A Systems Engineering Approach to Search and Rescue Operations

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Author Note: Our client for this Capstone Project is the Department of Defense's Joint Artificial Intelligence Center (JAIC), an organization that works to harness the power of Artificial Intelligence (AI). The JAIC uses different forms of AI to develop new military and government capabilities as well as increase efficiency within already existing programs. The JAIC is divided into six different mission initiatives. This project supports the JAIC's Humanitarian Assistance and Disaster Relief (HADR) initiative to advance search and rescue operations through technical platforms in order to optimize response times and effectiveness by better connecting victims with first responders with the proper critical lifesaving equipment.

Abstract: The Department of Defense is often called upon to support Humanitarian Assistance and Disaster Relief efforts to include domestic Search and Rescue operations. The key to success in these operations is the rapid identification of the location of the incident, equipment required, and the conditions of injured personnel. This research focused on improving search and rescue operations through the means of a technological platform to collect and organize vital information. The project seeks to develop a program architecture that will model a response system that will efficiently and effectively connect victims to first responders.

Keywords: Artificial Intelligence, Search and Rescue, Response Time

1. Introduction

Humanitarian Aid and Disaster Relief (HADR) efforts often provide immediate response to personnel in distress following various emergencies and natural disasters. Organizations such as the Joint Artificial Intelligence Center (JAIC) are looking to analyze and improve the overall processes of emergency response efforts within the scope of domestic search and rescues. Organizations today are constantly racing against the clock to reach distressed individuals in critical situations. Unfortunately, when first responders and emergency relief organizations fail to act quickly and efficiently, lives are lost. This research took a deeper look into the wide range of issues within the current flow of Search and Rescue (SAR) operations to identify areas of friction. Some key tasks regarding search and rescue efforts include allocating tools and resources, determining the best route to collect stranded personnel, managing wounded individuals, identifying and disposing casualties, restoring means of travel access to remote areas, and providing basic human necessities such as food, clean water, and shelter. This research created a foundation of research and identify critical elements to enable a widespread network of actors and organizations to work more efficiently and effectively. A focal point in the research is determining how to effectively manage the flow of information. This research analyzed the current process of SAR operations and provided alternative ways in which Artificial Intelligence (AI) can be utilized to effectively manage information. The product derived from this research will serve as a foundation for a system that will be used in larger scale HADR operations.

2. Search and Rescue Operational Systems

2.1 Overview of Search and Rescue Operations

With the implementation of new technological the DoD's capabilities within SAR operations have exponentially developed. Currently, many dynamic systems operate within emergency response operations, each capable of collecting and using a wide range of inputs and information types. However, first-level responders continue to face problems with information management, allocating resources, and making the most of their time. As information becomes more assessible, the inflow of data collection becomes overwhelmingly abundant. As a result, various nuisances emerge such as the recording and storage of futile factors within otherwise effective databases. These problems with data filtration and management are magnified throughout various SAR operations, which develop inadequacies that may result in the failure to save a life. Data management is essential when it comes to using technological platforms for such a critical field of work. Specifically, all operations relating to search and rescue depend on classifying input data into appropriate phases, analyzing the inadequacies present within data management, and identifying the types of outputs required for developing better alternatives.

2.2 Inputs and Outputs of Emergency Response Systems

Systems that identify data requirements while simultaneously filtering redundant or unnecessary data are being adopted by various organizations such as the JAIC. Currently, these systems separate incoming data into three main types: pre, during, and post. Organizations gather these inputs to initiate operations to provide the appropriate aid. Problems arise when manual workflows are forced to process all the incoming information. Eliminating manual workflow in the early and middle stages of data management will result in more efficient and effective mission outcomes. Categorizing the data is the first step to account for the unpredictable inflow of data, which enables stochastic inputs to be observed in a dynamic manner. After placing incoming data into these three types, the input can be used to identify primary factors regarding people, authority, and resources. This will lead the first responding organizations to develop accurate outputs that will improve mission effectiveness and efficiency.

2.3 Inadequacies present within Emergency Response Systems

Despite current capabilities regarding input assessments, modern organizations show reoccurring inadequacies over accountability and response times. The inadequacies present within SAR operations are a result of information overload. In addition to information overload, there is a lack of coordination and cooperation among different organizations. As stated earlier, manual workflows that analyze incoming information from multiple platforms fail to meet time constraints and limit effectiveness and efficiency of SAR operations. In instances such as Hurricane Harvey, Irma, and Maria these inadequacies proved detrimental to victims affected by these disasters because basic networks for communication were no longer available. As a result, other platforms such as social media and first-hand accounts were utilized for damage assessments and situational awareness. However, despite receiving any data first responders still lacked coordination with other humanitarian organizations. These common occurrences happened because of the inefficiencies when allocating the appropriate resources because there were still issues in managing and filtering the required information compatible with all responders nearby the critical situation.

This project sought to address the problem of how to control data in order to ease operations relating to humanitarian efforts and disaster relief. The strategy developed will expedite the flow of information within search and rescue systems as the Joint Artificial Intelligence Center seeks to develop new technologies to assist with search and rescue missions. A mission of the JAIC is to create artificial intelligence infused technology to assist search and rescue personnel on their missions.

3. Methodology

This research followed the Systems Decision Process (SDP), which is divided into four phases: Problem Definition, Solution Design, Decision Making, and Solution Implementation. This methodology acts as the main framework for creating solutions to a problem through proper analysis. During the first phase of this process, research and stakeholder analysis were conducted in order to create a problem definition. After developing the problem definition, the next phase will focus on an alternative solution that infuses of artificial intelligence into everyday life to increase efficiency and effectiveness of the given problem. The focal point of the solution design is determining how AI can be integrated into a user interface, such as an app, developed for search and rescue operations. The next step in design process is to assess various methods of integrating AI into different alternative models and assessing their relative efficiency as pertained to information management.

3.1 Problem Definition

JAIC's main goal is to leverage artificial intelligence to reduce response times associated with locating personnel, managing resources, and rescue operations. *This project seeks to develop physical and functional architecture of alternative systems capable of aiding in search and rescue operations.*

3.1.1. System Functions

First-level SAR operations involving the victim(s) and the emergency responder who first received the distress signal can be shown in a linear matter, where each party is a key actor in the flow of information pertaining to the distress alert. The figures below will help depict the functions needed to determine how data is best distributed and how AI can be implemented to create outputs focused on improving response times. The functional hierarchy shown in Figure 1 was developed to depict the main functions of a conceptual app. The purpose of this diagram is to show how incoming information is interpreted, categorized, and assessed to create alternative outcomes for decision-makers. The fundamental objective to efficiently manage data flow in SAR operations is divided in three main functions: collecting data, storing data, and distributing data.

Figure 1: Functional Hierarchy

4. Statistical Analysis

Statistical analysis was conducted on a data base consisting of 400 different Search and Rescue cases from 2019. The purpose of this analysis was to determine which of the recorded data, if any, had a significant affect towards an operation's success rate. Each recorded rescue case within the data base contained 26 different columns indicating different recorded variables. A few of the variables tracked are the event's location, the types of assets utilized, the type operations conducted, data availability, and the number of people involved. In order to properly analyze the data set, the cases were divided based on two main factors: SAR assistance and incident type. Each section was then assessed based off the number of cases, number of persons rescued, number of persons involved, and their corresponding rescue rates. As shown in Table 1, the two analyzed sections depict which variables (types of assistance or incident) had the highest and lowest rescue rates. In conclusion, SAR operations conducted in 2019 had a total rescue rate of 87%, having the most success in maritime operations using supporting data as the assistance type.

Table 1: 2019 Search and Rescue data

SAR Assistance type	data not used in SAR	First Alert	Only Alert	Supporting Data	Totals
cases	180	129	44	47	400
persons rescued	591	199	74	160	1024
persons involved	659	249	99	170	1177
Rescue Rate %	90%	80%	75%	94%	87%

SAR Incident type	Maritime	Aviation	Land	Totals
cases	156	166	78	400
persons rescued	579	498	100	1177
persons involved	542	392	90	1024
Rescue Rate %	94%	79%	90%	87%

4.1 Analysis of Variance between factors

To properly assess the filtered data presented in Table 1, an Analysis of Variance (ANOVA) was conducted to determine if any of these given variables had a significant affect towards an operation's rescue rate. By using a two-factor ANOVA test with a 5% significance level ($\alpha = 0.05$), two statistical models were created determining the presence of any significant difference between the defined variables. As shown in Figure 2, the two factors used for each test consisted of the defined variables within the SAR's assistance and incident type (Factor A) and the "operational status" for each event (Factor B). In accordance with this two-factor analysis, the created null hypothesis stated that all assistance or incident types (factor A) are statistically similar to the SAR's operational status (Factor B), concluding that each variable had no significant affect towards a SAR operation's rescue rate. If the model provides a probability greater than the significance level, the created null hypothesis is then rejected therefore concluding that these analyzed variables may have a significant affect towards an operation's number of cases, persons involved/rescued, and its rescue rate.

	Test 1	Test 2
Factor A	**SAR Assistance Type** (data not supported, first alert, only alert, supporting data)	**SAR Incident type** (maritime, aviation, land)
Factor B	**Operational Status** (# of cases, persons involved, persons rescued, rescue rate)	**Operational Status** (# of cases, persons involved, persons rescued, rescue rate)

Null Hypothesis	Alternative Hypothesis
$H_{0A} : \tau_1 = \tau_2 = ... = \tau_i = 0$	$H_{aA} : \tau_i \neq 0$ for at least one i
$H_{0B} : \beta_1 = \beta_2 = ... = \beta_j = 0$	$H_{aB} : \beta_j \neq 0$ for at least one j

Figure 2: Two-factor ANOVA test

If the ANOVA tests provide any probabilities within the significance level (p-value > α), the presented model then fails to reject the created null hypothesis concluding a lack of difference between the factor's statistical means. As shown in Figure 3, model 2 concludes that the conducted ANOVA test fails to reject the null hypothesis stating that the categorization of incident types into maritime, aviation, or land has no significant difference or affect towards the number of cases, persons involved/rescued, and rescue rate within an operation. In contrast to model 2, the probability from the ANOVA test in model

1 doesn't fall within the significance level (p-value < α), therefore rejecting the null hypothesis. In conclusion, this model shows that determining an operation's assistance type as either a first alert, only alert, data not used, or supporting data has a significant affect in comparison to the categorization of an incident's type.

Model 1: null hypothesis rejected

Model 2: fails to reject null hypothesis

Anova: Two-Factor Without Replication
Type of Assistance

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
cases	5	800	160	21296.5
persons rescued	5	2048	409.6	157418.3
persons involved	5	2354	470.8	203012.2
Rescue Rate	5	4.25467	0.850934	0.005998
data not used in SAR	4	1430.897	357.7242	101365.5
First Alert	4	577.7992	144.4498	11593.55
Only Alert	4	217.7475	54.43687	1786.689
Supporting Data	4	377.9412	94.48529	7000.001
Totals	4	2601.87	650.4675	300491.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Operational Status	719873.2	3	239957.7	5.265717	0.015053	3.490295
Assistance Type	980070.3	4	245017.6	5.376752	0.010236	3.259167
Error	546837.7	12	45569.81			
Total	2246781	19				

Anova: Two-Factor Without Replication
SAR Type

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
# of Cases	3	400	133.3333	2321.333
# of people involved	3	1177	392.3333	65734.33
# of people rescued	3	1024	341.3333	53001.33
Maritime	3	1277	425.6667	54882.33
Aviation	3	1056	352	28756
Land	3	268	89.33333	121.3333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Operational Status	112946	2	56473	4.139238	0.106128	6.944272
SAR incident type	187540.7	2	93770.33	6.872978	0.050807	6.944272
Error	54573.33	4	13643.33			
Total	355060	8				

Figure 3: Two-factor ANOVA models

4.1.1. Analysis Conclusion

Based off the analysis from Figure 3, the SAR's overall operational status is statistically significant due to the type of assistance used in search and rescue operations. A case's assistance type being a first alert, only alert, data not used, or supporting data showed to impact an operation's overall success rate. Because majority of the issues present within SAR operations relate with the inefficiencies of data management, this model prioritizes what type of data is needed through statistical comparisons. With a shift in focus prioritizing data regarding assistance type over incident type, the created models show the difference between data focusing on a victim's status over any factors present within maritime, land, or aviation operations. However, despite depicting a higher significance towards identifying the type of assistance per SAR case, this model does not minimize the importance of logistical availability or resource allocation for the type of SAR incident. Rather than specifically focus on one factor over another, this model depicts how current data filtration systems may be sequenced suggesting that information regarding the victim's status must first be collected before identifying the type of operation. By prioritizing a victim's overall status prior to logistical analysis within the data collection system of a SAR event, an operation's reaction time can be minimized.

5. Solution Design

After concluding the problem definition phase of the SDP and performing data analysis from the data sheet provided by JAIC, this project moved into the idea generation portion focusing on the development of an interface. As previously mentioned, this project will not extend to programing a machine learning software. The proposed solution is an architectural design of a program prioritizing first-level interaction between the victim and responder. In correspondence with the analysis conducted in section 4, the proposed design of the United Search and Rescue (USR) interface act as a basic foundation underlying the required features essential for the first responder assisting the distressed victim.

5.1 Interface Design

United Search and Rescue is a complex program that includes training, educating, and saving people of all communities with the United States. For users to get the most out of the program, they must visit and explore its capabilities and functions before they are placed in a dire situation. Users can create their own personal accounts on any smart device where they can log their physical description and all standard healthcare information. When a user then comes into an unfortunate information, first responders will be able to view a person's medical history and be aware of any preexisting health risks before they even arrive on scene. This is just one of many unique and effective features within the United Search and Rescue program.

5.1.1. Interface Features

Once users have created their accounts and squared away their personal information and program settings, they are ready to use the programs and feature within the USR app. The program is divided into five main sectors: "Find me", "Track me", "Help me", "Make a report", and "Community Alerts."

The "Track me" feature within our program allows users to be tracked by emergency services before they embark into any potentially dangerous situation. The management team associated to this program can track users and watch their status of well-being change as it related to their pre-inputted planned course of action or by any feedback from the user.

This feature program will increase the number of people successfully rescued by encouraging users to make initial conduct with emergency services earlier than they usually would. With this feature users are being connected to trained professional when they mildly concerned rather than in poor or emergent condition.

One way in which we will meet our purpose of saving the maximum number of lives possible in the scope of search is rescue is by preventing individuals from becoming lost and stranded. Within the "Find me" feature, there are several tools within our program that are designed to help users...help themselves. The feature is designed to allow users, specifically hikers, from becoming dangerously lost. Features within our program allow users who have strayed off their path to re-orient themselves without needing to contact any emergency services. This allows for those resources to remain available for those who truly need it.

For users who are past the point of being able to help themselves comes the "Help me" feature. The "help me" feature operates like that of the perfect Army 9-line. Users will not begin by speaking to an emergency operator similar to the 911 phone calls commonly used in America. The idea behind using a 9-line template is to get the most necessary information to allow first responder to dispatch a rescue unit as quickly as possible, without the panic and rambling that usually comes with a phone call. The 9-line template has been adjusted to serve in a domestic peace-time operation. Users also receive an adjusted version of the 9-line if the emergency is a maritime search and rescue operation. While many of the terms and concept within the "help me" feature come with additional information to aid civilian users while filling out their "help me 9-line" it behooves users to look at these features and terms before they need to use them. As mentioned previously, therefore the training portion of the app is not to be taken lightly, it will save users time when it matters most.

The last two features within the USR program operate cohesively. The "Make and Report" and "community alerts" are intended to both make the program management center and the nearby community aware of any local concerns, activities, or potentially dangerous situations. Some examples of alerts would be if there was a bear sighting in the area recently or a missing child. Users can file reports that go to the program management center. Once the report has validated and deemed beneficial to share, all users within the appropriate radius of where the incident occurred will receive an alert. Alerts allow for users to aid their community by steering others away from dangerous situations that may have led required a search and recuse operation otherwise.

6. Conclusion

Issues regarding data collection, distribution, and implementation within Search and Rescue operations has led to numerous inefficiencies within the departments of first responders. The lack of data management has led to discrepancies in four main categories: coordinated networks of communication, accountability of available personnel, proper distribution of resources, and the implementation of technological applications. With the assessed research, it is concluded that the optimal solution for deterring these current inefficiencies is to implement an AI machine learning program within the data analysis component of an interface that prioritizes a victim's status while providing the necessary information to the first responder.

This work prioritized such feature when developing the program model "United Search and Rescue." Going forward, this project will continue to build on the model already developed while working closely with the JAIC to improve any areas of concerns within the model. Doing so will allow for this project to continue to progress as it moves out of the solution design phase of the System Decisions Process.

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