Competency Matrix Design and Evaluation of Crisis Informatics Solutions for Transportation Authorities

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Competency Matrix Design and Evaluation of Crisis Informatics Solutions for Transportation Authorities

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ATIS	Advanced Traveler Information Systems
CALTRANS	California Department of Transportation
CARE	Community Augmented Rapid-response to Events
CRA	Castle Rock Associates
DOTs	Departments of Transportation
DUET	Data-driven detecting urban emergencies techniques
EMERSE	Enhanced Messaging for the Emergency Response Sector
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
ICM	Integrated Crisis Mapping
ICTs	Information and communication technologies
INDOT	Indiana Department of Transportation
IOT	Internet of Things
IP	Intellectual Property
IRIS	Intelligent Roadway Information System
IT	Information Technology
LDA	Latent Dirichlet Allocation
ML	Machine Learning
MnDOT	Minnesota Department of Transportation
MVP	Minimum Viable Product
NextGen TIM	Next Generation of Traffic Incident Management
RFP	Request for Proposal
SCCT	Situation Crisis Communication Theory
SMCC	Social Media Crisis Communication Theory

SUMMARY

The development of technologies such as AI and ML has contributed to the growth in interdisciplinary collaboration to address significant social and engineering challenges. The rise of crisis informatics and the utilization of social media data sources has permitted the development of models, methods, and theories around crisis communication. The motivation behind crisis informatics is to protect society with tools to improve emergency response during times of crisis. Crisis informatics can be applied on a large scale where events such as infrastructure collapse, earthquakes, fires, and hurricanes among others. But can also be targeted towards specific networks such as the road network for a transportation authority. Solutions for this type of event have been developed in industry and academia with different focuses and capabilities. These solutions can be integrated into the public through public procurement of IT software technologies.

In this thesis, a competency matrix was designed from the study of state-of-the-art technology in crisis informatics and the status of public procurement for IT software. The competency matrix was used to evaluate the different capabilities among the studied solutions. The three proposed solutions showed different capabilities and brought positive aspects to tackle the problem. However, it is the differences among them and their alignment with the client’s needs and goals that will determine the optimal solution.

CHAPTER 1: INTRODUCTION

Background

Cities grow at exceptional and challenging speeds. The World Bank estimates as of 2021 that half of the world's population occupies urban areas and that by 2050, it is projected that this proportion would represent more than two-thirds of the world population. (Wahba Tadros, et al., 2021). With unprecedented growth come unprecedented challenges related to urban growth such as mobility, safety, and utilities along with an increased concern about environmental threats such as floods, earthquakes, heat waves, and epidemics. An urban future opens the opportunity for smart sustainable cities. The International Telecommunication Union defines a smart sustainable city as: "An innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects". (Sang, Luo, & Mulquin, 2015).

With the development of technologies such as Artificial Intelligence (AI), Machine Learning (ML), cloud computing, big data analytics, and the internet of things (IoT) among others, the opportunities to develop and implement sustainable smart cities have become tangible. As of 2021, the market for smart cities in the United States is 271.4 billion US dollars which represent around a quarter of the global smart cities market with a compound annual growth rate of 21.6% and could be estimated to reach a market value of 1,577 billion US dollars by 2030. The smart cities market subsectors include smart governance, smart buildings, smart utilities, smart environmental solutions, smart healthcare, and smart transportation. (Grand View Research, 2020). The significant range of possibilities and solutions provided by sustainable smart cities make the concept attractive to public and private institutions.

With the increased number of natural disasters and human-made disasters, crisis informatics has risen as an essential field to implement in sustainable smart cities. The concept of crisis informatics relies on the interconnection of individuals, institutions, information, and technology during a crisis.

The principal objective is to manage information previous, during, and posterior to a catastrophe and improve the response to the event. Some of the problems in a disaster that crisis informatics could contribute to alleviate and solve include the coordination of information by crisis management agencies, the validation of the veracity of information sources, the integration of information between official channels, social media, and other evidence sources (Hagar, 2010). In the United States, the Federal Highway Administration (FHWA), in an effort to respond to the consequences on the roadway from more than 6 million crashes per year introduced the Next-Generation of Traffic Incident Management (NextGen TIM). The concept seeks to integrate technology, data, and training to improve safety on the roadway, enhance travel time and make operations more efficient (Jodoin & Austrich, 2020).

Several State agencies and local agencies have investigated methods and implemented solutions developed in partnership with academic institutions such as the photogrammetric mapping of crash scenes with drones to quickly represent extensive crash scenes, provide features for crash scenario reconstruction, and cover roadway conditions at the time of the crash (Bullock, Hainje, Habib, Horton, & Bullock, 2019). Additionally, private companies are also partnering with public institutions to provide smart highways as part of the managed lanes concession concepts in public-private partnerships. The smart managed lanes model utilizes sensors such as machine learning cameras and Lidar to identify real-time events on the highway to enhance safety as well as provide lanes and speed recommendations to enhance travel time (Ferrovial, 2022). Yet, Departments of Transportation (DOTs) also intend to implement crisis informatics and leverage free crowdsourced data such as the Waze Connected Citizens Program (Stolle, 2015) which involves the digitalization of their operations and partnerships for technology research, development, and integration.

Objective and Motivations

This research aims to provide a framework to design a competency matrix for state and local agencies procurement of private solutions to develop smart cities and more specifically crisis informatics implementation by considering the level of automation, event detection, and augmentation capabilities of the solutions and identifying factors affecting the rate of implementation between the different stakeholders involved in the public procurement decision process. The motivation to conduct the study stems from the growing market for smart sustainable cities and the need for public institutions to implement the next generation of response software. As part of this exploratory research, three research objectives have been formulated.

Research Objective I: Establish the needs, considerations, limitations, and strategies to design a competency matrix for public procurement of crisis informatics solutions.

A decision matrix is an evaluation tool to support decision-making based on preselected criteria. It organizes a list of parameters in rows and columns to assess the performance and relationships between the different studied parameters. As part of the first research objective, based on a literature review, different methods will be presented, and a suggestion of decision parameters based on the needs of a transportation authority will be proposed which would facilitate the competency matrix design for future similar projects and ideally set a standard to support the procurement process.

Research Objective II: Explore different solutions for augmented community response systems available in the market and the academia.

With the expanding need for crisis informatics solutions, the academia has focused on developing potential solutions with different datasets including Twitter and Waze. These research efforts have been conducted after different studies demonstrated the advantages of communication through social media. Social media has been used as a tool to support response to natural disasters. For instance, they have been used as methods to facilitate community awareness by broadcasting emergency warnings, and by supporting the recognition of areas in need of assistance through self-reported locations which reduce the response time and increased its overall effectiveness. (Muniz-Rodriguez, et al., 2020). The popularity of crisis informatics is a tangible hope shared by multiple researchers in academia that sees the potential and future of leveraging real-time social media processing for crisis responses. But the potential of these systems is not only focused on academia. In the business sector, private companies have been interested in filling the gap in these opportunities. Hence Departments of Transportation and other public institutions have the option of applying real-time crisis informatics solutions proposed by academia and the industry.

Research Objective III: Apply the designed competency matrix to evaluate the different options and provide a set of recommendations.

The designed competency matrix is used to compare the different solutions applicable to a transportation authority. This comparison detects the different levels of strength of the different solutions based on multiple criteria. The difference in capabilities, objectives, and methodologies between different solution providers can then be assessed.

<u>Thesis Outline</u>

The thesis is organized as illustrated in figure 1. In chapter 2, the state of the art concerning social media processing in crisis response and overall crisis informatics capabilities in the industry are summarized. Chapter 3 focuses on the exploration of the competency matrix and the different considerations to be taken into account for the design based on the current practices. Chapter 4 focuses on the design of the competency matrix, In the fifth chapter, different solutions available in academia and industry are described and studied. In the sixth chapter, a comparison between these solutions is provided as well as a competency evaluation based on the previously designed competency matrix. In the seventh chapter conclusion, and recommendations will be synthesized.

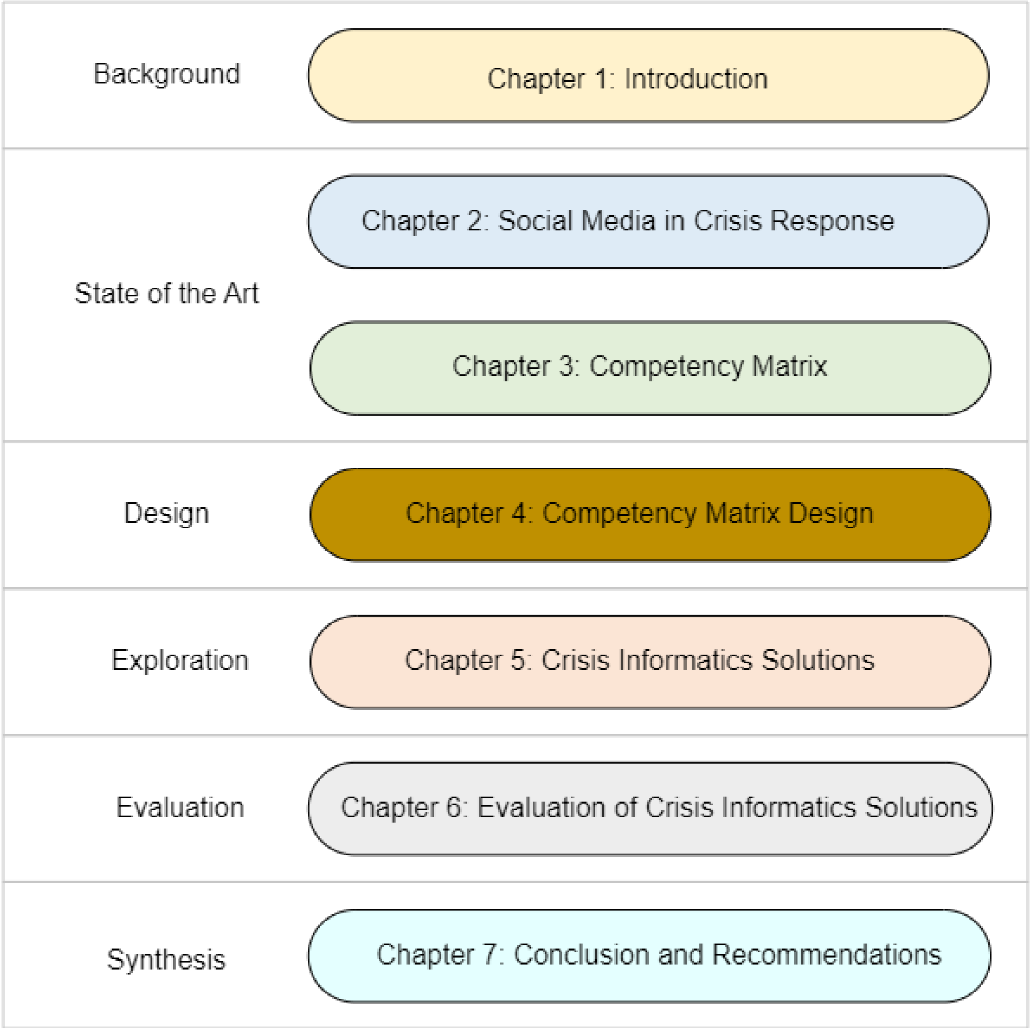

Figure 1: Thesis organization outline

CHAPTER 2: SOCIAL MEDIA IN CRISIS RESPONSE

Social Media Processing Systems

Social media in crisis response is generally associated with Twitter. The Twitter platform is organized such that users are allowed to post messages with a maximum of 280 characters and interact with the activity of other users in the network. Twitter has often been associated to be a source of news with a user base estimated a 396.5 million worldwide users, the facility to access Twitter public data from the Twitter API and the relationship between the use of Twitter and the broadcasting of emergency status from social media make Twitter an interesting platform for a focus in crisis informatics.

The current state of the art for social media data processing is explained by Coche et al., as being divided into four principal steps which include tweet collection, tweet pre-processing, information extraction, and information processing. According to Coche et al., tweet collection systems are usually designed to support real-time data feed into the system. During an emergency, keywords based on a geographical area are applied to the incoming message to filter relevant information related to the event. For text-based social media data, the tweet preprocessing known as the tweet cleaning pipeline, usually includes tokenization which splits a corpus into individual entities, for example, words in a sentence; the next steps include noise removal, lower casing text, and removal of stop-words. The next step is information extraction where tweets are vectorized and are used as inputs for machine learning algorithms that will derive labels on the original sentence. Finally, information processing is the stage where the system distributes the results from the analysis to decision-makers and can be augmented with other data sources such as phone calls or user reports. Yet, there are limitations like unequal access to information among the response team. (Coche, Romera Rodriguez, Montarnal, Tapia, & Benaben, 2021)

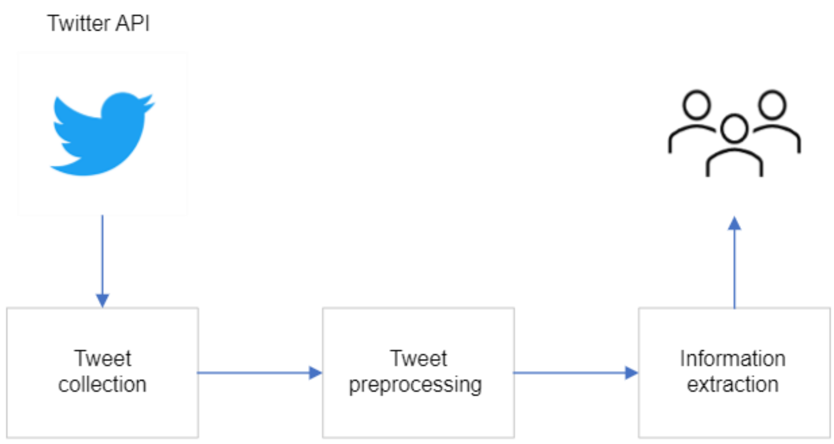

Figure 2: Generic Representation of existing social media processing systems. Coche et al. 2021 [1]

There are three principal approaches in the derivation of information from social media for emergency response these are data filtering where tweets associated with the emergency are identified, semantic enrichment which adds a layer of topic metadata such as location or sentiment related to the theme and finally the clustering of tweets which groups similar tweets based on common features such as keywords.

Data filtering

An information filtering system uses algorithms to automatically remove unnecessary features from the data stream. An application of data filtering system has been used as a method to classify and evaluate high-value tweets. Classifiers based on Support Vector Machines have the capability to understand a statistical model and therefore classify specific information related to the crisis (Cameron, Power, Robinson, & Yin, 2012). Feature selection methods seek to improve classification performance by eliminating irrelevant features; this is achieved by applying predetermined criteria on the available features and then minimizing the number of model parameters such that instances closest to the same class and opposite to the sample can be determined. Data filtering-based

[1] (Coche, Romera Rodriguez, Montarnal, Tapia, & Benaben, 2021)

systems have the capability to convey relevant information for enhanced emergency response. (Caragea, et al., 2011).

Semantic Enrichment

Semantic enrichment of tweets provides enhanced semantic filtering of messages for relevance. This supports the search for decision-makers on filtered information and provides further knowledge on the crisis in question. A framework architecture exploiting the advantages of semantic enrichment is “Twitcident”. Semantic enrichment is achieved with the Named Entity Recognition (NER) module to distinguish persons, locations, or organizations. The classification of messages is based on pre-determined rules. The contextualization of semantics in a tweet by using links posted in messages, which can be used to infer data like location. Additional contextualization can be achieved from the use of metadata extraction based on images attached to tweets or even information about the user associated with the authorship of the message. (Abel, Claudia, Houben, Tao, & Stronkman, 2012)

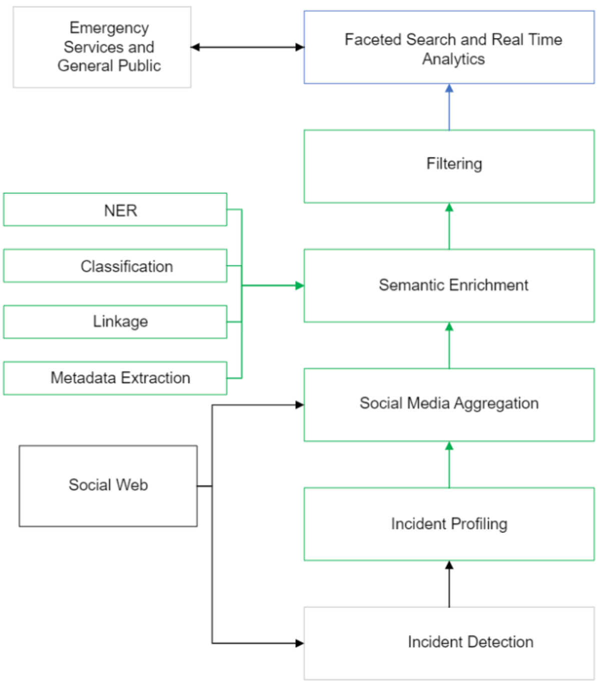

Figure 3: General Twitcident architecture. Abel et al. 2012 [2]

[2] (Abel, Claudia, Houben, Tao, & Stronkman, 2012)

Clustering

Clustering-based systems are characterized by the use of keywords to group and aggregate analogous tweets. There are two principal components for these methods: the distance metric which tests the resemblance between the data and the clustering algorithm which groups the data. These can be achieved by using the Jaccard Distance metric that measures the resemblance of finite sample sets as the quotient of the intersection and the union of sample sets. Whereas a clustering algorithm is usually an unsupervised method such as K-means. The K-means algorithm uses centroids to define clusters of data and converges after iterating the assignment of data points from the current centroids and the computation of new centroids based on the updated data point clusters. In clustering-based systems, keywords are considered nodes while individual tweets are treated as edges. Given that clustering techniques are based on the frequency of keywords to measure relationships between tweets they do not incorporate the hidden meaning of topics in the messages.

Topic Modeling

Latent Dirichlet Allocation (LDA) is an unsupervised topic modeling method for data classification. The probabilistic nature of LDA successfully reduces dimensionality for document classification given that each document is modeled in a compilation as a mix of topics and each topic as a distribution over keywords. Therefore, it is possible for systems to assess a variety of topics in a set of documents and create a probabilistic distribution of words within a topic. Some applications o of LDA in crisis management were used to create the Enhanced Messaging for the Emergency Response Sector (EMERSE) system based on text messages on the 2010 Haiti earthquake to classify messages and promptly distribute information across departments (Caragea, et al., 2011).

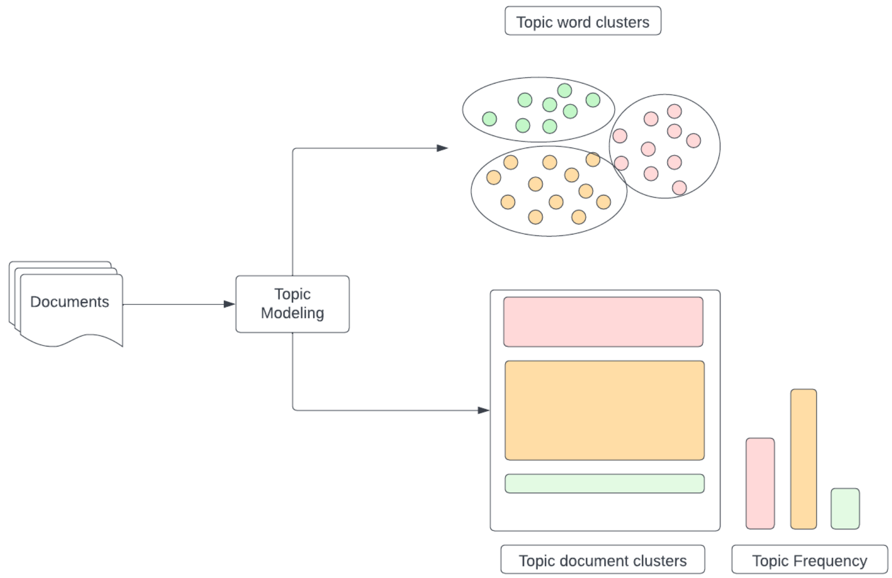

Figure 4: Overview of Topic Modelling using Latent Dirichlet Allocation (LDA)

LDA-based systems have evolved from only incorporating time and semantic dimensions to considering geographic dimensions for crisis detection. Researchers have proposed an “Urban Crisis Detection Technique” which uses an initial layer for Geo-Topic detection by measuring geographic and semantic similarities and a second layer of Geo-Topic Ranking employing sentiment analysis and quantifying the intensity of negative sentiments (Wang & Taylor, Urban Crisis Detection Technique: A Spatial and Data Driven Approach based on Latent Dirichlet Allocation (LDA) Topic Modeling, 2018). Using this method, researchers developed DUET which does not need a set of predefined keywords on the emergency type and detects the intensity of negative sentiments to enhance the situational awareness of decision-makers in an emergency (Wang & Taylor, 2019).

Crowdsourced data fusion

Crowdsourced datasets are the result of the interaction of an extended group of people who share information or opinions on the internet. A popularly used crowdsourced data source used in traffic incident detection is Waze. The Waze dataset includes incident data from accidents, road closures, traffic jams, and other large-scale events impacting the transportation network. Based on previous studies, Twitter streamed messages are not enough to overtake the time interval between the occurrence of an incident and a Waze alert displayed on a Department of Transportation platform (Samuels, Mohammadi, & Taylor, Social Media-Informed Urban Crisis Detection (No. FHWA-GA-20-1834)., 2020). In this project, researchers developed a framework to improve the usage of data from Twitter with the convergence of Waze and Twitter where incoming twitter data is remodeled to match the Waze data format prior to the integration on 511. The framework proposes the transposition of Twitter data in JSON format for integration with Waze and incorporates a geospatial dimension by leveraging the geolocated Twitter data with Geographic Information System Mapping. The framework presents a filtration of incoming Twitter data with the setup of a "Tweet score" determined from sentiment analysis, user history, geolocation, and aggregated value from additional data such as images and videos. With this information, alerts can be confirmed and mapped.

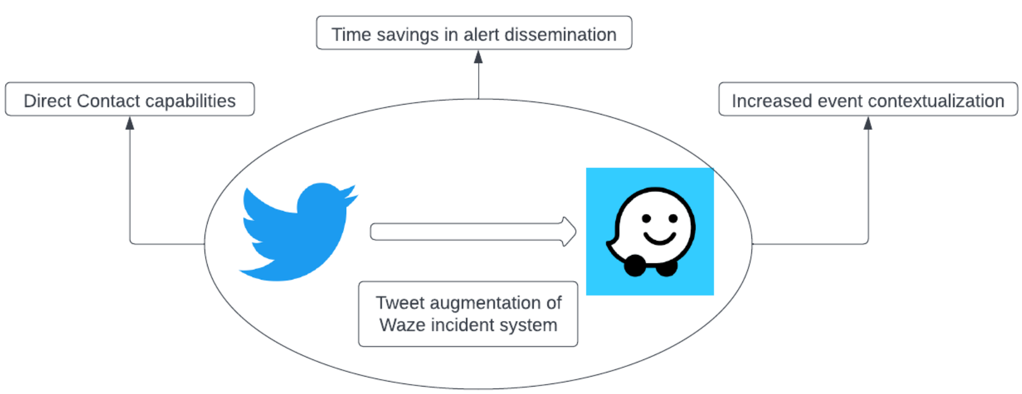

Figure 5: Benefits of Twitter-Waze data augmentation

Theoretical Models in Social Media Crisis Communication Crisis Informatics

Theoretical models in crisis informatics models have rapidly emerged with the expansion of social media platforms and the improvements in information technology. Crisis Informatics is a multidisciplinary field of study referenced as a sociotechnical system that combines computing, emergency management, and social interactions during a crisis (Palen & Anderson, 2016).

Researchers have studied theoretical models in crisis informatics and determined that crisis communication, crisis informatics, and social media are distinguished in two axes based on the generator and receiver of digital information. Four communication patterns arise for cooperation in crisis events (Reuter, Marx, & Pipek, 2012). Where the first type is from organizations to the public, the second type is from public to public which is characterized as the self-support of the community, the third type is from public to organizations which is based on citizen-crowdsourced data, and the fourth type which is from organization to organization to improve overall crisis awareness and response (Figure 6).

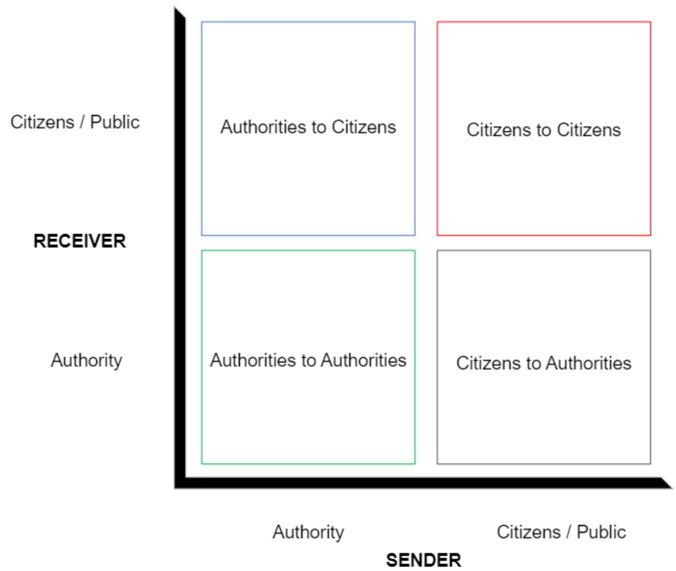

Figure 6: Crisis Management Matrix. Reuter et al. 2012 [3]

[3] (Reuter, Marx, & Pipek, 2012)

Bukar et al. (Bukar, et al., 2020)developed a taxonomy of the research body in crisis informatics and divided it into four principal categories that explore frameworks and theoretical models, methods, review papers, and others. This shows the development and capability of the academic field in the generation of solutions and contributions to crisis informatics.

The research field has covered a different range of topics from crisis communication models which include features such as pre-crisis, crisis origin, crisis type, post-crisis, response strategy, emotions, and interactions. Yet, Bukar et al. present three dominant theoretical models of crisis communication. The Integrated Crisis Mapping (ICM) developed by Jin et al., is aimed at creating an emotion-driven method to anticipate the emotions sensed during an emergency situation. In the ICM theory, there are four principal emotions anger, sadness, anxiety, and fright with two levels of emotions where the first is an immediate emotive response after a crisis and the second is tracking emotions throughout time after a crisis considering an organization's response to the event. (Jin, Pang, & & Cameron, 2007).

The second dominant theory in crisis communication is the Situation Crisis Communication Theory (SCCT) where the theory focuses on providing insight into the protection of assets during a crisis. This is achieved by generating an evidence-based anticipation of how an organization will respond to an emergency based on the reputational threat posed by the event. The components for this model include three clusters: the victim, accidental, and preventable. Reputational protection is maximized by identifying the respective cluster and applying the appropriate defensive or accommodative strategies. (Coombs, 2007)

The third dominant theory is the Social Mediated Crisis Communication Theory (SMCC) which proposes the application of the most adequate response strategy to an event given that emotional triggers should be coherent with the type of event. The reasoning behind the SMCC theory is that the crisis origin would result in dependent and independent emotion to which the response and the information systems such as social media should be optimized and tailored to the situation. (Bukar, et al., 2020).

Therefore, based on the theoretical models a response strategy can be designed from the intersection of the origin of the crisis, the level of responsibility attribution to a crisis, and the emotive reactions to the event. While being able to derive the type of crisis, the type of emotions involved, and the reputational threat. The main areas in the crisis communication theories are crisis phases, stakeholders, response strategy, emotions, and interactions.

Chapter 2 Summary

In summary, social media processing systems for augmented crisis response usually leverage data from Twitter for crisis informatics. Research has been conducted and methods developed for optimal system design where several techniques like data filtering, semantic enrichment, clustering, and topic modeling have been implemented in different ways. Multiple Departments of Transportation have used Waze crowdsourced datasets for event detection and emergency management. Previous research proposed methods for the data fusion of Waze and Twitter datasets. Some of the benefits are direct contact capabilities for emergency organizations, time savings in alert dissemination, and increased event contextualization with additional data such as images and videos.

Within crisis informatics, crisis communication has been developed to further understand the cooperation between crisis organizations, information flow, and crisis management strategies. Additionally, several theories have been developed in crisis communication to include the emotions of different organizations and individuals affected by a crisis to try and improve the management of an emergency situation.

CHAPTER 3: COMPETENCY MATRIX

After studying the implications of methodology and theories in crisis informatics for emergency response, a competency matrix design is feasible after understanding the conditions of the information technology applications within organizations and the alignment needs within different members of an organization. It is not only necessary to think about the most technologically advanced solutions without weighing the considerations of which can be most successful when implemented. Ideally, all solutions bring positive outcomes in different aspects of implementation. Yet, important things to consider are the status of AI in the public sector, the considerations among the procurement team, and the value or capabilities of the proposed solutions.

AI in the Public Sector

The application of AI in the public sector needs to be considered a current technology given its present predominance yet, there is an essential need to understand the opportunities, risks, barriers, and drives in the adoption of AI in the public sector. Ideally, AI can be deployed to address different interdisciplinary challenges in the public sector (Kumar & Sharma, 2017). The conceptual application of AI should be such that the way the technology is deployed will create an impact and disrupt existing processes rather than the meaningless application of the technology. Yet the imminent disruption of AI in the public sector will reshape the behavior of organizations and individuals which would then impact again AI applications.

Even if AI is a present technology, there are multiple challenges and barriers that are associated with AI in public organizations ranging from ethical issues to the need for capacity building. Public organizations face difficulties when hiring experts in the AI field due to the lack of competitive salaries which causes limited expertise on applications, deployment, and ability to run them (Surya, 2019). As explained by Surya, AI faces problems in procurement given that algorithms are protected as Intellectual Property (IP) and which complicates the intention of customizable solutions. Organizations are therefore more likely to upgrade the technology rather than commit to a technology maintenance program.

With the currently limited capability of public organizations to create AI-powered solutions to address interdisciplinary problems, it is more likely that organizations outsource the development of applications and attempt to acquire the software. For this, organizations need to realize the factors that limit the rate of software acquisition. The Institute for Defense Analysis developed a study where seven principal categories were fundamental for a prompt software acquisition process and sustainment.

Table 1: Speed limiting factors in software acquisition (Garrison, Tate, & Bailey, 2019)

Factors	**Description**	**Considerations**
Required Functionality	Defined scope of the software program.	• Assess the negative requirements of a system. • Achieve Minimum Viable Product (MVP) to gather feedback and refine issues. • Review the modularity of systems for parallelization of development efforts.
Architecture	Program organization and operating environment.	• Develop system to support agile improvements. • Consider the lifespan of the system and the need for upgrades in the future. • Contemplate the interoperability needs and capabilities. • Determine the degree of inclusion of current avant-garde technologies. • Evaluate the need for the rapid implementation of new capabilities or a rapidly upgradeable system.

Table 1 Continued: Speed limiting factors in software acquisition

Technology Maturity	The maturity level of innovative solutions implementation.	• Assess the level of maturity of software and hardware design processes. • The Department of Defense evaluates AI as immature technology given that there are issues such as the validation and maintenance of datasets or the achievement of testable requirements.
Resources	Ecosystem required for a successful implementation.	• Determine the experience of the implementation team. • Evaluate access to datasets and specialized IT infrastructure for system development and deployment. • Consider the level of funding stability for a program.
Testing Strategy	Defect detection and interactions throughout the development.	• Debugging, finding, and fixing defects within the system in a periodical and rigorous manner. • Implement the testing strategy as early as possible in the process. • Ensure correct testing methods are completed and results are adequately conveyed to the development process.
Contract Structure	Alignment of contractor and outsourcing organization.	• Consider the need for maintenance and future upgrades of software-intensive systems. • Existing law forbids making a condition of contract award from IP rights.
Change Management	Transformation of processes for adaptation.	• Align stakeholders controlling system requirements and developing/fielding the systems. • Establish the definition of system need, and place requirement thresholds.

Although software development and deployment time are important factors in the success of IT (Information Technology) projects in the public sector and there are several factors to be considered to accelerate the process it is important to note the early warning signs of IT project failures. Early warning signs would be defined as risk indications of a project's future problems and potential failure. Kappelman et al. (Kappelman, McKeeman, & Zhang, 2006) conducted a study seeking to determine from the participation of 138 experienced IT managers the early warning signs of IT projects. The results indicate two principal causality groups: People Related Early Warning Signs and Process Related Early Warning Signs (Figure 7).

People Related Early Warning Signs	**Process Related Early Warning Signs**
• Absence of top management support. • Inefficient project manager. • Lack of stakeholder participation and involvement. • Fragile project team commitment. • Inexperience or knowledge gap from the team. • Experts are unvailable from extensive responsibilities and workload.	• Absence of scope requirements and success criteria. • Lack of change control process. • Weak management and scheduling. • Communcation breakdown with stakeholders. • Limitation of resources and resources reassignment. • Shorfall of project business case.

Figure 7: Warning Signs of IT Project Failure (Kappelman, McKeeman, & Zhang, 2006)

Ideally, considering and evaluating these dominant warning signs during the initial 20 percent of an IT project would permit the identification of indices that would contribute to long-term project failure. Nonetheless, it is vital to also understand the importance and role of public procurement for IT solutions.

Procurement of IT solutions

IT procurement is the acquisition of hardware systems, software programs, and upgrades along with other services through a series of steps that include a proposal, bidding, contract awarding, and contract management. The extensive process needs to be structured and organized to ensure program success. Therefore, several procurement maturity models have been developed to support the efficacy and capability of managing procurement challenges. Hua (Hua, 2022) proposed a procurement maturity model expanding from current models in the theory and subsequently applied four different maturity stages while taking into account political and managerial objectives. Hua determined that for organizations looking to improve procurement maturity, firstly organizations have to conduct a strategic assessment of how the procurement process integrates with the organization’s leadership. Secondly, organizations should achieve increased awareness from the procurement team members on software development methods. Finally, the procurement team needs to comprehend the vendor and handle business negotiations during the process (Hua, 2022).

Academic and industry reports show that around 46 percent of software projects are challenged which signifies that although they are operational, they have problems with their budget, schedule, or even capabilities requirements (Johnson, 2018). Nguyen et al, (Nguyen, et al., 2022) conducted a study to determine the criteria for software acquisition, understand the timeline during procurement, and the variations in the requirements of Request for Proposal (RFP) from multiple software categories.

Although the evaluation weights assigned for software RFP vary from software category and the type of organization, a common evaluation criterion was determined by Nguyen et al. (2022) (Table 2). The cost proposal covers software installation, conversion, training, licensing, and maintenance. The response to RFP requirements covers the capability of the vendor in covering the scope and purpose of the service. The implementation approach covers the implementation methodology. The company qualifications cover the technical experience of the company on similar projects. The project team qualifications cover the expertise of the specific team involved in the development of the solution. The system capability covers the ability to meet functional, business, technical, and security requirements. The software demonstration covers the integration of the solution. Finally, the other criteria include financial capability, business structure, and others. (Nguyen, et al., 2022)

Table 2: Evaluation criteria weighs for different software categories. Nguyen et al., (2022)[4]

Evaluation criteria	Average Weight (%)				
	Enterprise Resource Planning	Financial Systems	Asset Management Systems	Common Business Application	Specialized Business Application
Cost proposal	20	23	20	16	24
Response to RFP requirements	2	9	3	4	4
Implementation approach	22	23	28	29	26
Company qualifications	15	21	20	21	19
Project team qualifications	3	6	5	6	3
System capability	27	17	21	22	19
Software demonstration	9	0	2	0	2
Other criteria	2	1	1	3	2

[4] (Nguyen, et al., 2022)

For incident management systems the most relevant category would be the Asset column in Table 2. On average a larger weight percentage is given for the implementation approach (28%) which consists of assessing the system deployment methods proposed by the vendor and the customization capabilities regarding different scenarios. Secondly, with 21 percent, the system capability is evaluated, and the procurement team rates the capacity of the vendor to meet the functional, technical, and security requirements of the project while also understanding the potential integration of future modules within the system.

Thirdly, with 20 percent, is the cost proposal which refers to the overall financial burden including the installation, training, licensing, and maintenance of the software system. Equally important during RFP evaluation, with 20 percent, company qualifications reflect the experience and expertise of a vendor to handle the project. Lower importance is given to the project team qualifications, the response to the requirements of the Request for Proposal, and other criteria such as the business structure of the vendor or the past experiences between the two sides. Other significant findings from Nguyen et al., show that on average the implementation duration noted on the RFP is 265 days which corresponds to almost 70 percent of the time allocated in a project on the RFP (Nguyen, et al., 2022).

Technology Choice in Procurement

Although technological choice and procurement is a formal process, the acquisition is not simply the result of a rational decision but the tension between sociocultural factors. A study by Pollock and Williams (Pollock & Williams, 2007) explores the sociology behind the procurement of software technologies by observing a joint venture between a city council and an IT company along with management and computer science experts. During the yearlong selection, the research team observed the procurement process and conducted interviews which allowed them to determine the following findings. The decision environment was described as having high uncertainty levels where the features of the vendors were negotiable within the procurement team, making the comparative measures flexible. The authors claim that the property of each system is not relevant in the comparison of similarities and differences but instead it is the validation of evaluating criteria that provided meaning to these properties. The scaffolding metaphor and the disentangling, framing, and overflowing framework converge towards a decision not only dominated by a formal process but as a sociological attempt to reach a common decision.

CHAPTER 4: COMPETENCY MATRIX DESIGN

With the consideration of the current aspects of Artificial Intelligence in the public sector, the understanding of the success and failure factors in IT solutions, the current practices in public software procurement for IT solutions and the implications of a formal process and a cultural sociological approach driving a decision I designed a competency matrix to evaluate the range of capabilities and alignment of potential IT solutions for AI-powered crisis informatics leveraging social media (Figure 8). The vertical axis of the matrix addresses 9 dominant factors that were determined to be important from the technical and procurement perspectives ((Garrison, Tate, & Bailey, 2019), (Nguyen, et al., 2022), (Samuels, Mohammadi, & Taylor, Social Media-Informed Urban Crisis Detection (No. FHWA-GA-20-1834)., 2020), (Abel, Claudia, Houben, Tao, & Stronkman, 2012), (Endsley, Bolte, & Jones, 2003), (Jodoin & Austrich, 2020), (Jin, Pang, & & Cameron, 2007), (Thales, 2022), (Kappelman, McKeeman, & Zhang, 2006). The horizontal axis of the matrix addresses the level of proficiency around each item where the scale includes A+, A, B, C, and D, is similar to the American Society of Civil Engineers infrastructure report card (American Society of Civil Engineers, 2021). Each cell in the matrix has been given a baseline that was determined from the current trends in technology, transportation authorities' requirements need, and considerations during the acquisition of a solution. Each solution is then evaluated with the designed competency matrix following the baseline of each factor.

Factors

The Architecture of a software system addresses the fundamental structure and behaviors of a system. Software Architecture is the basis for qualities such as modifiability and security. In the procurement process, it is essential to verify the feasibility and applicability of a potential solution. Garrison et al. (2019) explain that an efficient Architecture will determine the cost and maintenance effort of a system in the future. According to Nguyen et al. (2022), the weight given during RFP to the implementation approach is 28%, and system capability is 21% which indicates system architecture is given significant importance by the procurement team. In the context of crisis informatics for transportation authorities: "*A+*" system Architecture would show high modularity to integrate with the existing system while being designed for long-term operations within the organization. *"A"* Architectures includes the integration of modular components within existing transportation authority's systems but lack the extended design mindset that factors system longevity from an absence of agile and lean methods in their improvement requirements. *"B"* Architectures include modular components towards a solution but are not designed towards integration with the existing system. These can be systems that parallelly support existing systems but have the potential to be integrated in the future from their modular nature. *"C"* Architectures are systems without modular components and interoperability concerns that could be integrated from their technical design despite not being modular. *"D"* Architectures do not consider modularity or address interoperability in their system design.

The Automation of a system covers the level of independent applications that reduce the need for human input to operate. Previous research showed the importance of automatic event detection for the reduction of response time and enhanced emergency response for road-related incidents (Samuels, Mohammadi, & Taylor, Social Media-Informed Urban Crisis Detection (No. FHWA-GA-20-1834)., 2020). In the context of crisis informatics for transportation authorities, it addresses the need for automatic event detection of road-related events and emergencies. *"A+"* Automation is a reliable completely autonomous system to detect events without human intervention in the determination process. *"A"* Automation is achieved from autonomous systems that detect automatically detect events but require human intervention for validation. *"B"* Automation in event detection is achieved from advanced automation in event detection that corresponds to the integration of automated reporting methods not limited to social media such as phone calls. *"C"*

Automation is achieved from the automatic integration of externally determined events with the transportation authority operating system. *"D"* Automation is attributed to solutions that do not consider automation in event detection.

Event Detection of a system encompasses the range of events a system can detect and the range of information received and transmitted to be considered during an emergency response. In the context of Transportation Authorities, the main requirement is to model the road network yet additional contextualization of events can provide additional information to support emergency response (Abel, Claudia, Houben, Tao, & Stronkman, 2012) from the use of metadata. "*A+"* Event Detection identifies various types of emergencies not limited to the state road network but aggregated among a variety of public networks, for example, utilities. *"A"* score event detection is reached from the identification of a different type of event affecting the road network. *"B"* Event Detection is reached from the identification of various types of road-related events across the road network but not limited to vehicle incidence, for instance, flooding or ice on the road. *"C"* Event Detection is reached from the detection of vehicle-related events including predetermined road conditions such as planned road closures from construction. Finally, *"D"* Event Detection is given to single event detection across the road network such as vehicle crashes or traffic.

Situational awareness of a system is defined by Endsley, Bolte, and Jones (2003) as being sensitive and informed about the events happening around and understanding the meaning of the information now and in the future. Three levels are given for the obtention situational awareness: perception of elements in the environment, comprehension of the current situation, and projection of future events. In the context of Transportation Authorities situational awareness is achieved when more information is shared and complemented with the operator's training. *"A+"* is given for systems that deploy FHWA views for NextGen TIM (Jodoin & Austrich, 2020). *"A"* is achieved by leveraging live video communication with individuals on-site to guide and support the emergency response. *"B"* is reached by the augmentation of situational awareness through live visual media from existing static or dynamic cameras. *"C"* is achieved from the inclusion of social media-filtered data streams to obtain metadata such as videos and cameras. The strength of social media relies on the derivation of emotions that can shape the strategic response of an organization. (Jin, Pang, & & Cameron, 2007). *"D"* is given from situational awareness only provided by current 511 phone reports.

Detection Speed covers the time between the time an event occurs to the time it is informed to the emergency operator. Getting the information as fast as possible is important to rapidly create situational awareness and support emergency decision-making response (Kwan & Lee, 2005). In the context of Transportation Authorities, the detection of events is critical on the road network across large networks. "*A+"* is achieved by ideal systems that achieve detection in real-time or between 0 and 1 minute of the event happening. *"A"* is achieved by a system that has perfected near-real-time reporting of events or in a timeframe between 1 to 3 minutes. As the time for event detection increases the score achieved is lower such that a *"B"* is scored between 3 to 10 minutes, a "*C"* is scored between 10 to 20 minutes and a *"D"* is scored for more than 20 minutes. The detection speed is fundamental in crisis informatics and specifically social media has demonstrated to be a tool capable of leveraging near real-time detection of events.

System Maintenance is a requirement that considers the contract method by which a vendor or solution provider will design the system in the long term and its commitment to ensuring the appropriate level of operation of the system requirements. Given the speed at which technology is updating and how new challenges arise software usually undergoes corrective, preventive, perfective, and adaptive maintenance (Thales, 2022) but given constraints such as intellectual property (Garrison, Tate, & Bailey, 2019) affect the proposed contract regarding maintenance. Therefore, in the context of transportation authorities, it consists of the maintenance of ATIS systems. "*A+"* score is received for a system that is operated by the user, in this case, the respective Transportation Authority. A self-dependent DOT is able to maintain and update its modules, saving costs and customizing the solution to their needs. *"A"* is achieved from regular maintenance of the system by a contractor, this includes current updates and system tests and checks that would detect any malfunction or failure. A score of *"B"* is achieved for maintenance as needed, the downsides of this aspect include the potential crashes and system integration problems which would compromise the effectiveness of the system, *"C"* is reached if maintenance is not provided as part of the solution provided. And a "*D"* is given for planned obsolescence where the system cannot be maintained and eventually becomes obsolete and needs replacement.

Deployment speed is one of the main concerns studied in the procurement of software solutions. Nguyen et al. (2022), determined the expected duration of the project durations in the RFP. On average the total time of implementation was 382 days while some projects were faster at 43 days others took up to 1384 days. In the context of Transportation Authorities, the faster they can deploy technology and put into effect crisis informatics systems the more impact they will have on the public. According to the SCCT crisis communication theory developed by Coombs (Coombs, 2007), the protection of assets is induced by the reputational threat to an organization posed by an event, motivating transportation authorities to be prepared for crisis scenarios. An "*A+"* is achieved by an ideal system that has the capabilities of immediate implementation. An "*A*" is given for a faster-than-average deployment of 6 months while a *"B"* score is achieved for an average deployment rate. A *"C"* is reached for a slightly slower-than-average deployment while a "*D"* is a system that can be deployed in more than 2 years.

Contractual Needs are the basis of public procurement and different setups with the potential solutions providers will have repercussions in the short and long term. Procurement contracts scope the product selection the payment conditions among others. In the context of a transportation authority, a ranking is based on what would be more beneficial. An "*A+"* score is achieved from an internally developed solution; this would avoid interaction with vendors and avoid risk from outside vendors. *"A"* is achieved by awarding a renewable contract, in the software development industry time-and-materials contracts are usually awarded from the uncertainty in the solutions. *"B"* is reached with a contract that includes the development and maintenance of the system on a fixed price contract that defines roles and responsibilities yet is more complicated to renew the contract on similar terms after the solution development. *"C"* is achieved for contracts that only cover the development scope of the project and do not include future interaction with the deployed system. On the Transportation Authority, a *"D"* is given for long-term concessions of a system and the complete dependence on a company to operate their crisis informatics solution.

Experience is determined by the impact on the field and the setup of an adequate team to design a solution. The relevance of experience has been linked by Kappelman et al. (2006), as a people-related warning sign to IT project failure. Along with this, experience factors the team commitment, knowledge, and quality of managers involved. In the context of Transportation Authorities, a team must be chosen to effectively implement crisis detection systems. For experience, scores are determined based on the National Institute of Health proficiency scale (US National Institute of Health, 2022) that examines teams based on involvement with past projects, impact in the sector, and market position as: expert, proficient, competent, average, and novice.

Competency Matrix Application

The competency matrix (Figure 8) can be applied by transportation authorities to evaluate the factors determining the competency to implement crisis informatics solutions. The basics to determine a score are derived from knowledge on the corporate standing of vendors and technology maturity and refinement. Pollock and Williams (2007) determined that although procurement is a formal process it is also a decision process that engages the procurement team through a malleable process or negotiation. From this, the matrix has been designed such that the procurement team for crisis informatics solutions can be tasked with attributing a weight to the factors. The composition of the procurement team has to be diverse and group representatives across the divisions of a transportation authority. Pollock and Williams (2007) in their case study encountered the procurement team to be integrated with the primary end users of the system, IT personnel, project managers, a chairperson, and other parts of the organization. Although not part of the procurement team, academic professionals were present during the meetings and throughout the process. Conceptually, different members of the procurement team could weigh the different factors of the competency matrix based on their experiences, needs, and acceptable tradeoffs. The use of the competency matrix is intended to be used during the exploration phase prior to procurement and could be used in a periodical manner to continuously assess the options available in the market and evaluate other alternatives. Chapter 6 of this thesis utilizes the presented competency matrix design and applies it to evaluate a set of different crisis informatics solutions. To evaluate the solutions, factors were scaled from the perspective of a transportation authority. For example, when evaluating Situational Awareness, the solutions of each vendor are assessed on the holistic added value on that factor and scaled on the perspectives of a transportation authority.

Competency Matrix

Factors	A+	A	B	C	D
Architecture	High modularity and interoperability design for long term operations	Modular components and interoperability design	Modular components without interoperability design	Non-modular system with interoperability concerns	Non-modular systems and interoperability issues
Automation	Autonomous System without human intervention	Human-in-the loop ML powered system	Advanced Automation in event detection	Novice Automation in event detection	Lack of Automation
Event Detection	Supports various types of event emergencies across multiple networks	Supports various types of event emergencies across the road network	Supports various types road related events across the road network	Supports only road related events across the road network	Supports unique road related events across the road network
Situational Awareness	Deploys Next Gen TIM with UAV and LiDar technology	Supports live conference streams with responders	Supports various types of data streams including live cameras from response vehicles	Supports various types of data streams including social media	Supports phone call based data streams
Detection Speed	Real time	1 minute to 3 minutes	4 minutes to 10 minutes	11 minutes to 20 minutes	more than 20 minutes
System Maintenance	Maintained and Operated by user	Scheduled maintenance and update by contractor	Maintenance and update by contractor as needed	No Maintenance	Planned obsolescence
Deployment speed	Immediate	within 6 months	within 1 year	between 1 and 2 years	more than 2 years
Contractual Needs	Internal Authority Development	Renewable Contract	Single Development and Maintenance contract	Development Contract	Long Term Concession
Experience	Expert team from past projects and market position	Proficient team from past projects and market position	Competent team from past projects	Average teams without past projects	Novice team

Figure 8: Competency Matrix for Evaluating Crisis Informatics Solutions by Transportation Authorities

CHAPTER 5: CRISIS INFORMATICS SOLUTIONS

The development of Crisis Informatics solutions has been rising in academia and commercially. The solutions are to be tailored to the needs of the Georgia Department of Transportation with the intention of identifying events and emergencies in the highway and road network systems across the state of Georgia. Nonetheless, these applications have the potential to be deployed around the United States and other parts of the world. A shortlist of vendors including DataCapable and Castle Rock Associates are presented and evaluated as well as a tailored solution by the Network Dynamics Laboratory at the Georgia Institute of Technology.

DataCapable

At the time of writing this thesis, DataCapable is an AI-powered platform providing real-time situational awareness of events. The software development firm is based in San Diego, California, and was founded in 2013. From online research, DataCapable is estimated to have between 25 and 50 employees. The areas of focus of the company are social media aggregation, emergency response communication, and event detection. The areas of technical expertise are real-time geospatial modeling, social media analytics, and machine learning. (DataCapable, LinkedIn, 2022)

The web-based platform has the potential to serve businesses, administrations, and the public with critical information to effectively and timely respond to critical situations and events demanding a response. The market DataCapable has captured for augmented situational awareness in the utility sector includes investor-owned utilities, cooperatives, and municipalities; in the government sector, it includes the local, state, and federal levels and for the public sector for Department of Transportations, Turnpike Authorities, and Transit Authorities. Some of the clients and partnerships DataCapable has had in the past include the Virginia Department of Emergency Management, and the Pennsylvania Turnpike among others (DataCapable, About DataCapable, 2022).

DataCapable offers three principal modular products. ‘Threat Detector’ addresses the communication gap between the public and emergency management organizations with the application of AI and machine algorithms on structured and unstructured data. The proposed solution uses human verification of events and promptly warns stakeholders to address the crisis. The alert is mapped on the DataCapable platform dashboard for context visualization by emergency managers. As the situation unfolds, DataCapable updates the information around the event and ranks the alerts based on importance. Additional contextualization is achieved with the detection of the affected areas and boundaries or the restart of operations. DataCapable offers full integration of the ‘Threat Detector’ module with existing systems and allows live video broadcasting with unlimited stakeholders. (DataCapable, Threat Detector, 2022)

The ’Community Portal’ allows real-time reporting of active response teams and initiatives. Reporting can be completed by field personnel, officials, and citizens. The portal supports metadata including videos and images which helps the coordination of the response. Incident reporting is located with GPS coordinates and then mapped in the admin control panel where additional demographic information is displayed to estimate the communities affected. The muti-platform capability of the module augments response coordination either from desktop or mobile applications. The ‘Community Portal’ simplifies and optimizes the reporting process liberating call centers during emergencies. (DataCapable, Community Portal, 2022).

The ’Outage & Event Map’ allows stakeholders to inform in real-time the community about different types of events and outages. This updates the status of the damage, repair as well as other temporal information. From an image, everyone can report for an update of the ‘Outage & Event Map’. Although the ‘Outage & Event Map’ is more geared towards smart cities and utilities and is not part of the solutions offered for Departments of Transportation, it is possible that the company can adapt the module if this is a system requirement (DataCapable, Outage & Event Map, 2022).

The algorithms developed by DataCapable to power their solutions have been patented in November 2018 as “Automated customer engagement and issue location, prediction, and response through utilization of public and private data sources” with patent number 10140642 (JUSTIA, 2022). The algorithm patent leverages structured and unstructured data including social media, weather, news, real estate information, and asset information. The algorithm framework follows the overall method of social media processing systems (Figure 1). The first module collects data by keyword association and is complemented by a key concept extension model that requires human interaction in the development of key concept extension to determine possible causes of failure. The second module focuses on the predictive model process which feeds from raw social media data that uses a logical statement to determine whether the process is to be completed with active learning and interaction with the end-user or completed from manually labeled training datasets with keywords. The third module uses the output of the predictive model for classification using Naïve Bayes text classifiers which determine the truth of a report. False reports are labeled and reused for future training while true reports can be conveyed to the user. Additional modules apply for true reports, the burst detection model uses a Kleinberg detection algorithm and is subject to a burstiness threshold before being reported. Then the true reports are subject to the aspect extraction module where frequency-based criteria are used to find similarities in big data; the report is conveyed to the user and then labeled for future machine learning datasets validation. For detailed figures and a more in-depth explanation of the algorithm, refer to the patent in question. (United States Patent No. 10140642, 2018)

The patent was designed initially for utility applications yet it has larger capabilities and value from the continuous increase of their datasets. In an interview given to MMM Tech Law & Business Report, Pete DiSalvo, the CEO of DataCapable, mentioned that as of July 2020, 80 percent of the company's revenue was coming from the utility sector which shows a strong prevalence in this area but an opportunity for expansion on transportation authorities. Regarding the technology, he expressed the lack of trust or reliance on only algorithms for which the company uses human-in-the-loop models where human users have a maximum of 3 minutes to verify the truth of a report. (DiSalvo P. , 2020)

The solution provided by DataCapable supports transportation authorities during natural disasters or extreme road conditions such as heavy snow, rain, or ice. The solution models traffic flow and emergency response during different events as well as emergency evacuation. The management of critical infrastructure using DataCapable provides enhanced emergency responses to events and traffic accidents.

Castle Rock Associates

Castle Rock Associates, Inc. (CRA) is an Information Technology firm established in 1984 focusing on the application of technologies in the transportation industry, specifically for transportation agencies. The company is based in Portland, Oregon and at the time of writing the thesis, it is recognized as a Woman's Business Enterprise. From online research, the company is estimated to have between 23 and 50 employees. The areas of focus of the company include smart transportation systems, transit information, software, and application development. The areas of expertise include Waze Connected Citizens integration, and Advanced Traveler Information Systems (ATIS) among others (Castle Rock Associates Inc, LinkedIn, 2022).

The solutions offered by CRA currently support transportation authorities with a range of different products. CRA has partnered with several transportation authorities including the Departments of

Transportation of the states of Minnesota, Idaho, Iowa, Nebraska, Indiana, Kansas, Colorado, Massachusetts, and Oregon as well as other transportation authorities like the British Columbia Ministry of Transportation and Infrastructure or the New York State Thruway. Therefore, CRA is well-established in the market. (Castle Rock Associates Inc, Home, 2022)

CRA's principal product is 'CARS' which is an event management platform where events and road condition reports can be imported manually or stream data such as the Waze Connected Citizen system or the National Weather Service. For example, the 511 platform for the Nebraska Department of Transportation is powered by 'OneWeb' from the 'CARS' system. The network mapping across the state includes layers such as road reports, Waze reports, winter driving conditions, live cameras, traffic speeds, weather station alerts, weather warnings, electronic sign placement, and weather radar. (Figure 9).

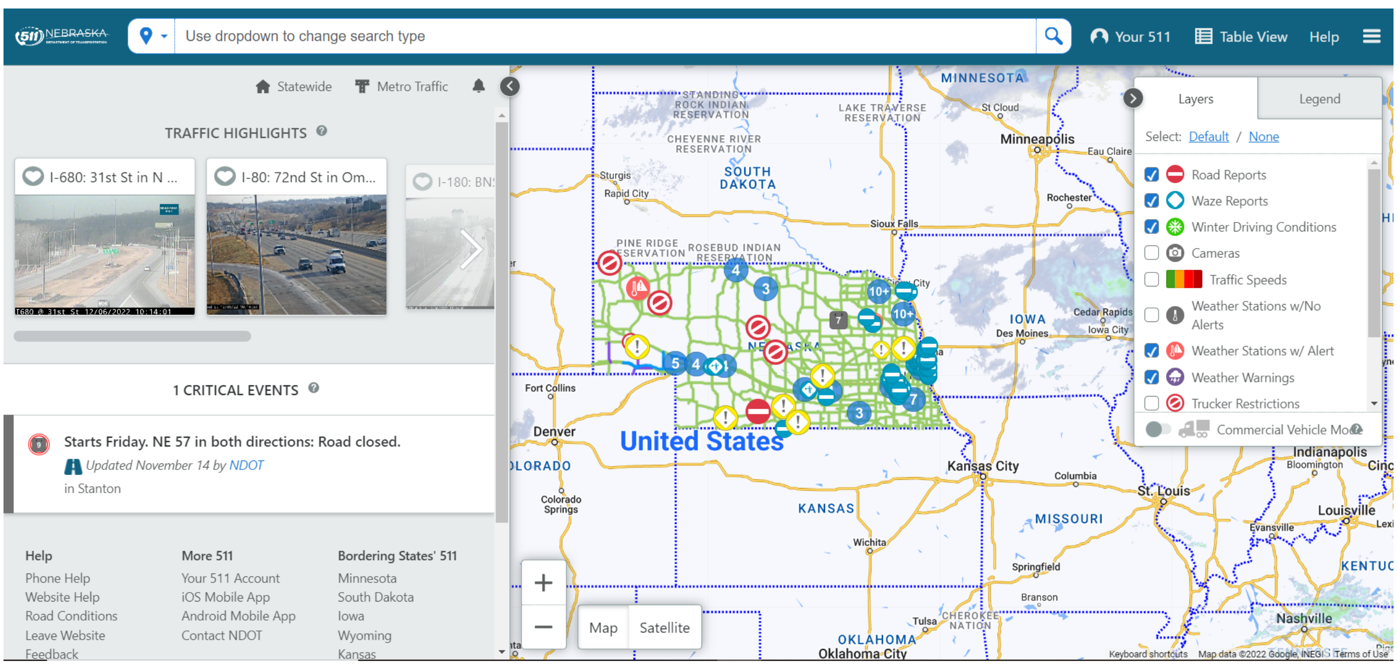

Figure 9: OneWeb Nebraska DOT Platform powered by Castle Rock Associates, Inc, Retrieved from 511 Nebraska DOT[5]

[5] (Nebraska Department of Transportation, 2022)

The platform powered by CRA includes a critical event feed and shows the streamed reports from Waze. Which are filtered into categories including weather reports, road closure, road hazard, road construction, road accident, and level of road traffic (Figure 10).

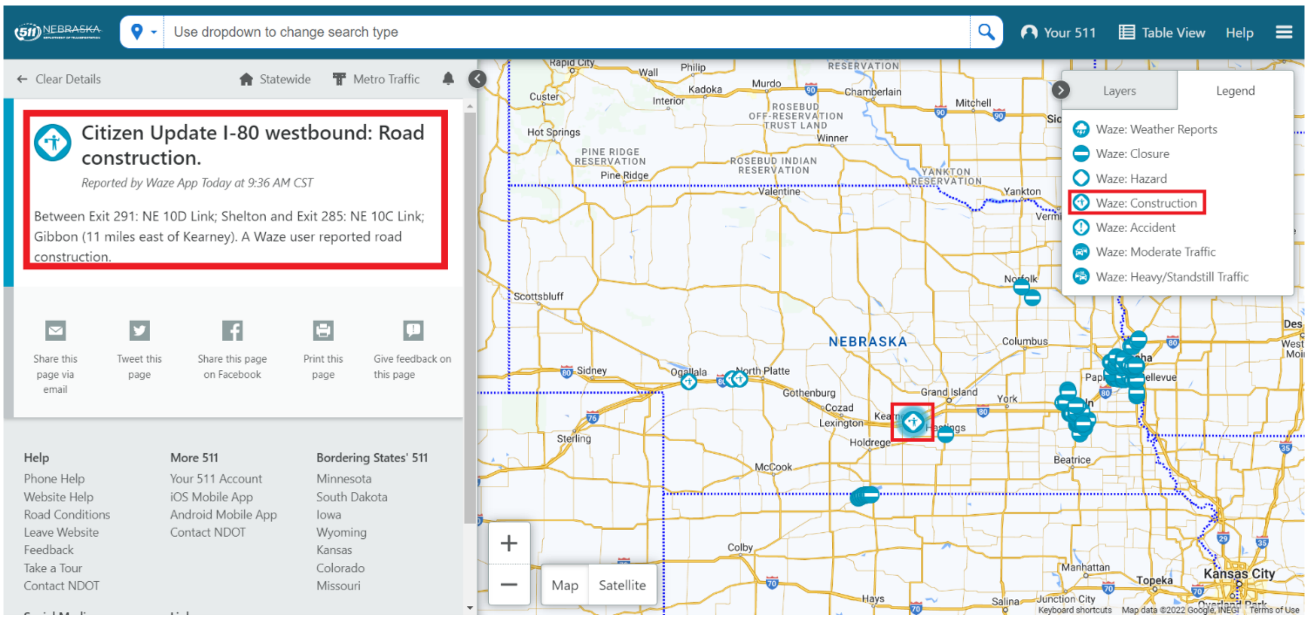

Figure 10: OneWeb Nebraska DOT Platform powered by Castle Rock Associates, Inc, Retrieved from 511 Nebraska DOT[6]

According to CRA, during the 2019 Nebraska floods, the 'CARS" platform detected road closures due to flooding which helped Nebraska DOT convey the information to the public and deploy the necessary response team (Castle Rock Associates Inc, CARS, 2022). The Indiana Department of Transportation (INDOT) features additional layers such as live videos from slow plow cameras, flooded roads, and other unplanned traffic incidents through the TrafficWise application developed by CRA.

[6] (Nebraska Department of Transportation, 2022)

CRA and the Indiana Department of Transportation partnered for the development of ‘IRIS-X’, an open-source (deployed for INDOT but available to other DOTs if wanted) ATIS with multiple modules developed in conjunction with DOT Traffic Management Center operators. The modules from the ‘IRIS-X’ system provide videos, message automation, and event management (Castle Rock Associates Inc, Iris-X, 2022). IRIS-X is inspired by the IRIS system.

The IRIS system (Intelligent Roadway Information System) was developed by Doug Lau and the Minnesota Department of Transportation (MnDOT) to manage traffic monitoring and control devices. IRIS is deployed in California, Minnesota, Nebraska, and Wyoming. Given the open-source focus on IRIS, the California Department of Transportation (CALTRANS) has conducted several research developments on IRIS to adapt to existing infrastructure and field devices. A significant advantage of IRIS is the cost-effectiveness for deployment in rural areas and the versatility of the IRIS source code (Hassas, 2013). Additionally, MnDOT improves IRIS with state base projects. For example, improved Dynamic Messages Signs to convey information to the public, video handling improvements, and real-time integration of arrow board messages. (Minnesota Department of Transportation, Traffic Engineering Projects 2016-2020, 2022). The IRIS system allows operators to manage incidents yet, in the IRIS manual there is no mention of machine learning or artificial intelligence-powered modules to detect incidents from social media. In IRIS, incidents are mapped manually with human interaction where the user is required to create the incident, label its type, and select the lane type, hazard, and verification camera (Figure 11). Then the operator must specify the lane impact, edit, and clear the incident (IRIS, 2022). IT developers like CRA have extensive experience with IRIS systems and can customize the system based on transportation authorities’ needs.

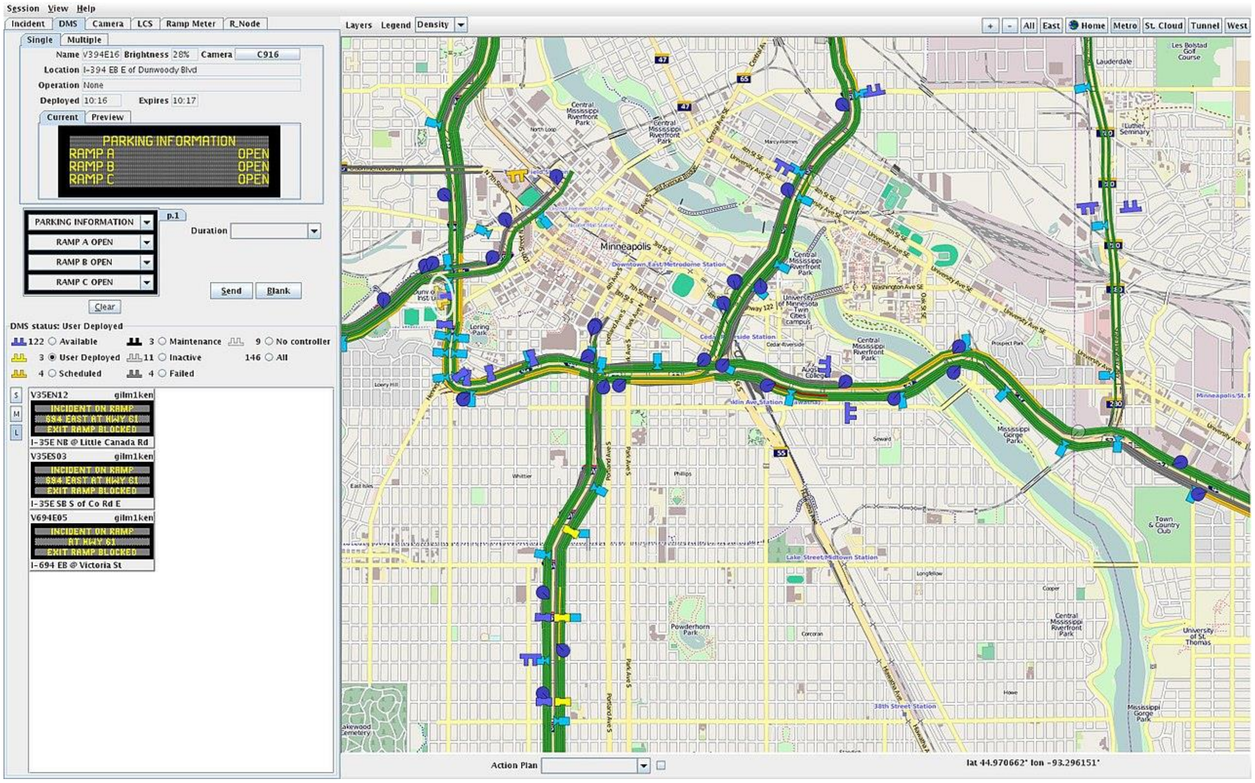

Figure 11: IRIS screenshot supplied by MnDOT, Retrieved from Wikipedia [7]

Additional products available at CRA include applications for automated 511 phones to obtain information about the transportation network in real-time. They provide desktop and mobile applications for public use based on real-time data including videos. Finally, they have the capability to stream video and location of snowplows across the state for the operators and the public.

[7] (Minnesota Department of Transportation, IRIS screenshot supplied by Mn/DOT for Wikipedia, uploaded by Michael Darter, 2011)

Network Dynamics Lab – DUET - CARE

The Network Dynamics Lab at the Georgia Institute of Technology led by Professor John E. Taylor focuses its research on extreme event dynamics, information system integration dynamics, network dynamics globalization, and building occupant network dynamics. As part of the research, the laboratory has tackled several projects in the crisis informatics domain in conjunction with transportation authorities. (Network Dynamics Lab, 2022)

Data-driven detecting urban emergencies technique (DUET) developed by Wang and Taylor (Wang & Taylor, DUET: Data-Driven Approach Based on Latent Dirichlet Allocation Topic Modeling, 2019), is an event detection technique capable of identifying a wide range of emergencies including infrastructure failure, earthquakes, and fires. DUET is designed for real-time event detection to improve prompt and efficient emergency response to crisis events. The DUET algorithm leverages social media, specifically the live Twitter data stream. The algorithm is designed into three principal modules. The first module focuses on data preprocessing from the live Twitter streams. The initial tweet preprocessing removes links, user mentions, punctuation marks, stop words, numbers, and other special characters. Then the authors classified the words in a sentence based on their grammatical nature and determined the base of the words in question providing meaningful basic entities. The second module focuses on determining candidates for potential emergencies, Wang and Taylor used geo-topic detection to determine geographic proximity and semantic relativeness. This was achieved with the use of LDA and LDA-based cosine similarity to find associations of terms and the degree of similarity among them. Geographical proximity and clustering were defined from a weighted network where hubs and connections could be potential emergencies. The third module focused on emergency detection through geo-topic ranking. In this module, Wang and Taylor focused on quantifying the negative sentiment intensity. To achieve this objective, the module implemented machine learning techniques to quantify sentiment. Sentiments were measured on a binary scale where positive and neutral sentiments were 0 and negative sentiments were 1. The authors then tested the DUET methodology on a set of different catastrophes ranging from bridge collapses, earthquakes, and fires. Wang and Taylor successfully detected the events and were even able to rank the sentiment intensity for each event.

Additional research was conducted at the Network Dynamics Lab by Samuels, Mohammadi, and Taylor, (Samuels, Mohammadi, & Taylor, Social Media-Informed Urban Crisis Detection (No. FHWA-GA-20-1834)., 2020) on the integration of crowdsourced datasets with social media in social media convergence for increased precision in event detection. The designed framework leverage Twitter data streams and Waze reports. The principal objective behind the data fusion is to add value to the response system by improving the detection time and being able to detect out-of-normal scenarios from historical data. The convergence of data streams is effective during information parsing in a single database for further conjunct analysis. The designed framework explains that the mapping of events can be achieved through a convergence buffer. From interviews with the Georgia Department of Transportation, the authors determined that 8 Waze data points are required to activate an incident alert in GDOT systems, in this case, Twitter data can contribute with additional data points to reach the 8 points threshold and activate the alert. Additional value in situational awareness is achieved with the contribution of metadata in the form of images and videos. Finally, the events are mapped to contextualize the incident for emergency managers.

As a continuation of the project in crisis informatics and event detection, the Network Dynamics lab team focused on the Community Augmented Rapid-response to events (CARE) in partnership with the Georgia Department of Transportation (GDOT). As part of the project, the research team designed a modular approach for interoperability implementation with the requirements from GDOT. The detection system is based on social media data streams from Twitter and crowdsourced data reports from Waze to achieve near real-time detection of events through online-mode detection of events from an extensive dataset. The application behind the CARE project is based on the advances from the DUET system. At the time of writing this thesis, the research team has successfully completed the revision of alternative data streams, established a near-real-time data streaming platform, processed and integrated social and community data streams, and implemented information parsing, textual analysis, and sentiment analysis. The team has also made significant advancements in the development of the training and classification of the online detection model, spatial temporal mapping, and design of a confidence point analysis where a community evaluation of a Waze event will be factored into the machine learning algorithm. As part of the initial scope of work, the team will implement the proposed solution with GDOT and manage a social media campaign for validation and deployment.

CHAPTER 6: EVALUATION OF CRISIS INFORMATICS SOLUTIONS

The three solutions explored were evaluated using the competency matrix designed in Chapter 4 of this thesis.

DataCapable Evaluation

Factors	A+	A	B	C	D
Architecture	High modularity and interoperability design for long term operations	Modular components and interoperability design	**Modular components without interoperability design**	Non-modular system with interoperability concerns	Non-modular systems and interoperability issues
Automation	Autonomous System without human intervention	**Human-in-the loop ML powered system**	Advanced Automation in event detection	Novice Automation in event detection	Lack of Automation
Event Detection	**Supports various types of event emergencies across multiple networks**	Supports various types of event emergencies across the road network	Supports various types road related events across the road network	Supports only road related events across the road network	Supports unique road related events across the road network
Situational Awareness	Deploys Next Gen TIM with UAV and LiDar technology	**Supports live conference streams with responders**	Supports various types of data streams including live cameras from response vehicles	Supports various types of data streams including social media	Supports phone call based data streams
Detection Speed	Real time	**1 minute to 3 minutes**	4 minutes to 10 minutes	11 minutes to 20 minutes	more than 20 minutes
System Maintenance	Maintained and Operated by user	**Scheduled maintenance and update by contractor**	Maintenance and update by contractor as needed	No Maintenance	Planned obsolescence
Deployment speed	Immediate	**within 6 months**	within 1 year	between 1 and 2 years	more than 2 years
Contractual Needs	Internal Authority Development	Renewable Contract	**Single Development and Maintenance contract**	Development Contract	Long Term Concession
Experience	Expert team from past projects and market position	Proficient team from past projects and market position	**Competent team from past projects**	Average teams without past projects	Novice team

Figure 12: DataCapable Evaluation Matrix

DataCapable was evaluated with the competency matrix designed in Chapter 4. The result of the analysis shows that concerning the system architecture the company shows modular components without interoperability design because their existing modules are not designed with existing ATIS yet they are a separate product however, they have the capability to adapt the solution to the need of the customer. At the automation level, DataCapable has advanced machine learning and AI algorithms deployed yet they rely on human-in-the-loop decisions which indicate there is still a need for human interaction for event detection. In the level of event detection, DataCapable showed to be strong at identifying different types of events across multiple networks for instance they are able to look at the impact across the road network but also the utility network which brings an increased level of contextualization to the emergency response teams. When considering situational awareness, all three solutions provided mapping solutions yet DataCapable is able to interact directly with emergency responders on-site through conferences in their community response module and even citizens can participate. In detection speed, DataCapable is able to detect an event within 3 minutes according to their CEO Pete DiSalvo which is a near real-time response system. Given the nature of DataCapable as a formal vendor and the fact that their solutions and algorithms are patented and under IP protection, the company has to be directly involved in the maintenance of their system, and because of the human in the loop-based algorithm, the DataCapable team must always be involved in any detection made and alert the client. It is expected that the deployment of this technology would be within 6 months given they already have the working technology in place and would need to set it up for the specific needs of any authority. Regarding Contractual needs, DataCapable would be responsible to develop and maintain the project and would need to prove themselves to a new client, yet they have a high potential of obtaining renewable contracts for their services. Regarding experiences, DataCapable offers solutions for transportation authorities yet their main market is the utility sector, and could expand their division for transportation authority solutions.

Castle Rock Associates, Inc. Evaluation

Factors	A+	A	B	C	D
Architecture	**High modularity and interoperability design for long term operations**	Modular components and interoperability design	Modular components without interoperability design	Non-modular system with interoperability concerns	Non-modular systems and interoperability issues
Automation	Autonomous System without human intervention	Human-in-the loop ML powered system	Advanced Automation in event detection	**Novice Automation in event detection**	Lack of Automation
Event Detection	Supports various types of event emergencies across multiple networks	Supports various types of event emergencies across the road network	**Supports various types road related events across the road network**	Supports only road related events across the road network	Supports unique road related events across the road network
Situational Awareness	Deploys Next Gen TIM with UAV and LiDar technology	Supports live conference streams with responders	**Supports various types of data streams including live cameras from response vehicles**	Supports various types of data streams including social media	Supports phone call based data streams
Detection Speed	Real time	1 minute to 3 minutes	3 minutes to 10 minutes	**10 minutes to 20 minutes**	more than 20 minutes
System Maintenance	Maintained and Operated by user	**Scheduled maintenance and update by contractor**	Maintenance and update by contractor as needed	No Maintenance	Planned obsolescence
Deployment speed	Immediate	**within 6 months**	within 1 year	between 1 and 2 years	more than 2 years
Contractual Needs	Internal Authority Development	**Renewable Contract**	Single Development and Maintenance contract	Development Contract	Long Term Concession
Experience	**Expert team from past projects and market position**	Proficient team from past projects and market position	Competent team from past projects	Average teams without past projects	Novice team

Figure 13:Castle Rock Associates Inc. Evaluation Matrix

The evaluation of Castle Rock Associates Inc. with the competency matrix designed in Chapter 4 showed that for system architecture, CRA presents high modularity and interoperability for long-term operations this is because they currently design the systems for several Departments of Transportation and have been partnering with them to create open-source solutions that could be adopted by any transportation authority. In terms of automation, CRA is able to detect events from Waze event alerts yet, based on the 'IRIS' system, the creation of incidents is a manual process completed by the system operator. For event detection, CRA is very strong at identifying events on the road network yet these are mostly related to road incidents and not other types of emergencies. Regarding situational awareness, CRA is able to leverage datasets to fixed cameras on the network but most interestingly it features streaming of live mobile cameras from snowplows on the road, it is this combination with other data streams including weather that provides enhanced situational awareness to the operator. On Detection Speed, given that it uses current technologies and Waze reporting it is estimated that its event detection time would be around 10 to 20 minutes after an incident. CRA has partnered with other DOTs, in this condition they have been assigned the maintenance of the system for years, for example, it has been operating 'CARS' for the Nebraska Department of Transportation since 2015. On deployment speed, it is likely that it will be similar to DataCapable given that they already have the technology. In terms of contractual agreements, their ambition would be to obtain renewable contracts given that it is their main business area and their past projects show that behavior. Finally, in terms of experience, CRA is a strong IT developer with a strong portfolio of past projects and constant integration of emergency operators in their design of solutions.

Network Dynamics Lab – DUET – CARE Evaluation

Factors	A+	A	B	C	D
Architecture	High modularity and interoperability design for long term operations	**Modular components and interoperability design**	Modular components without interoperability design	Non-modular system with interoperability concerns	Non-modular systems and interoperability issues
Automation	**Autonomous System without human intervention**	Human-in-the loop ML powered system	Advanced Automation in event detection	Novice Automation in event detection	Lack of Automation
Event Detection	**Supports various types of event emergencies across multiple networks**	Supports various types of event emergencies across the road network	Supports various types road related events across the road network	Supports only road related events across the road network	Supports unique road related events across the road network
Situational Awareness	Deploys Next Gen TIM with UAV and LiDar technology	Supports live conference streams with responders	Supports various types of data streams including live cameras from response vehicles	**Supports various types of data streams including social media**	Supports phone call based data streams
Detection Speed	Real time	**1 minute to 3 minutes**	3 minutes to 10 minutes	10 minutes to 20 minutes	more than 20 minutes
System Maintenance	Maintained and Operated by user	Scheduled maintenance and update by contractor	Maintenance and update by contractor as needed	**No Maintenance**	Planned obsolescence
Deployment speed	Immediate	within 6 months	**within 1 year**	between 1 and 2 years	more than 2 years
Contractual Needs	Internal Authority Development	Renewable Contract	Single Development and Maintenance contract	**Development Contract**	Long Term Concession
Experience	Expert team from past projects and market position	**Proficient team from past projects and market position**	Competent team from past projects	Average teams without past projects	Novice team

Figure 14: Network Dynamics Lab – DUET – CARE Evaluation Matrix

The solution designed by the Network Dynamics Lab team has been designed as a module for interoperability with the current GDOT system. In levels of automation, the solution is designed for online detection with machine learning algorithms that can detect the event using the DUET framework. Regarding event detection, the solutions proposed not only detects events related to the road network but can also detect different types of events such as earthquakes and fires across the built environment which shows great potential for a larger emergency management application. In terms of situational awareness, its modular condition to supplement the existing system is different from other vendors that bring their own systems to the table. Currently, the module relies on Twitter and Waze data streams and is the strongest solution in terms of social media-generated awareness. However, the other solutions bring other capabilities like mobile cameras that strongly augment situational awareness. The detection speed of the current algorithm is around 3 minutes which shows the strength of the machine learning model to complete its designed objective of fast event detection. In terms of system maintenance, given that the solution spans from a research project, maintenance of the system is not envisioned after implementation which could lead to update problems in the future. On deployment speed, given the advanced nature of the algorithm certain phases are still in development and the setup of a social media campaign to validate the results would be achieved within 1 year with full support from the Department of Transportation. Because the solution is a research project, the scope of the solution is limited to the development but if successful it has the potential to become a permanent adoption by GDOT. Finally, on experience, the research team has completed multiple research projects and publications in the area.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

Recommendations

The results from the evaluation of the three different solutions with the designed competency matrix presented in this thesis provide an increased knowledge of the options available in the market. Although this information is a guide to study capabilities, the final decision to implement a solution is to be decided by the procurement team of the public institution. The procurement team should be integrated with a range of professionals with different expertise, visions, and needs. The procurement team should understand the state of the art in crisis informatics technology, should be familiar with the challenges of public procurement of IT solutions, and consider the sociocultural aspects of procurement as a negotiation process.

Conclusion

Technologies such as AI, ML, and others have contributed to the development of sustainable smart cities. With the increased number of natural disasters, crisis informatics has risen as an essential component of sustainable smart cities. Crisis informatics manages information previous, during, and after a catastrophe to improve the response to emergency events with the principal objective of protecting the public and assets. Transportation authorities have shown interest in crisis informatics solutions for the road network and have been open to innovation in their operations. The first objective of this thesis was to establish the needs, considerations, limitations, and strategies for the development of a competency matrix capable of evaluating different solutions for transportation authorities. An extensive review of the current state-of-the-art technology in crisis informatics covered social media processing systems, along with the different analysis methods available. To further understand the importance of the theory behind crisis informatics several theoretical models were studied including ICM, SCCT, and SMCC. This study provided a strong technological background to design the competency matrix. Additionally, an extensive review of the status of public procurement of IT software solutions considering the challenges and barriers to implementation including negotiation was studied to obtain a strong awareness of the ecosystem around technology procurement in the public sector. The competency matrix was designed from the understanding of these two principal concepts. Three different crisis informatics solutions were explored as potential solutions to be implemented in a DOT. The solutions were evaluated with the designed competency matrix and were determined to bring positive solutions to the problems. The evaluation from the proposed competency matrix shows the status of the current capabilities of these solutions, yet a decision must be taken from a diverse procurement team that aligns the needs and requirements of the authority with the capabilities of the solution provided.

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