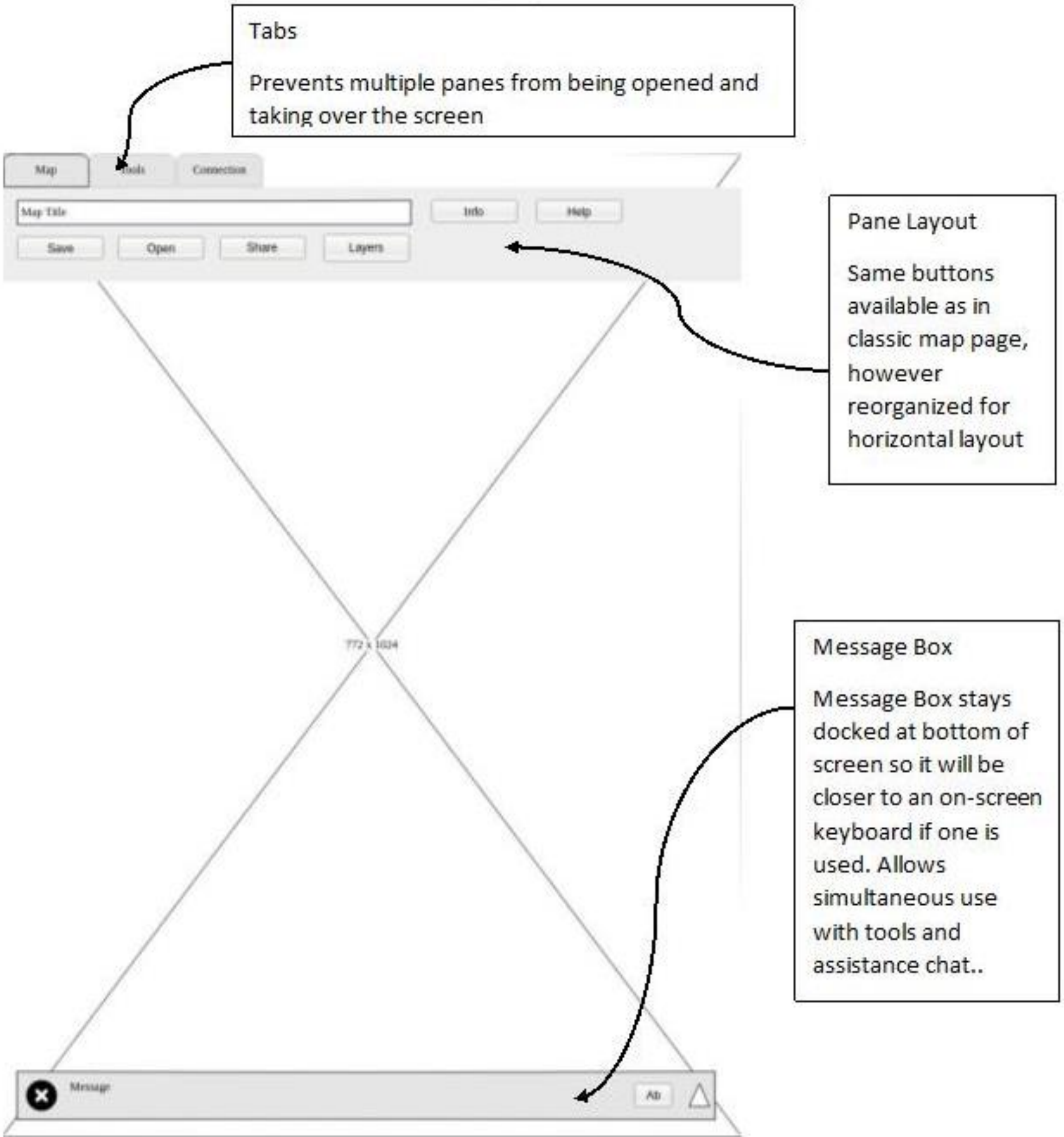

Figure 3. The mobile map pages. This page is identical to the classic map page but adopts a different layout of the elements to accommodate smaller screens and the likelihood of using an on-screen keyboard.

User Steps for User Settings Dialog

1. Click on the new role button to create a new role for planning.

2. From the category dropdown select the routing tools

3. In the filter search bar type in “Build”

4. Find the “Build Routing Network” tool listed with a checkbox, reading a hover tip description confirm that the tool does what you expect it to.

5. Turn the checkbox on

6. Select all of your roles in the role selector

7. Select “General Tools” from the category drop-down

8. Find the measurements tool that you never use and unselect it from all of your roles

9. Close the dialog with the X button

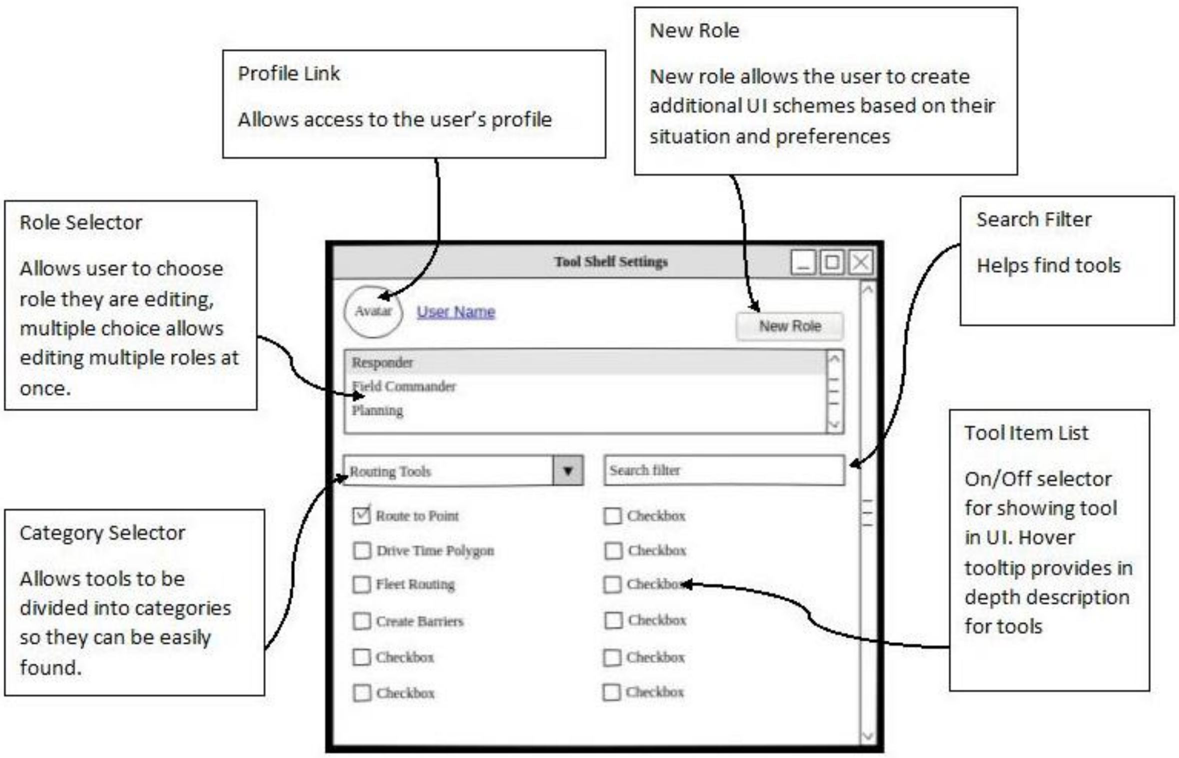

Figure 4. A user setting dialog. This primarily allows a user to create and edit roles that determine the tools available on the tool shelf on the map page. This helps maintain a unified interface for many diverse types of users and facilitates rapid switching depending on the scenario.

User Steps for Tool Dialog

1. Select a file on your device using a file entry dialog OR

2. Select the road layer from the layer dropdown

3. Select from multiple options to configure the settings as needed

4. Run the tool to create a new data layer for use by other tools

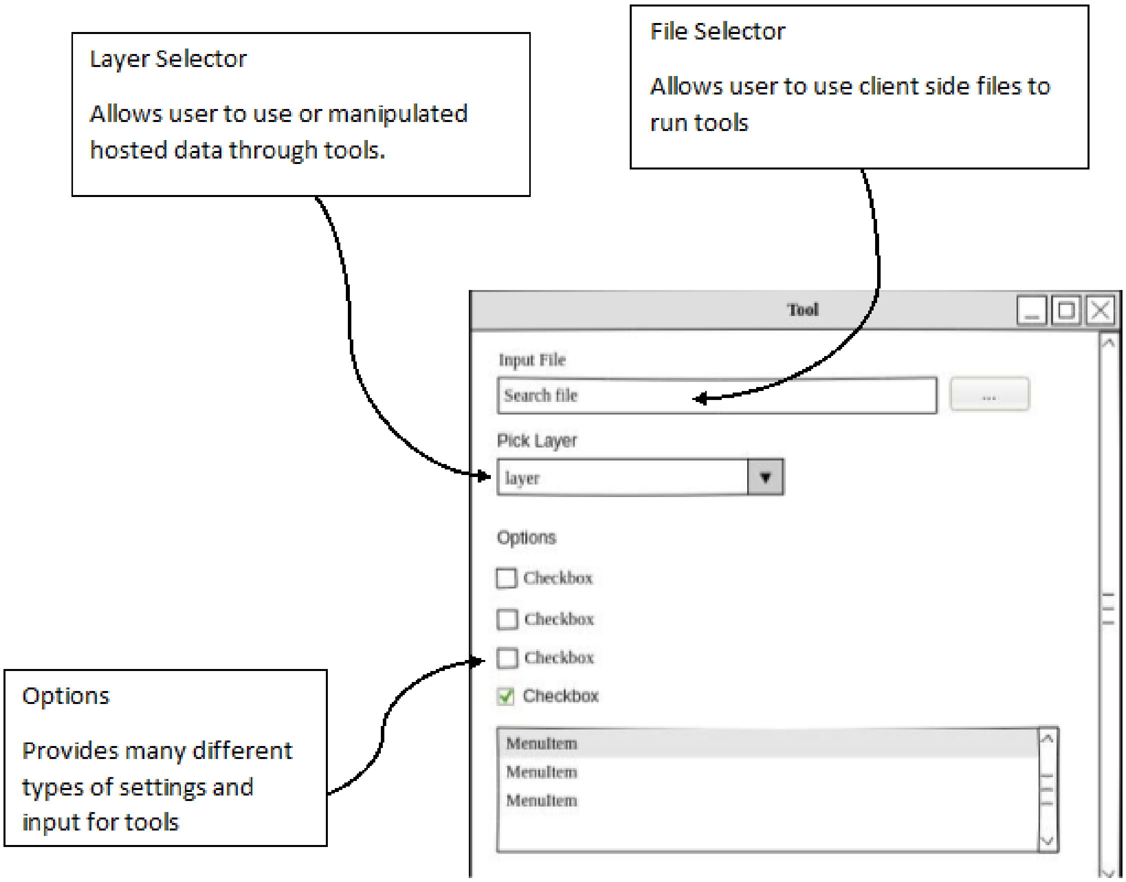

Figure 5. A Generic Tool Dialog. Many tools will need to be developed containing different elements from this dialog.

User Steps for Group Profile Page

1. Observe the group details, including the leader of the group and the hierarchical parent group that this group inherits roles, chat, and map access from.

2. Click on the import role button in the shared roles section to share a planning role created by the user with the group

3. Click on another existing role to edit the tools that are associated with the role

4. Observe all the groups of children inherited from this group in the sub-groups section. Clicking on one will take the user to another group profile page.

5. Observe the different maps that have been created by and/or shared with the group. Clicking on one will take the user to one of the map pages.

Architecture Components

My term project is the design of a collaboration focused web application for emergency response organizations that can be utilized in the field. The overall architecture for the application follows a traditional three tier architecture, with presentation, application, and data tiers. In this application's case, the presentation tier consists of an optional client-sided application for offline utilization derived from and interacts directly with the web application, as shown in Figure 1. The web application serves as the main point for interacting with the stores data, the collaborative center for distributing data to other users.

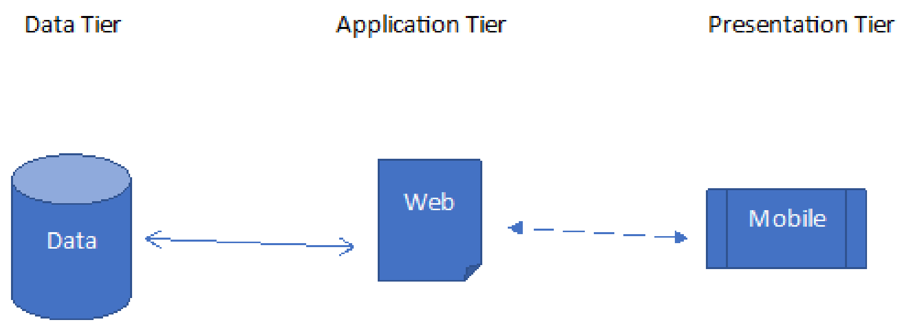

Figure 7. A traditional three tier architecture. The data Tier consists of a database server that serves as the primary source of data. The application tier is created by a web server running a web application that allows users to pull and edit data from the data tier. The presentation tier is a mobile application that is downloaded from and updated by the web application, the mobile application can store and upload data by requesting it through the application tier.

GIS software

The proposed design relies on a web application software, this can be created through several options including pure JavaScript and HTML, although it would benefit from the utility provided by web frameworks like Angular, React, Django or some combination of many others. To create offline client versions a web application bundler will need to be used, the most popular options for this including Webpack and Rollup. Lastly the file access API needs to be used to create and use offline data, and compatible browsers need to be used on client machines. For the data server PostgreSQL is the simplest option and mobile devices may need a native wrapper application created from a cross-platform framework like Electron or Flutter to access the device's networking capabilities to create ad-hoc networks. Table 1 provides a summary of these required software.

Web Application	**Data Server**	**Mobile Application**
Web Framework • JS • Angular • React	PostgreSQL	Bundler • Webpack • Rollup

• Django		
File Access API		Modern Web Browser
		Cross-platform framework • Electron • Flutter

Table 1. A table summarizing the software requirements for the proposed project design, organized by the architectural tier. Bullet items denote potential options for each required software component.

GIS hardware and networking

The critical hardware can be divided into each of the architectural tiers. For both the web and database servers a critical decision must be made to rent the servers from cloud providers or to supply them on premises, introducing a larger upfront cost. Cloud hosting has a long-term benefit, however for simplicity both the data server and web server can be hosted by the same on-premises machine for the development of a minimum viable product. The machine will primarily need access to large and fast data storage to host the data layers needed to support the application. The server will require a high-speed internet connection to interact with client devices.

For the mobile application, the devices running it will be provided by the client and will not factor into the cost, but consideration must still be made for the supported devices. As a minimum both Android and IOS mobile platforms should be targeted. Additionally support for Linux, Windows and Apple laptops and tablets should be considered.

Database Design and Requirements

The database design needs to feature significant optimization since substantial amounts of data will be required to host geographic data layers. The database should separate the tables needed to manage user profiles and groups from the tables for geographic data layers. The PostGIS extension provides ideal formats for storing geographic data. Data tables should protect their information by employing access roles to prevent unprivileged users from accessing the data.

Another important data consideration is the format stored when deployed to a client machine. A client-based database like SQLite may allow the data to easily be transferred between the two devices, however, a more standard format like Shapefiles or GeoJSON would allow the data to be edited by other applications. Given that the focus of this project is on improving collaboration, supporting outside editing is the more desirable outcome, as such GeoJSON is the first-choice format. With GeoJSON as a target format for both sending and receiving data, the PostgreSQL tables should limit input so that it adheres to GeoJSON specification standards.

Enterprise GIS components

Performance Considerations

As a core principle, the performance of the application should be limited to the lowest device that may be running it. In the case of this system design that is an unknown variable since the mobile devices are provided by outside organizations. Therefore, a minimum requirement should be specified as the target for performance. At minimum, the application must support viewing and editing data at near instantaneous rates, and basic analysis tools like routing within seconds to meet the needs of emergency users. More advanced analysis tools may not need to run well on these devices, but they should display a performance warning to curb user expectations.

While the server running the web application is unlikely to face processing limitations on running analysis tools like mobile devices, it is more likely to face issues with scale. A significantly larger number of users may be utilizing the web server at the same time and the server must have the capacity for surges in demand for larger emergencies. Scaling for demand can come through either physical backup servers, or a hybrid cloud solution to spin up additional servers when needed.

Maintenance Considerations

The primary maintenance consideration is the updates to client mobile application versions. Having multiple versions out in the field after performing updates is an undesirable potential when allowing offline applications. To prevent this, mobile application versions should be checked and updated every time the user downloads or uploads data. Newer versions should also be easily available to download for offline users that do not access data frequently.

Along with offline applications also comes offline data that can quickly become stale. The data layer owner should be able to specify a maximum checkout time for which the data layers will allow edits before refusing them from being checked back in.

Further maintenance will also be needed to prune or archive inactive data and users. Allowing data to sit on the server can quickly inflate storage costs in the database.

Security Considerations

Security for users and their data is an oft assessed problem in computer science. The newest industry standard requires two-factor authentication to make up for the increasing vulnerability of password only systems. Recent direction in the industry has been moving towards passwordless authentication, this type of authentication is ideal because it not only tends to be more secure than passwords, but they are also easier and quicker for users to setup, which is beneficial for a collaborative platform in attracting more users.

Outside of actual vulnerabilities in creating or logging into user accounts, there are security concerns for users being given permission to access data when they should not. The straightforward way to combat this is by using obvious visual indicators in the UI (User Interface) for when users are granted permission and tools to audit lists of all users with access to a particular item.

Of special concern for this web application is ensuring that there is a way to easily revoke permissions. Organizations will regularly have turnover or stop working with each other; therefore, they need an effortless way to remove a user or group's access. Group hierarchies can help by propagating revocation actions throughout subgroups. Sometimes it may also be required to block specific users from access if they are part of or may end up in a group that does have access.

Data Design

My term project is the design of a collaboration focused web application for emergency response organizations that can be utilized in the field. To fully support the collaborative nature of the project, it must utilize data from both open and proprietary sources. Some organizations that will need to upload their data onto the web application have various requirements as to what data they can publicly release. Other organizations may not have their own data and will require open data to build their maps from. To support users with limited access to data the web application will host open data of diverse types, while proprietary data will be provided by organizations themselves.

Data Characteristics

The data provided by the web application must be open so that it can be accessed by all users that sign up to the application. The data that is most critically needed to support emergency operations is city infrastructure, especially including buildings and roads. This data will need to be provided as both vector geometry and through basemaps. For basemap data the inclusion of aerial/satellite imagery can supplement a lack of vector data.

Data provided by users of the application will vary depending on needs; utilities are a common requirement for emergency response but are often not included in public datasets due to their sensitivity, for example. Other uses might involve features used for planning and districting or emergency incidents tracked by local organizations.

Data Sources

The primary data source that will be provided is OpenStreetMap data, much like that shown in Figure 1. The OpenStreetMap project contains lots of high-quality data that has been validated by many organizations and volunteers that use the data. A downside of the volunteered geographic information that comprises OpenStreetMap is that volunteers can potentially compromise the data (maliciously or not). Data quality can be assured by relying on older downloaded copies of the data, rather than pulling from the source website each time. Downloaded copies also enable download functionality for users, however it also introduces overhead in the system as users will need to download or reference the data directly from the web server, instead of OpenStreetMap's servers. The entirety of current OpenStreetMap data can be downloaded (*Planet.osm* 2006), however the large file size makes this discouraged, instead data should be downloaded through a third party at a country, state or potentially even county level. The Overpass API provides a means to download the data (*Overpass API User's Manual*) and allows the data to be redownloaded periodically through automated tools which will be necessary to ensure the data does not become stale.

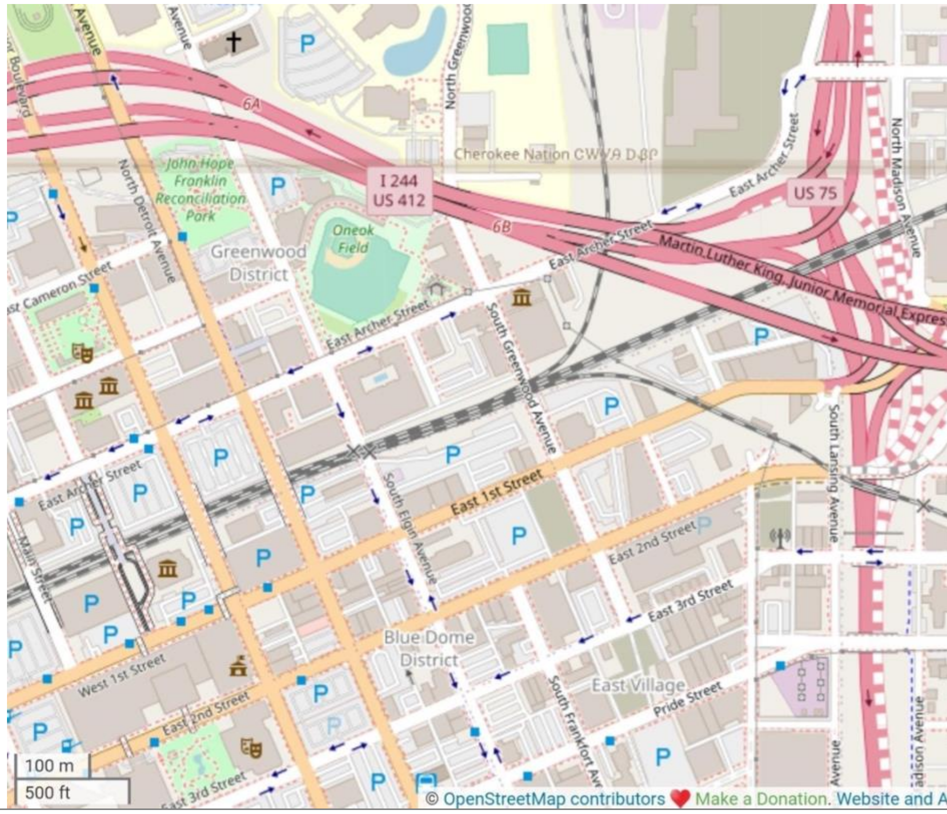

Figure 8. An example overview of OpenStreetMap as seen in Tulsa, Oklahoma. Attained from OpenStreetMap.com and created by Open Street Map Contributors.

Due to the potentially large size of data, users of the web application should be discouraged and limited in what they are allowed to download for offline use. One way to make offline download sizes smaller is by offering basemaps instead of the vector data directly. Stamen provides stylized basemaps from OSM data that are available using the open CC BY 3.0 license (*Stamen maps*).

Freely available satellite and aerial imagery is available from several sources, however many of them, like ESRI, place limitations on downloading the imagery tiles which is necessary for offline use. The best source of downloadable imagery data in the United States is through the NOAA data access tool (*Data Access Viewer*), however this interactive tool requires manual input to find and download the imagery. The lack of automated tools means that imagery provided by the web application is not likely to be updated frequently, therefore high-quality offerings should be chosen for the initial provisions.

The source for user provided data can come from many places, they may be created in-house by the organization or might be given to the organization by another party to share via the web application. It can generally be assumed that users will provide data at the quality level that they need it at.

Data Quality

All the data that is hosted on the web application, whether the open data provided by the application or the data that is brought by the users, should be utilizing the same projection. Ideally this projection would be the Web Mercator projection, to ensure all data is using the same projection, and the application displays data similarly to other GIS web applications. However, the Web Mercator projection has a significant downside in that it does not have accurate distance or area measurements, this lack of accuracy is likely to cause significant issues for analysis tools like measurement or distance cost routing that are needed for the application. An alternative projection is to use UTM projections, however this has the downside of requiring multiple different projection zones for the data. One strategy may be to utilize the Web Mercator projection to display the data while having analysis tools convert to UTM projections on-the-fly when needed.

The data will need to be serviced at a high resolution, enough so that emergency responders would be able to make out the unique geometry of features when looking at a city block level for navigational purposes. When viewing at a smaller scale, there is less need for high resolution and some accuracy loss will not be as important, but the data must still have high resolution for analysis tools.

Data Storage

The primary storage for data in the web server will be a PostgreSQL database that stores features as PostGIS geometry types. This storage format ensures that features can be shared with many users quickly and securely. A Postgres database is not feasible for offline use, instead the data will need to be converted to shapefiles or GeoJSON when sent to the user. Users might be expected to provide their data in Shapefile or GeoJSON format at which point it will be converted to the PostGIS format by the web server.

Data Design Rationale

The dual model of providing open-source base data and allowing users to upload their own proprietary (or open) data provides many advantages for collaboration. The use of open data for the application itself prevents any unnecessary fees if the number of users expands drastically while also avoiding potential issues from some organizations not having access to the data. On the other hand, allowing users to upload and control the sharing settings for their proprietary data allows them to engage with the platform, even if they are not necessarily open to sharing that data with everyone else on the platform. A disadvantage to this choice is that the licensing of the data accessible via the application may become confusing to the users. It will be important to appropriately label the licensing restrictions and sources for data in the application, while also making sure that users have the option to do so while uploading their data.

Evaluation

My term project is the design of a collaboration focused web application for emergency response organizations that can be utilized in the field. The primary evaluation methods I will use for my term project are field and tabletop exercises. With the focus on improving collaboration, heuristic measures and surveys cannot easily evaluate the application's success. The first step in establishing exercises as an evaluation method is to establish benchmark performance from a control group that is utilizing existing methods. As a cost-saving measure real-world historical emergencies can be utilized as a control, provided there is sufficient data to determine benchmark performance. One useful benchmark metric is network analysis, a recent method to evaluate collaboration in real scenarios proposed by Cross et al. (2009). Other benchmark metrics for exercises can include task completion time, data quality and post-exercise user surveys. A secondary focus for the application is field usage, which does lend itself well to heuristics. For first responders field performance is of utmost concern, heuristics will be used to evaluate the utility of the application in reducing response times. The main heuristics that will be useful to collect are task completion time and time spent utilizing a device, which would also be considered time that the first responder is not aware of their situational environment.

Cost-Benefit Analysis

The primary costs for implementing the web application in this project are with the hosting of the web server. No licensed software will be utilized which makes demand scaling straightforward. As more users become involved in the project more processing power and bandwidth will be needed to properly serve all the users. Additionally, as more data is uploaded to the website, storage space will need to be purchased and allocated to host the data for users. These hosting costs are summarized in Table 2 for both their initial implementation cost, and estimated costs accounting for user growth.

Item	Initial Cost	Continuous Cost
Web Server Hosting	$100	$100 per 1000 users
Data Storage Hosting	$100	$100 per 1000 users (2gb/user)
Software Development	$300,000	$300,000 per year
Professional Evaluation	$400,000	-
Comparable Licensing	-	-$100,000 per 1000 users
Saved Human Life	Priceless	

Table 2. The itemized list of costs and benefits for developing and implementing the web application for this project. Hosting costs are estimated based upon self-hosted dedicated servers and storage drives. Professional evaluation is estimated based on 1 month of evaluation with 24 professionals at an average salary of $100,000. Comparable licensing is conservatively estimated based on ESRI's field application at $100 per user.

Beyond hosting costs are also the costs to design and implement the web application. Although it is highly likely the customer organizations would contribute either significantly or entirely to the design and production, their members would still be involved in the project instead of their typical duties, resulting in opportunity costs. Therefore, it is reasonable to assume that the cost of creating the web application should be equivalent to the costs that would be required to pay an outside contractor to build the application, in this case it is estimated to be 3 full time software developers working full time for 1 year. There are additional maintenance costs associated with the development of the web application, security will need to be reviewed frequently and new features may need to be implemented based on feedback from users. Again, the estimate for maintenance is assumed to be 3 full time software developers. The costs for the initial development and subsequent maintenance for the application are summarized in Table 2. The application's design also requires evaluation by subject matter experts for field exercises which take time away from their typical duties, the cost of which is expressed in Table 2.

The benefits for the web application are harder to quantify than the costs. The easiest to quantify benefit is the lack of licensed software needed to be purchased by participating organizations. It is difficult to determine if users of the web application would otherwise be using another software product, however if it offers similar functionality, it could be considered a replacement. The most comparable application is ESRI's field application which does not openly advertise the cost for users, however the basic personal account costs $100 and does not even include field application functionality (ESRI), therefore it could be used as a minimum cost for a comparable application per user, as shown in Table 1. Other benefits for an improved emergency application include improved emergency response times or accuracy which could both result in the protection of human life which is not an easily quantifiable measure but still a significant one for the public good and well worth the low hosting and development costs for the application. Additionally, although the time of professionals to complete evaluation exercises is accounted for a cost of the application, it also provides the professionals an opportunity for much valued training, which may alone justify the cost.

Future Work

The conclusion of this conceptualize stage begins further work which must be completed on schedule if the estimated costs are to be realized as shown in Table 3. Immediately following the conceptualization is the evaluation phase which will require paper designs to conduct the required field and tabletop exercises. Following the first evaluation and a short redesign period a prototype application must be created. The prototype will begin evaluation stages where time to complete tasks becomes most accurate, therefore the prototype must contain the functionality to complete most of the basic tasks. Following the prototype and evaluation comes the minimum viable product, evaluation for which will determine the applications usefulness in prolonged collaboration settings, such as after emergency incidents and thus the basic frameworks for group interactions must be established. After the minimum viable product is evaluated, the final product will be ready to be completed, including any UI improvements to ensure accurate benchmarks for task completion time in the final evaluation. If the application has proven successful during the final evaluation, the project will begin maintenance efforts including the design of more analysis tools, security updates and new features or design improvements based on user feedback.

Time	Milestone
1 Month	Paper model designs and first professional evaluation
2 Months	Analysis and redesign based on evaluation
4 Months	Prototype web application completed • Functional Map and Chat Web Interfaces • Basic Analysis tools functional • Data uploading capability

	• Data offline and sharing capabilities implemented
5 Months	Completion of prototype evaluation
7 Months	Minimum Viable Product Completed • All web interfaces are completed • Most analysis tools are functional • Offline application is ready
8 Months	Completion of MVP evaluation
10 Months	Final Product Completed • Web UI is polished • User accounts are functional and secured • Analysis tools are complete • Offline application available for download
11 Months	Final Evaluation
12+ Months	Ongoing maintenance based on user feedback

Table 3. The complete work schedule for the web application project ending with the ongoing maintenance phase. The time column represents the number of months since the conclusion of the conceptualization phase.

Most of the issues that are not currently solved by this project are potential future expansions. An example of this may include the implementation of more offline data types that would require more effort. Additionally, there may be organizations that require self-hosted rather than offline or web-hosted data in which case new data pipelines would need to be created for the web application. Finally, the scaling of the web application and addition of new users may create the need for more developers to become involved in the project to deliver features that are demanded by the users, such features are however not included in the scope of this project as they would be a significant expansion of work.

UML Use Case Diagram

The UML diagram in Figure 9 represents the use cases for the collaboration focused emergency response field application proposed for this project. The actors for this diagram represent the various user personas captured in the application design. The actors include First Responders that will use the application as an aide in the field, Operators that will coordinate emergency response from a tactical control center, Field Managers that organize and supervise First Responders in the Field, Organization Coordinators that assist in organizing users into groups and granting permissions both inside and outside of their organization, infrastructure data managers that are responsible for ensuring that responders have up to date GIS layers available to them, and Map Designers who are responsible for creating maps from the available layers into a useful format for other users. All the use cases will be available to all users, provided they have been granted appropriate permissions, however some of the actors have no need for some of the use cases, for example an organization coordinator has no need to view maps considering their function deals entirely with the group function of the application. The primary use cases for the application are logging in, view profiles, viewing maps, and viewing groups. Each of the viewing use cases are further extended by interaction to perform additional actions concerning the viewed information. Viewing profiles for instance are further extended by allowing the user to change their UI role or edit the information in their profile, while also containing subordinate use cases for viewing maps and groups. The map and group use cases are each extended by multiple use cases, particularly the group chat use case included in both. The map viewing use case is also extended by downloading offline application use case which is significant because it provides access to the offline application sub-system which includes offline viewing/editing and data resyncing use cases.

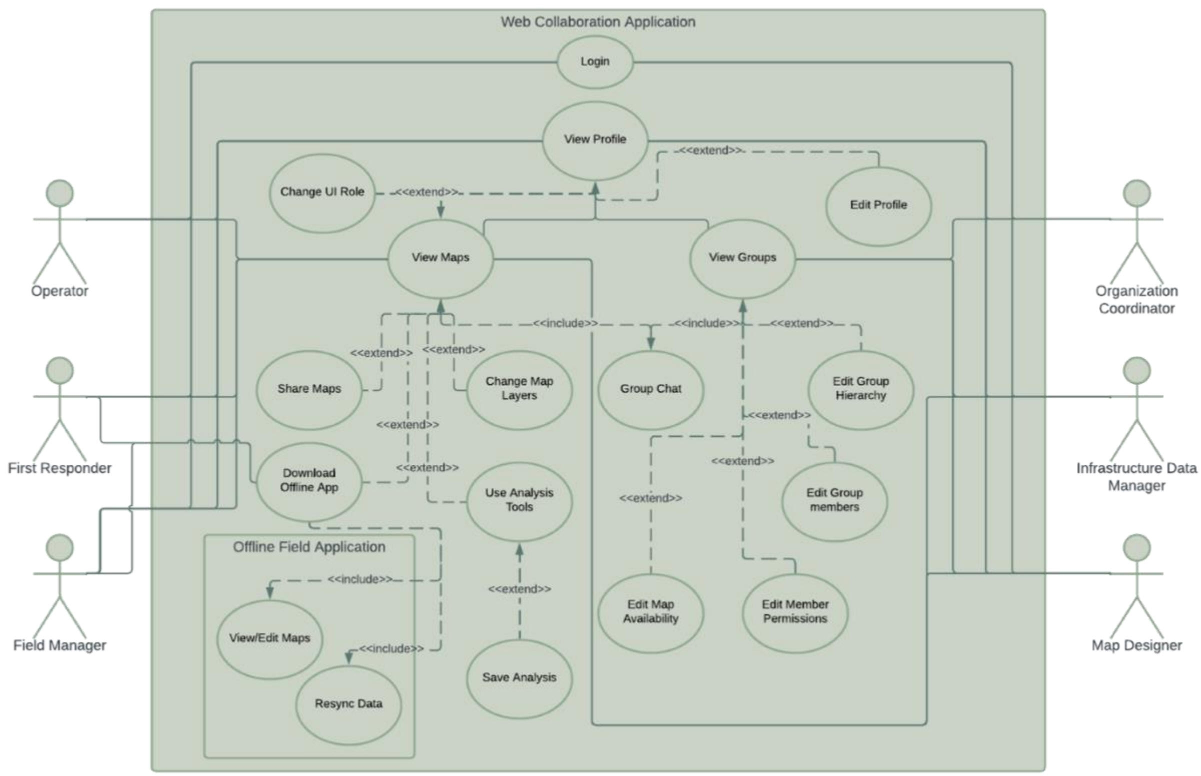

Figure 9. UML use case design for Emergency Response Field Collaboration System.

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