A Holistic Spatial Platform For Managing Infectious Diseases, Case Study on COVID-19 Pandemic

Louai Alarabi
Umm Al-Qura University
Mecca, Saudi Arabia
lmarabi@uqu.edu.sa

Saleh Basalamah
Umm Al-Qura University
Mecca, Saudi Arabia
smbasalamah@uqu.edu.sa

Mohammed Abdalla
Beni-Suef University
Cairo, Egypt
mohammed.a.youssif@fcis.bsu.edu.eg

Abdeltawab Hendawi
University of Rhode Island
Kingston, USA
hendawi@uri.edu

***Abstract*—The coronavirus outbreak is first and foremost a human calamity, severely affecting the health of millions of people around the globe. It is also having a significant impact on the national and global economy. As this crisis has a two-sided negative impact, health, and economy, this makes it hard to manage. A full lockdown of the society can help control the spread of the infection. However, the economy will suffer significantly. On the other side, allowing normal life activities will protect the growth of the economy. But, it will decisively increase the spread of the infection, and consequently, cause a collapse in the whole medical system. In response to the COVID-19 pandemic, this paper presents the development of a real-time crisis management system that is able to holistically control the country's resources at both micro and macro levels. The ultimate goal of this system is to assure the harmonic balance between crucial actions needed for the containment of the coronavirus spread and at the same time protect the national economy from the negative impacts caused by these actions. To achieve this goal, the system will privately monitor users' geo-social interactions to assist in applying a reasonable social distance when it is needed. The system will alert the people who were in interaction with an infected person or area and recommend the appropriate health care provider. In addition to the fine crafted mobile and web interfaces, the proposed system will be equipped with a set of infrastructures such as data warehousing, data mining, maps, and dashboards. These tools will facilitate heterogeneous data management and analytics to efficiently handle the COVID-19 pandemic crisis at various levels of the decision-making process. We present the proposed crisis management system which can significantly contribute to winning the battle with COVID-19.**

***Index Terms*—Pandemic, Crisis Management, COVID-19, Spatial, Spatio-temporal, Contact Tracing, Surveillance.**

I. Introduction

On December 2019 unknown outbreak disease struck the city of Wuhan, China [1]. This mysterious disease reveals itself to the globe as Coronavirus disease 2019 (COVID-19). This contagious disease dramatically spread and affected millions of people world wide [2]. This threat leads the World Health Organization (WHO) to trigger an international emergency warning to this unprecedented virus[3]. At the time of writing this paper, WHO reported that the number of people lost their lives is over 500 thousand, and over 10 million others are still struggling and fighting for their survival. The Crises of this virus spread and affected almost every country. In the majority of these highly affected countries, the percentage of patients in need for intensive care closely follows an exponential trend on a daily basis. For example, the Italian hospitals reached their maximum capacity in terms of a few weeks [4]. When this happens, COVID-19 patients are either navigating from one care provider to another seeking for an Intensive Care Unit (ICU) admission, or waiting in the hospital hall holding on for dear life [5]. At the peak of the pandemic, the medical staff has been left with no options than priorities ICU for patients with the best chance of survival.

In fact, the COVID-19 Crises is not a local issue that disturbs a small group, a specific country, or a limited region. Rather, it is a global threat for national and international health, economic and society. The International Air Transport Association (IATA) reported a global revenue losses over \$113 billion [6]. The governments all over the world spent thousands of billions to mitigate the unprecedented effects and consequences of the coronavirus global pandemic crisis. In May 2020, the United States House passes a \$3 trillion coronavirus aid bill [7]. In addition to the money cost and health issues caused by the pandemic crisis, other main activities have been broken down too. All schools and universities are closed, Operations of many markets and malls are suspended. Social gatherings in parks, resorts, in-house are prohibited and social distance imposed. All Restaurants are closed with the exception of take-away service. Operation of Hospitals, clinics, pharmacies and grocery stores remain open with limited boundary premises.

Governments and giants tech companies across the globe share the burden to contain COVID-19 spread. For example, the government of Singapore recently released `TraceTogether` smartphone application [8], which allows people to share their data location and trace the spread of the Coronavirus. Several other countries including, India [9], China [10], have also been limiting the unprecedented spread using similar technology to trace people movements and predicate who has been in contact with a positive case of COVID-19. Recently, the two tech giants Apple and Google, support hosting several location-based tracking apps to fight COVID-19 [11] digitally. Others have also contributed with electronic self-screening using a smartphone service and via `MAWID` app [12]. Unfortunately, all these efforts are mainly centered on either self-testing or identify positive coronavirus person and push notification to warn people who have been in contact with this person to watch for symptoms or seek medical attention. All of these efforts are doing a good at the micro level where a specific type of services are managed. There is a lack for a holistic management for the pandemic crisis at the macro level.

At another dimension on the same line of the pandemic management, there is a trade-off between imposing strict quarantine measures and maintaining regular societal and economical sectors. Hence, We argue that there is a high demand for a national crisis management framework, which mitigates COVID-19 pandemic and other similar crisis in a holistic manner. In this paper, we present a crisis management framework that efficiently balances between contaminating the spread of COVID-19 and maintaining the prosperity of economic and enforce reasonable social distance as needed. The proposed crisis management system will offer several main functionalities that include; (1) Monitoring people health, (2) Tracking users' locations, (3) Efficiently giving the patient access to medical resources without jeopardizing their life, (4) Assisting the officials and medical agencies to early predict infected people, and identifying the areas or groups of people who are starting to develop COVID-19, (6) Assisting authorities and decision-makers to impose new regulations, (7) Helping disaster management agencies to early identify, predicate, and control the spread of the disease, and (8) Providing a data warehouse such that the data will be available for researchers, medical staff, and relevant professionals. In this project, we craft a holistic crisis management system equipped with the required tools to control the spread of COVID-19 and similar pandemics in an early stage, make the proper decision, enforce regulations, and monitor the health of people. We envision that the crisis management framework will allow the government to control the spread of the virus, maintain business revenue, and reduce public anxiety.

The rest of the paper is organized as follows. Section II gives a brief overview of the proposed system for pandemic crisis management. Section III describes the details of the framework architecture. Section V overviews related work, and Section VI concludes the paper.

II. Framework Overview

Figure 1 illustrates an overview of the main users and the functionality of the real-time monitoring and surveillance crisis management system.

A. Overarching and Concerns

In this project, we present a full-fledged crisis management system that has the ability to friendly monitor people health, social interaction, hospital utilization, and at the same time be alert and available for handling outbreaks, crisis, and pandemic in specific, and disasters in general. Besides, people will get an initial quick screening that is available 24/7 through the app interface from health practitioners and automated pre-checkup list approved by the health agency. Most importantly, what would motivate people to use the system is being able to obtain the needed medical services without risking their lives in a catastrophic crisis. However, people would have a concern regarding their privacy and security. No private data will be shared or released without user consent. All private data will be encrypted and not shared outside the service loop. The users will have a full control over their data. In case data is shared with any external agency, the data will go through the anonymization process and location transformation to hid and maintain users' identities and privacy. The system will allow policy makers to impose various regulations on different levels and efficiently utilize medical resources to save people lives. The system will provide a middle ground to balance between facing the crisis, saving lives, and preventing an economic collapse a global depression.

B. Users and Stakeholders

Various types of users can interact with the system as follows; (1) The casual user who has minimal interaction through a nicely designed smartphone app. Once the user downloads the app, then the app will automatically track the current user location. A notification will be sent to the user if the user violates the boundary of the self-quarantine or entering a disallowed geographical zone. Each user will be asked a few questions about his/her general health. Based on the received answers, the app will generate an automated recommendation and accordingly synchronizes this information with the core system. A notification will be sent to the user if the user has been in contact with a positive COVID-19 case. The system will send a recommendation for a specific hospital checkup. The system assures a balanced distribution of the patients over the available hospitals such that each patient receives the needed medical attention. That is turns maximize the utilization of the medical resources as a whole. In a case of full lock-down or isolation, the user can receive a temporary e-permit to go outdoor. The given e-permit will show the allowed zone area and time window for the e-permit carrier. (2) The Health care provider interacts with the system through a website to share information about their ICU, bed capacity, continuously updated availability, and schedule. The system is able to each patient to a specific hospital based on the required care as well as the distance from patient. Once a patient checked-in, the medical staff can confirm whether the patient is a positive COVID-19 case or not. The crisis management system will also send a geo-location attached with an emergency request for patients who seek on-the-spot medical attention. (3) Decision-makers who are interested in gaining a deep understanding of the pandemic situation on grounds will have ability to discover patterns, extract valuable information, predict, and control the spread of the crisis. To serve this category of users, the system will provide a dashboard equipped with a set of mining and visualization tools that assists real-time analysis. The decision-maker will access data and information by submitting their queries and receive the responses via the dashboard. (4) Government officials will interact with the system by updated their imposed regulation, i.e., level of lock-down. The system will provide the authority agency the ability to cast the level of quarantine, such as regional, city, area, zone, or a complete lock-down, i.e., stay at home. The crisis management system will backbone its

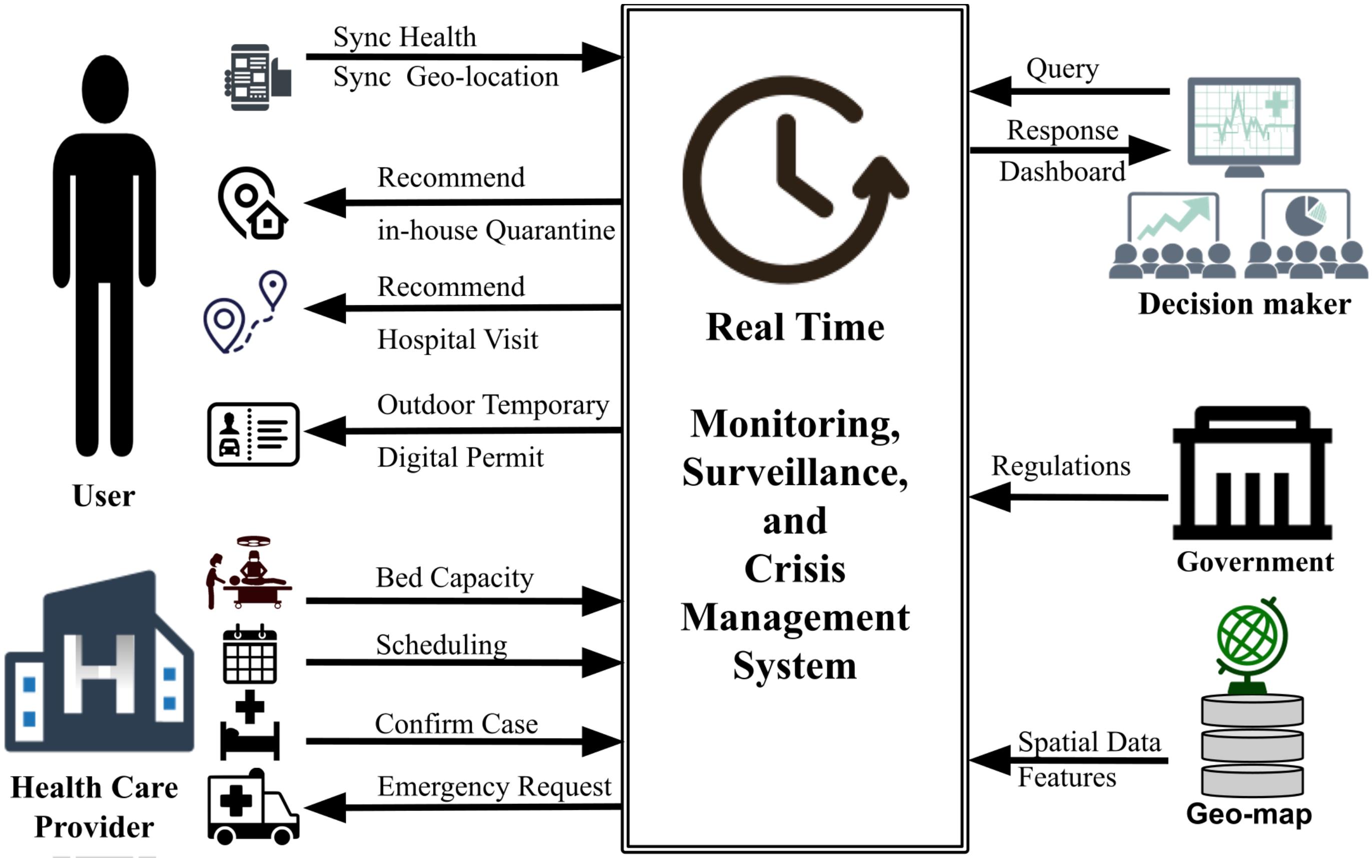

Fig. 1. Overview of The Proposed Framework, Its Service, and Stakeholders

infrastructure by importing spatial data features to utilize all of its functionality from the available geographical map data source.

In a nutshell, we envision that the crisis management system can significantly contributes in winning the battle with the COVID-19 outbreak and can be generalized for similar pandemics.

III. System Architecture

In this paper, we design an innovative real-time surveillance and monitoring crisis management system. The presentation of this section first gives an overview of the proposed system internals design, then discusses in great detail the scientific and technical of internal components. The design is extendable, which allows room for any future enhancements or appends new extra features, or digests new data sources. We envision the extendability nature of the design will motivate authorized and agencies to extend the system capability and add extra functionality and services.

A. Design Glimpse

As shown in Figure 2, we are proposing to design a full-flagged real-time management system for monitoring, surveillance crisis. The system consists of eight modules. The first module of the system will initially crawl heterogeneous data from several sources, including geographical data from digital maps, tracking user locations, hospitals' capacity, hospitals' schedules, and government regulations. For this purpose in our system, we will design a data lake ingestion layer for streaming and ingesting the data, as mentioned earlier. The second module digests the incoming streams of data by applying various Extraction, Transforming, and Loading techniques (ETL), including data cleaning, data fusion, spatial features extraction, geo-social graph construction, map matching, and trajectory formulation and segmentation. Once the data is processed and ready to be obtained into the system internals, we will design efficient indexing data structures and querying algorithms to process and retrieve data with low latency. The fourth module of Surveillance and Monitoring will be mainly responsible for designing a set of efficient algorithms that impose geo-fencing, validate real time location tracking, detect outliers locations, and predicate users' future locations. The system will be equipped with a set of modules that are responsible for the implementation of efficient mining, analyzing, and routing algorithms that fulfill robustness and keen to be responsive in real-time. Finally, in the last module, we will build an interactive dashboard equipped with geographical visualization tools. This module will arm the decision-makers with the right gears to queries and interactively visualize data in different forms. The dashboard will provide the right tools that assist decision-makers to gain an eye bird overview of the crisis, easily understand relevant information, and grasp hidden knowledge by mining data.

B. Data Lake Ingestion

This component of the system is responsible for crawling data, including users locations, geographical maps data, hospitals capacity, and government regulations. Initially, we will build a crawler that frequently update user locations and archive it in the system. To provide the promised features of the crisis management system , we will backbone the system with the rich geographical information by crawling data from available geographical maps. Next, we will implement data hose to collects health care providers capacity and scheduling. Finally, will allow to crawl officials regulations to be updated through specific data hose and reflects its policy to tune the system configuration for imposing policy. In this subsection, we will briefly discuss the two vital crawled data (i.e., geo-map and user location data), while other data can be collected by an interface or API to acquire the information from hospitals and government agencies.

• **Real-time Tracking of Users Health and Location:** The ubiquity of smartphones enhanced location-based services capability to track users' locations and identify users' behaviors. The appropriate use of user location can be beneficial for both users and our proposed system. For the user, sharing location will assist the users in navigation when medical attention needed, notify the users when they accidentally violate the boundary quarantine, and warn users if they have been contacted with other positive coronavirus cases. The simple collection of user location data enables tracking features in their smartphones. From the system side view, the system will allow users to frequently update their locations, as well as implement a process that periodically fetches users updated locations. As for the health of the user, the system will periodically send a simple questioner for users to update their health information. As we understand the privacy concern of users and the limitation of others who can not share their GPS location due to lack of internet connections, we will implement several techniques that do not mainly rely on using GPS. Instead, we will user other techniques, such as Bluetooth [13], [14], WiFi [15], [16], and telecommunication tower [17] signals to track locations. All these location data will be collected and crawled into the data lake layer in the crisis management system.

• **Geo-Map Data:** The system needs to have full access to underlying real road networks, hospitals, buildings, cities, streets, among other geographical spatial features. Road network for example will be used in the system to execute various algorithms, such as shortest path queries [18], [19], [20], [21], [22], [23], k-nearest-neighbor queries [24], [25], [26], [27], reverse nearest neighbor query [28], [29], range queries [30], skyline query [31], [32], among others (e.g., [33], [34], [23]). Unfortunately, it is always challenging to get such a real road network, which imposes a major obstacle in advancing the research and implementation of our system. Although it is hard to get such data, in the proposed framework, we will implement a batch crawling process that extracts spatial features from OpenStreetMap [35]. OpenStreetMap [35] has been launched in 2004 to allow volunteers to combine their efforts in building an exhaustive and trustworthy map for the whole world with an increased focus given to road networks in a single half-terabyte file *Planet.osm*. Despite its richness, using OpenStreetMap data is not an easy task due to its huge size and non-standard format. For example, to extract the road network of a specific area, one needs to: First, understand the OpenStreetMap file formats. Second, navigate through a huge data file to extract only the parts within the needed area. Third, once data is extracted from the specified city, records are carefully parsed to extract specific spatial features, such as buildings, hospitals, road networks, city boundaries, and exclude everything else. Finally, one of the other challenges when manipulating with voluntarily geographical information is to deal with noisy data.

C. Data Processing

This layer of the system is responsible several processing modules to prepare the data for further indexing and manipulation. a brief details of each of these modules will be discussed below.

• **Data Cleaning:** The process of data cleaning is to remove any noise and outliers from the data. For example, volunteer contributes their data to build the geographical information in OpenStreetMap. This data is not necessary with high accuracy. A volunteer might mistakenly label the hospital as a grocery store, or identify a skyway as a street on the road network [36]. On the other hand, collecting trajectory data usually is not accurate, due several factors such as poor positioning signals, errors in collections. For example the system might receive inaccurate or wrong location, this could happen when a cloud blocks the global positioning satellites that reports the user location. The dirty data should be transformed into the correct value or removed from the dataset. The data cleaning modules will process each data source independently, as we will introduce different techniques for data cleaning for each data source.

• **Data Integration:** Data integration is an essential phase in data processing, in which it fusion different datasets together to form a unified view. This process allows us to identify the relationship between data and discover a new set of information. In this module, we will carefully investigate the relationship between the data source. For example, investigate the relatives and friends of a person from their trajectory, which assists in geo-social graph construction. Discovering this information from user locations is extremely important as if the system sends a warning to someone who has contacted an ill person, it should automatically send a warning to those who also have contacted this person to watch out for

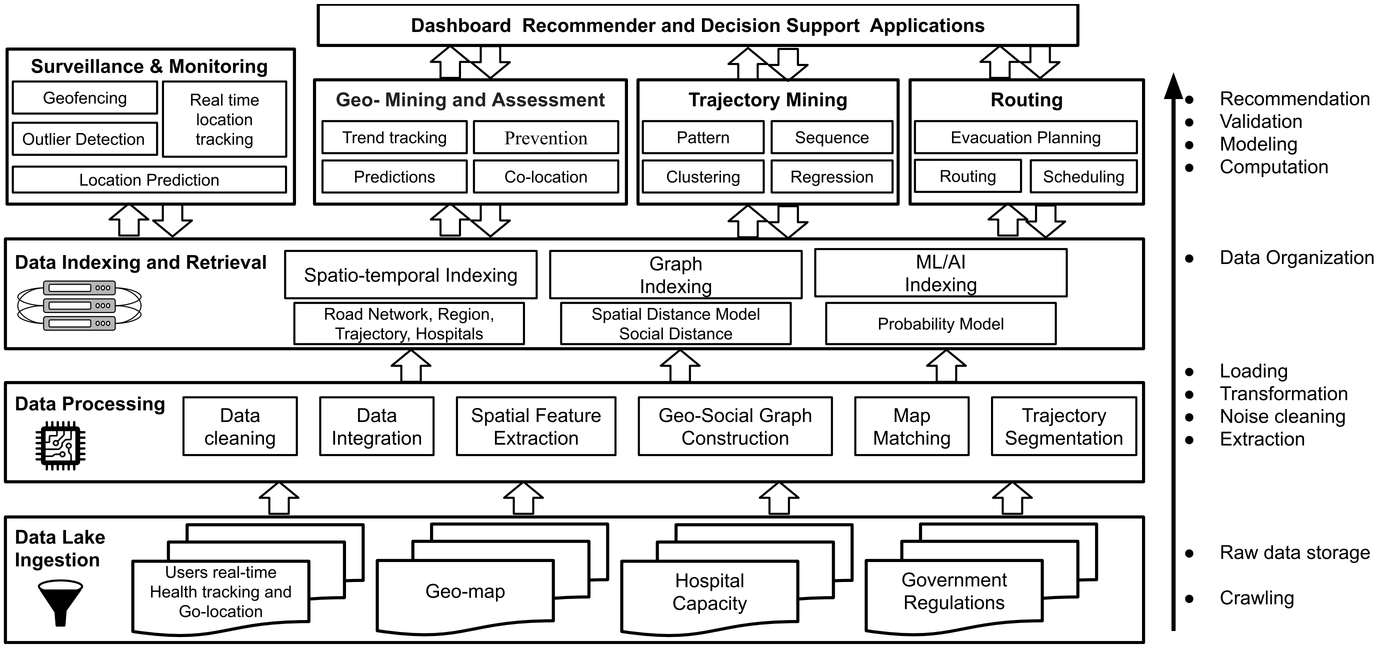

Fig. 2. Main Framework Architecture Design

symptoms.

• **Spatial Feature Extraction:** Extracting information from OpenStreetMap is not a trivial task. OpenStreetMap dataset stores all data types sequentially in one large volume file in a semi-structured XML format. The XML file starts with nodes, then ways, and at last, relations and tags are nested in these data types. The challenge of extracting information from OpenStreetMap depends on identifying the annotation (i.e., tags) that imply categorized spatial data. We will implement efficient algorithms to extract spatial features from OpenStreetMap. The output of data extraction will be several categorized files. Each file contains a piece of homogeneous spatial information, e.g., hospital data will be stored in one file and road networks in another one. This Extracted spatial features will be used in other modules within this layer, such as map matching.

• **Geo-social Graph Construction:** This process module identifies the relationships between users' locations, such as construct a spatial graph of user relatives and friends. In this module, we will analyze spatial user information and find the frequent nearest neighbor location to a user [37], [38], [39], [40]. The association rules will be applied between user locations to discover the co-location between users [41]. We will investigate other efficient techniques to discover this relationship, such as clustering.

• **Map Matching:** User location is not always received with high accuracy. The accuracy depends on additional factors, including satellite geometry, signal blockage, atmospheric conditions, and receiver design features/quality. Location data is transformed from raw GPS data into a single or sequence of data aligned with the other information, such as location on the geographical map (e.g., inside a building or on the road network), or other trajectories. The map matching will allow the system to know where the user was. Hence, this is a critical feature to allocate user location accurately. Several efficient algorithms could be used in map matching [42], [43], [44]. In our proposed framework, we will depend on the geometry of location sampling from the user trajectories. For instance, if the user trajectories are usually in the Taif city and suddenly a location reported in Jeddah for quite some time, that would not have a possibility for someone to travel all that distance at that time, then the reported location should be mapped and aligned with other user trajectories. Another example, the accuracy of the GPS location is estimated to be between $0.5 \sim 7.0$ meters, which makes it impossible to know the exact location of the user without applying a map matching algorithms to predicate his/her exact location.

• **Trajectory Segmentation:** The objective of this phase is to maintain the correlation between the sequence of spatio-temporal shapes. In the literature there are different types of trajectory segmentation, namely Temporal, Shape, and Semantic segmentation: (1) **Temporal Segmentation**, trajectory are divided based on time interval. For instance, a trajectory is segmented based on a fixed time interval such as every 10 minutes. (2) **Shape Segmentation**. this approach splits trajectory based on defined criteria that serve specific applications need. For example, in animal studies one might need know how trajectories are spreads over some defined regions, or study trajectories pattern. (3) **Semantic Segmentation**, the entire raw trajectory scanned, and an algorithm enrich raw trajectory with some semantic annotations such as trajectory accelerations. For example divide trajectory whenever movement of an object change its behavior from walking to driving or vice versa. In our proposed system we initially targeting temporal segmentation for trajectories; however, we will also study other trajectory segmentation algorithms and extensively study their accuracy and performance on the real-time crisis management system.

D. Data Indexing and Retrieval

Organizing the spatio-temporal data with a particular data structure is domain-dependent. For instance, in location-based services, the uniform grid is frequently adopted due to its low-cost overhead when updating the movement of spatial objects. While employing R-tree or Quad-tree are favored for GIS applications due to the complexity of spatial shapes and geometric operations [45], [46], [47]. Although these data structures are well defined, the efficiency of their temporal extension also varies between applications. In our crisis management system, we will investigate the optimal data structures that will support the real-time nature of the system. Initially, we will adopt several layers of indexing data of spatio-temporal [48], graph, and intelligence tuned for AI operations. For each index, we will develop two-layer index one in the memory for fast access and retrieval, and the other will be on a distributed storage medium.

E. Surveillance and Monitoring

This module is mainly responsible for the surveillance and monitoring of users' locations. Reporting the GPS current location of the users by itself is not sufficient enough for monitoring people. Since users' locations are not always received with high accuracy, the system needs to verify the valid user location; this can be done by detecting the outlier locations of the users and trying to predicate their future locations. In our system, we will also introduce a distinct sub-components that are responsible for innovative techniques for tracking locations, such as using mobile network, Bluetooth, WiFi, or IP Internet address. As one of the central functionality of the system is to impose deferent levels of quarantine, the internal design needs to be equipped with an efficient Geofencing capability [49]. The main idea is to surround a virtual wall on a specific geographical area and send a notification to users if they either enter or across that fence.

F. Geo-Mining and Assessment

Combining people trajectories, confirmed cases from hospitals, and geographical spatial on the map enables the crisis management system for a wide range of mining and knowledge discovering, such as discovering spatial crisis spread, co-location of the crisis combined the geographical resources. For instance, one could mine whether specific geographical features (e.g., water source) contribute to the escalate the crisis. In addition, geographical mining of the crisis will assist in predicating how the crisis will spread and impose some prevention techniques.

G. Trajectory Mining

The advances in the location tracking and the complete stack that support computing trajectory have manifest a broad range of mining techniques include: (1) Discovering patterns of a group of trajectories that are moving together for a specific period of time [50], which allows decision-makers and system internals to better design a geofence that separate this pattern. (2) Mining trajectory clusters, which group similar trajectories using specific criteria or constraints. For instance, finding a cluster of people trajectories that do not adhere to the evacuation city plan [51]. (3) Finding a sequence from trajectories that reveal sequential patterns for a group of people trajectories who visit places using a similar spatial or temporal sequence. (4) Observing regression between trajectories can illustrate how people practice self-quarantine. All these trajectory mining techniques will assist decision-makers and system internals to analyze trajectories and assists in a better direction to control the crisis.

H. Routing

The crisis management system must be equipped with a set of efficient routing algorithms. Routing is an essential component in navigation; it does not merely find the shortest path between two locations on the map, which typically seen in services such as in Google Maps or Apple Maps. Instead, routing is one of the NP problems in computer science as there is a various optimization problem, especially in an emergency. For example, navigate a patient to a hospital that can offer the medical attention needed in a short time; this could save the patient life. The hospital that can admit patients not necessarily means a hospital within the patient neighborhood or a hospital that is located on the next block. Thus, routing is not a trivial and vital task in a crisis management system. Yet, another critical example, a case where a hospital assigns an ambulance to rescue several individuals allocated on different geographically locations (i.e., they do not share the same neighborhood), where each of the patients has a condition that threatens his/her life. A simple shortest path algorithm will help the ambulance to arrive earlier to a single patient, but when pickup multi-patients, then the algorithm would dramatically give a negative consequence. Hence, in this module, we are introducing several routing algorithms. Initially, we are going to implements and design efficient algorithms for the following set of problems: (1) Navigate patient to a hospital without risking the patient life. (2) Suggest a route from the hospital to rescue a group of patients. (3) Build a routing plan in a case of area evacuation. Suggesting a route in an evacuation is an extremely challenging problem. The main objective in any of the routing algorithms that will be designed is to save patients' lives.

IV. System Implementation

This section describes the developed modules in our proposed system.

A. Contact Tracing Module

We proposed a technique named *TraceAll* that trace all the contacts exposed to an infected patients and generates a list of the potentially infected persons. The novelty of *TraceAll* lies in performing real-time tracing of suspected contacts.

First, three fundamental parameters that must be defined before the tracing process start which is: (1) tracing period; which represents the incubation period of the virus or disease, (2) exposure time; which represents the exposure period between infected patient and other individuals which means after this period these individuals may become infected, and (3) social distance; which represents the average distance between the infected patient and other individuals which means within this distance these individuals may become infected. Then, the infected patient (query user) marks himself as infected, this represents a query to the technique. Next, the technique starts to inspect all objects moved nearby the querying user and obtain their trajectories during the configured tracing period. Then, each trajectory obtained represents a suspected case and the technique investigates it from two perspectives; exposure time and social distance. Next, the technique inspects each trajectory; it starts by identifying the meeting points between the querying user trajectory and other trajectories. Meeting points mean points that the two trajectories are meeting each other at the same time at different points or the same point. Then, the technique computes if these trajectories remain with each other period equivalent to the configured exposure time within the configured social distance, if these two conditions matched together, the technique considers this object that owns this trajectory as a potentially infected patient, and add it to the infected patient list[52].

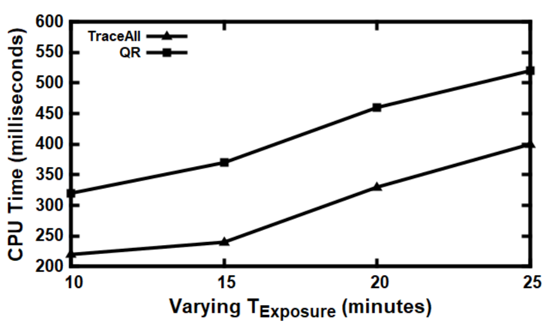

Fig. 3. Effect of Exposure Period on CPU Time.

Indeed, figure 3 compares the *TraceAll* technique with the QR-tree when the exposure time increasing against CPU processing time to answer contact tracing query (CTQ). The figure measures the time consumed to answer CTQ in terms of the *TraceAll* and the QR-tree and highlights the results. The x-axis presents the varying of $T_{Exposure}$ in minutes, while the y-axis presents the CPU processing time consumed in milliseconds. The figure illustrates that the QR-tree consumed more time to answer CTQ than the *TraceAll*. The tests are repeated several times to confirm the results. The justification behind that QR-tree consumed more time is that the QR-tree must retrieve and check the same time buckets for each point then group points from both trajectories and compare them until the end of $T_{Exposure}$, while in the proposed approach utilizes the verification of social distance to filter out noisy points and save time.

B. Hospital Admission Module

We developed an effective multi-objective admission system for Covid-19 patients to admit patients to the most suitable hospitals in real time and considers the comorbidities of the patients. The method employed in this system considers two main criteria in the admission process: (1) the patient status regarding the hospital preparations and (2) the admission time (reach time and admission time). This method can minimize the in-bed time of patients as it directs each patient to the most suitable hospital. Additionally, the system implemented method using the Pareto Optimization (PO) to vary among the conflicting objectives as admitting a patient to a non-suitable hospital in less time can result in transferring the patient to a different one. Results showed the efficiency in obtaining the correct hospital for patients. Also, the method showed its effectiveness in obtaining the correct hospital in real time despite the increase in the number of hospitals[53], .

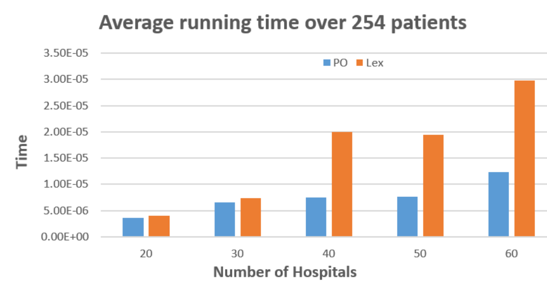

Fig. 4. A comparison between Pareto optimization and the lexicographic method according to the average running time in seconds

Figure 4 presents a graphical comparison between the proposed algorithm using PO and the lexicographic method to vary among a different number of hospitals. The graph shows the average running time of the two methods, evaluated into seconds. The figure shows that the average running time of the lexicographic increases with the increase in the number of hospitals. However, the increase in the proposed method is very small even with the increase in the number of hospitals. This emphasizes the stability of the proposed method as it keeps a near steady performance despite the number of hospitals.

C. Hotspot Detection Module

We developed a novel hotspot prediction framework which is effectively combine the advantages of two different deep learning models, i.e., CNN and LSTM into a single end-to-end framework. Generally, the framework extracts multi-time scale features from different layers of CNN to incorporate changes in time-series data. The obtained multi-time scale features are then concatenated and utilized by multiple layer

LSTM to learn dependencies of multi-time scale features. The framework then provides the output of LSTM to two fully connected layers that predict the number of positive cases[54].

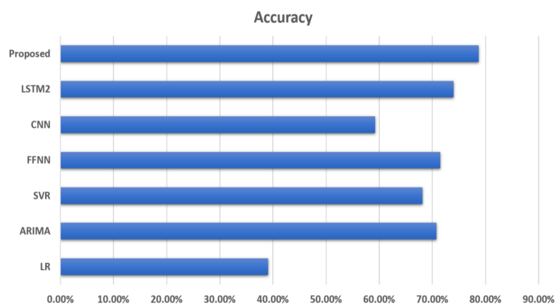

Fig. 5. Performance comparison of different methods in terms of precision recall curves.

From the experiment results as shown in figure 5, it is obvious that proposed method outperforms other state-of-the-art methods. Among the reference models, Linear Regression (LR) performs relatively badly. This is due to fact that the LR model linearly approximates the target data. In other words, the LR model assumes a linear relationship between the forecast and predictor values. However, in our case, the relationship between the number of positive cases versus days is not linear. Furthermore, the LR model is susceptible to outliers. We also evaluate the performance of CNN model and the results using different evaluation metrics are reported in Table 3. From experiment results, it is obvious that CNN performs better than the LR model; however, it lags behind the other reference methods. This is because CNN models can not learn the temporal dependencies and not suitable for time-series prediction problems. SVR and ARIMA, and FFNN show similar performances in our case.

V. Related Work

This section explores the previous attempts that manage and handle the crises. Basically, crises can be classified into different types such as pandemic diseases, natural disasters, terrorist attacks, to name a few. Crisis management systems or contingency management systems are designed and developed to avoid emergencies, in addition, to plan how to deal with the crises when they occur to mitigate their disastrous consequences [55], [56].

In [57], [58], [56], the authors describe the planning for a crisis "is the action of eliminating risk and uncertainty to enable decision-makers to achieve more control on crises". To deal with the crises, authors in [59], [60] define the crises as isolated events that can be examined via three things: (1) causes, (2) consequences, and (3) caution and coping. First, the causes of crises can be described as failures that triggered the crisis immediately and the antecedent conditions which make the failures occur. Second, the consequences of the crises are the impacts caused by the crises, consequences include immediate and long-term impacts. Finally, the caution and coping with crises, crises caution can be described as the actions taken to prevent or reduce the potential impact of the crisis. Crises caution can be described as the measures considered to respond to the crisis that has already occurred. According to [57], a crisis passes by four various phases: (1) prodromal phase, (2) acute phase, (3) chronic phase, and (4) resolution phase. The prodromal crisis phase is the first stage; where the initial symptoms of the crisis begin to appear. The acute crisis phase is the second phase where the crisis starts causing damage. The crisis response in this phase is intuitively centered around the level of the readiness of the entity (e.g., organization or society), and how to react efficiently. The chronic crisis phase is the third phase, it is also named as "clean-up" phase of the crisis, where the entity attempts to get back from the catastrophic situation, defines its weaknesses and records the lessons learned from the Accomplishments and falls of its reaction. The crisis resolution phase is the final phase, where the entity returns to the regular routine and continues its complete capacity. To conclude, the successful contingency management comes from proactive actions to identify crisis indicators at early stages.

In [61], the authors propose a flexible service-oriented architecture, which aims to plan and support decision-makers in environmental crisis management.

In [62], authors present a system named epiDMS which aims to manage the analysis of large epidemic simulation ensembles. Indeed, epiDMS covers the lack of decision support system to facilitate decision making process during crisis that affect healthcare systems.

In [63], [64], [65], [66], the authors investigate the design of a model to manage a stochastic epidemic on a global scale. Furthermore, this investigation considers the data of airline travel flow between urban areas. Additionally, the investigation makes a sensitivity analysis of different and distinct levels of infectiousness of the epidemic and initial outbreak conditions, as a result, the investigation concludes the temporal and spatial evolution of the pandemic. Finally, decision-makers receive heuristic information to respond in these situations of emergency.

In [67], authors design a framework to react to organizational crises. The output from this framework is a narrative analysis that identifies the weaknesses in the chain's crisis response and presents good proposals to overcome them.

In [68], the authors design a novel system to control the aircraft fault contingency. For this purpose, this system aims to achieve an on-board health state assessment on real-time and automated contingency management efficiently.

Motivated by the need for schools to be destined in responding to different crisis situations, authors in [69], present a framework to facilitate crisis response activities by providing a common set of concepts, principles, terminology, and organizational processes. As a result, this framework coordinates the communication between multiple agencies which following a crisis and facilitates the lack of information flow.

In [70], the authors present a system named *IDAPS*, which stands for Intelligent Distributed Autonomous Power System.

IDAPS aims to efficiently manage the energy resources belong to and owned by customers. Authors expect that *IDAPS* will make significant contributions during emergency conditions, in addition, to create a new market for electricity transactions among customers.

In [71], authors propose a framework that provides the communication and information needs to first responders, in addition to supporting the decision making needs from command and control personnel. Moreover, this framework focuses on the value of insights and information consolidated from different communities. Consequently, the framework proposes how command and control personnel can be brought to bear on crisis decision making.

In [72], authors describe a contingency system that controls a team of vehicles. This system includes three major ingredients: (1) a plan dependency identifier, (2) a contingency monitor, and (3) an alert formulator. First, the *plan dependency identifier* starts to analyze a mission plan and identify mission constraints of the mission plan. Second, the *contingency monitor* continuously reviews the execution of the mission plan for violations of the mission constraints. Finally, the *alert formulator* determines whether a part of the mission plan is threatened by a violation of one of the mission constraints.

From the above overview of the previous work related to crisis management, it is obvious that there is a lack for a system that can provide a holistic management for resources, users, executors, and decision takers.

VI. Conclusion

In response to the COVID-19 pandemic, this project aims at developing a real-time crisis management system that is able to holistically control the country's resources at both micro and macro levels. The ultimate goal of this system is to assure the harmonic balance between crucial actions needed for the containment of the coronavirus spread and at the same time protect the national economy from the negative impacts caused by these actions. To achieve this goal, the system vision is based on the global management of the national resources and getting the main users and stack-holders fully management in a closed loop.

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References

[1] L. Li, Q. Zhang, X. Wang, J. Zhang, T. Wang, T.-L. Gao, W. Duan, K. K.-f. Tsoi, and F.-Y. Wang, "Characterizing the propagation of situational information in social media during covid-19 epidemic: A case study on weibo," *IEEE Transactions on Computational Social Systems*, 2020.

[2] P. Jandrić, "Postdigital research in the time of covid-19," *Postdigital Science and Education*, pp. 1–6, 2020.

[3] "Wrold Health Organization," https://www.who.int/emergencies/diseases/novel-coronavirus-2019, 2020, accessed: 20-Apr-2020.

[4] A. Remuzzi and G. Remuzzi, "Covid-19 and italy: what next?" *The Lancet*, 2020.

[5] "EuroNews," https://www.euronews.com/2020/03/12/coronavirus-italy-doctors-forced-to-prioritise-icu-care-for\-patients-with-best-chance-of-s, 2020, accessed: 20-Apr-2020.

[6] "International Air Transport Association," https://www.iata.org/en/pressroom/pr/2020-03-05-01/, 2020, accessed: 20-Apr-2020.

[7] R. Cowan and S. Cornwell, "U.s. house passes $3 trillion coronavirus aid bill opposed by trump," https://www.reuters.com/article/us-health-coronavirus-usa-congress/house-passes-3-trillion-coronavirus-aid-bill-opposed-by-trump-idUSKBN22R1G9, 2020, Accessed: 7-2-2020,Published: 5-15-2020.

[8] "Singapore government agency," https://www.tracetogether.gov.sg, accessed 20-Apr-2020.

[9] I. G. M. of Electronics and I. Technology, "Aarogya Setu," https://www.mygov.in/covid-19, 2020, online; accessed 20-Apr-2020.

[10] "Ant Financial," http://www.antfinancial.com/, 2020, online; accessed 20-Apr-2020.

[11] "Apple," https://www.apple.com/newsroom/2020/04/apple-and-google-partner-on-covid-19\protect\discretionary{\char\hyphenchar\font}{}{}contact-tracing-technology/, 2020, published 10-Apr-2020.

[12] "SAUDI HEALTH MINISTRY; MAWID," https://www.moh.gov.sa, 2020, accessed: 20-Apr-2020.

[13] Y. Wang, X. Yang, Y. Zhao, Y. Liu, and L. Cuthbert, "Bluetooth positioning using rssi and triangulation methods," in *2013 IEEE 10th Consumer Communications and Networking Conference (CCNC)*. IEEE, 2013, pp. 837–842.

[14] C. Song, M. Ito, Y. Nishiyama, and K. Sezaki, "Using mobile sensing technology for capturing people mobility information," in *Proceedings of the 3rd ACM SIGSPATIAL International Workshop on Prediction of Human Mobility*, 2019, pp. 33–40.

[15] Y. Chen, X. Wang, Y. Yang, and H. Li, "Location-aware wi-fi authentication scheme using smart contract," *Sensors*, vol. 20, no. 4, p. 1062, 2020.

[16] ——, "Location-aware wi-fi authentication scheme using smart contract," *Sensors*, vol. 20, no. 4, p. 1062, 2020.

[17] M. Li, H. Zhu, Z. Gao, S. Chen, L. Yu, S. Hu, and K. Ren, "All your location are belong to us: breaking mobile social networks for automated user location tracking," in *The Fifteenth ACM International Symposium on Mobile Ad Hoc Networking and Computing, MobiHoc'14, Philadelphia, PA, USA, August 11-14, 2014*, J. Wu, X. Cheng, X. Li, and S. Sarkar, Eds. ACM, 2014, pp. 43–52.

[18] C.-C. Lee, Y.-H. Wu, and A. L. P. Chen, "Continuous evaluation of fastest path queries on road networks," in *SSTD*, 2007, pp. 20–37.

[19] M. N. Rice and V. J. Tsotras, "Graph indexing of road networks for shortest path queries with label restrictions," *PVLDB*, vol. 4, no. 2, pp. 69–80, 2010.

[20] S. Vanhove and V. Fack, "An effective heuristic for computing many shortest path alternatives in road networks," *International Journal of Geographical Information Science*, vol. 26, no. 6, pp. 1031–1050, 2012.

[21] L. Wu, X. Xiao, D. Deng, G. Cong, A. D. Zhu, and S. Zhou, "Shortest path and distance queries on road networks: An experimental evaluation," *PVLDB*, vol. 5, no. 5, pp. 406–417, 2012.

[22] W. Zeng and R. Church, "Finding shortest paths on real road networks: The case for a*," *International Journal of Geographical Information Science*, vol. 23, no. 4, pp. 531–543, 2009.

[23] A. D. Zhu, H. Ma, X. Xiao, S. Luo, Y. Tang, and S. Zhou, "Shortest path and distance queries on road networks: Towards bridging theory and practice," in *SIGMOD*, 2013, pp. 857–868.

[24] X. Ma, S. Shekhar, and H. Xiong, "Multi-type nearest neighbor queries in road networks with time window constraints," in *SIGSPATIAL GIS*, 2009, pp. 484–487.

[25] K. Mouratidis, M. L. Yiu, D. Papadias, and N. Mamoulis, "Continuous nearest neighbor monitoring in road networks," in *VLDB*, 2006, pp. 43–54.

[26] M. L. Yiu, N. Mamoulis, and D. Papadias, "Aggregate nearest neighbor queries in road networks," *TKDE*, vol. 17, no. 6, pp. 820–833, 2005.

[27] L. Zhu, Y. Jing, W. Sun, D. Mao, and P. Liu, "Voronoi-based aggregate nearest neighbor query processing in road networks," in *SIGSPATIAL GIS*, 2010, pp. 518–521.

[28] G. Li, Y. Li, J. Li, L. Shu, and F. Yang, "Continuous reverse k nearest neighbor monitoring on moving objects in road networks," *Information Systems*, vol. 35, no. 8, pp. 860–883, 2010.

[29] S. Shang, B. Yuan, K. Deng, K. Xie, and X. Zhou, "Finding the Most Accessible Locations: Reverse Path Nearest Neighbor Query in Road Networks," in *SIGSPATIAL GIS*, 2011, pp. 181–190.

[30] Z. Chen, Y. Liy, R. C.-W. Wong, J. Xiong, G. Mai, and C. Long, "Efficient algorithms for optimal location queries in road networks," in *SIGMOD*, 2014.

[31] K. Deng, X. Zhou, and H. T. Shen, "Multi-source skyline query processing in road networks," in *ICDE*, 2007, pp. 796–805.

[32] Y. Tian, K. C. K. Lee, and W.-C. Lee, "Finding skyline paths in road networks," in *SIGSPATIAL GIS*, 2009, pp. 444–447.

[33] S. Luo, Y. Luo, S. Zhou, G. Cong, and J. Guan, "DISKs: a system for distributed spatial group keyword search on road networks," *Proceedings of the International Conference on Very Large Data Bases, VLDB*, vol. 5, no. 12, pp. 1966–1969, 2012.

[34] J. R. Thomsen, M. L. Yiu, and C. S. Jensen, "Effective caching of shortest paths for location-based services," in *SIGMOD*, 2012.

[35] "Openstreetmap," http://www.openstreetmap.org/export.

[36] L. Alarabi, A. Eldawy, R. Alghamdi, and M. F. Mokbel, "TAREEG: a mapreduce-based system for extracting spatial data from openstreetmap," in *Proceedings of the 22nd ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, Dallas/Fort Worth, TX, USA, November 4-7, 2014*, Y. Huang, M. Schneider, M. Gertz, J. Krumm, and J. Sankaranarayanan, Eds. ACM, 2014, pp. 83–92.

[37] Z. Chen, H. T. Shen, X. Zhou, and J. X. Yu, "Monitoring path nearest neighbor in road networks," in *SIGMOD*, 2009, pp. 591–602.

[38] L. Hu, Y. Jing, W.-S. Ku, and C. Shahabi, "Enforcing k nearest neighbor query integrity on road networks," in *SIGSPATIAL GIS*, 2012, pp. 422–425.

[39] C. S. Jensen, J. Kolárvr, T. B. Pedersen, and I. Timko, "Nearest neighbor queries in road networks," in *SIGSPATIAL GIS*, 2003, pp. 1–8.

[40] Y. Jing, L. Hu, W.-S. Ku, and C. Shahabi, "Authentication of k nearest neighbor query on road networks," *TKDE*, vol. 26, no. 6, pp. 1494–1506, 2014.

[41] H. Liu, F. Chang, and C. Liu, "Multi-target tracking with hierarchical data association using main-parts and spatial-temporal feature models," *Multimedia Tools Appl.*, vol. 78, no. 20, pp. 29 161–29 181, 2019.

[42] J. Gudmundsson and M. J. van Kreveld, "Computing longest duration flocks in trajectory data," in *14th ACM International Symposium on Geographic Information Systems, ACM-GIS 2006, November 10-11, 2006, Arlington, Virginia, USA, Proceedings*, R. A. de By and S. Nittel, Eds. ACM, 2006, pp. 35–42.

[43] L. O. Alvares, V. Bogorny, B. Kuijpers, J. A. F. de Macêdo, B. Moelans, and A. A. Vaisman, "A model for enriching trajectories with semantic geographical information," in *15th ACM International Symposium on Geographic Information Systems, ACM-GIS 2007, November 7-9, 2007, Seattle, Washington, USA, Proceedings*, H. Samet, C. Shahabi, and M. Schneider, Eds. ACM, 2007, p. 22.

[44] Y. Zheng, L. Capra, O. Wolfson, and H. Yang, "Urban computing: Concepts, methodologies, and applications," *ACM TIST*, vol. 5, no. 3, pp. 38:1–38:55, 2014.

[45] H. Samet, "The quadtree and related hierarchical data structures," vol. 16, no. 2. ACM, 1984, pp. 187–260.

[46] A. Guttman, "R-trees: a dynamic index structure for spatial searching," in *SIGMOD*, 1984.

[47] J. Nievergelt, H. Hinterberger, and K. C. Sevcik, "The grid file: An adaptable, symmetric multikey file structure," in *TODS*. ACM, 1984, pp. 38–71.

[48] L. Alarabi, M. F. Mokbel, and M. Musleh, "ST-Hadoop: a mapreduce framework for spatio-temporal data," *GeoInformatica*, vol. 22, no. 4, pp. 785–813, 2018.

[49] S. R. Garzon and B. Deva, "Geofencing 2.0: taking location-based notifications to the next level," in *The 2014 ACM Conference on Ubiquitous Computing, UbiComp '14, Seattle, WA, USA, September 13-17, 2014*, A. J. Brush, A. Friday, J. A. Kientz, J. Scott, and J. Song, Eds. ACM, 2014, pp. 921–932.

[50] Y. Zheng, Y. Liu, J. Yuan, and X. Xie, "Urban computing with taxicabs," in *UbiComp 2011: Ubiquitous Computing, 13th International Conference, UbiComp 2011, Beijing, China, September 17-21, 2011, Proceedings*, J. A. Landay, Y. Shi, D. J. Patterson, Y. Rogers, and X. Xie, Eds. ACM, 2011, pp. 89–98.

[51] Z. Fu, W. Hu, and T. Tan, "Similarity based vehicle trajectory clustering and anomaly detection," in *Proceedings of the 2005 International Conference on Image Processing, ICIP 2005, Genoa, Italy, September 11-14, 2005*. IEEE, 2005, pp. 602–605.

[52] L. Alarabi, S. Basalamah, H. Abdeltawab, and A. Mohammed, "Traceall: A real-time processing for contact tracing using indoor trajectories," *Information*, vol. 12, no. 5, 2021.

[53] A. M. AbdelAziz, L. Alarabi, S. Basalamah, and A. Hendawi, "A multi-objective optimization method for hospital admission problem—a case study on covid-19 patients," *Algorithms*, vol. 14, no. 2, 2021.

[54] S. D. Khan, L. Alarabi, and S. Basalamah, "Toward smart lockdown: A novel approach for covid-19 hotspots prediction using a deep hybrid neural network," *Computers*, vol. 9, 2020.

[55] R. Linlejohn, "Crisis Management: A Team Approach," *New York: American Management Associations*, 1983.

[56] H. Kitano and S. Tadokoro, "Robocup rescue: A grand challenge for multiagent and intelligent systems," *AI Magazine*, 2001.

[57] S. Fink, "Crisis Management: Planning for the Inevitable," *American Management Association*, 1986.

[58] L. S. M. Contreras, and C. Valencia, "Intelligent multi-agent support for the contingency management system," *Expert Systems with Applications*, 2004.

[59] P. Shrivastava, "Crisis theory & practice: towards a sustainable future," *Industrial and Environmental Crisis Quarterly*, 1993.

[60] S. L. P. G. Pan and D. E. Leidner, "Crisis Response Information Networks," *Journal of the Association for Information Systems*, 2012.

[61] V. V. N. Doulamis, and S. Karagiorgou, "A service oriented architecture for decision support systems in environmental crisis management," *Future Generation Computer Systems*, 2012.

[62] S. R. P. K. S. C. K. G. Chowell and M. L. Sapino, "epiDMS: Data Management and Analytics for Decision-Making From Epidemic Spread Simulation Ensembles," *Journal of Infectious Diseases*, 2016.

[63] V. C. C. G. B. G. M.Quaggiotto, and A. Vespignani, "Modeling the worldwide spread of pandemic influenza: baseline case and containment interventions," *PLoS Med*, 2007.

[64] V. den BroeckW, C. Gioannini, B. Gonçalves, M.Quaggiotto, V. Colizza and A. Vespignani, "The GLEaMviz computational tool, a publicly available software to explore realistic epidemic spreading scenarios at the global scale," *BMC Infect Dis*, 2011.

[65] T. S. G. M. G. Szabo, and A. Barabasi, "WIPER: A multi-agent system for emergency response," *In Proceedings of the third international ISCRAM conference*, 2006.

[66] E. Tsang and E. Ngai, "EXSGACM: An expert system for gas crisis management," *Expert Systems with Applications*, 1996.

[67] A. Paraskevas, "Crisis management or crisis response system: A complexity science approach to organizational crises," *Management Decision*, 2006.

[68] M. R. L. T. S. Bharadwaj and C. Belcastro, "An Integrated Aircraft Health Assessment and Fault Contingency Management System for Aircraft," *AIAA Guidance, Navigation and Control Conference and Exhibit*, 2008.

[69] A. B. N. S. E. Brock and M. A. Reeves, "School Crisis Teams within an Incident Command System," *California Association of School Psychologist*, 2006.

[70] S. R. M. Pipattanasomporn and Y. Teklu, "Intelligent Distributed Autonomous Power Systems (IDAPS)," *In Proc. the IEEE PES Summer Meeting in Tampa*, 2007.

[71] M. T. M. J. C. B. V. de Walle and X. Yao, "The design of a Dynamic Emergency Response Management Information System (DERMIS)," *Journal of Information Technology Theory and Application*, 2003.

[72] J. L. F. S. M. J. R. D. Paradis and R. J. Szczerba, "Hierarchical contingency management system for mission planners," *Application US11/059,286 events*, 2011.