Using Dijkstra and Fusion Algorithms to Provide a Smart Proactive mHealth Solution for Saudi Arabia's Emergency Medical Services

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Abstract*—Ambulance diversion in overcrowded hospitals and Emergency Departments (EDs) can have negative consequences on patients' health and safety. Saudi Arabia is thriving to enhance its healthcare sector through an ongoing digitization transition as part of Vision 2030. However, existing infrastructure is still ill-equipped to integrate the distributed siloed systems involved in hospital bed and Emergency Medical Services (EMSs) ecosystem leading to delayed decisions and poor outcomes based on incomplete and inaccurate information. This article addresses this problem by proposing, mEmergency, a smart proactive mobile healthcare solution that connects EMS ambulances with EDs in Riyadh trauma centers to facilitate making real-time informed decisions in a timely fashion to save lives. First, mEmergency predicts inpatient bed capacity using Fusion Algorithm and prioritizes the nearest and most equipped ED for the patient's condition to paramedics using a mHealth application. Second, it uses Dijkstra's Algorithm to route the ambulance path taken to the right ED, while the patient's vital signs are being recorded into the solution along with physical assessment. Finally, mEmergency disseminates the paramedic's assessment information to the ED prior to arrival to optimize time and resources for continuous readiness. mEmergency is an effective solution that should optimize EMS resources, reduce ED crowding, and increase the quality of urgent care services to help stakeholders regain trust in Saudi urgent care service delivery.

Keywords- mHealth; Emergency medical services; Emergency department; Dijkstra algorithm; Fusion algorithm.

I. INTRODUCTION

Ambulance diversion is a strategy often used by overcrowded hospitals and Emergency Departments (EDs) with unavailable beds or resources. EDs that do not have available inpatient beds for emergency patients often have to divert ambulances to other hospitals. This adds to the total time it takes the ambulance to transport the patient, and thus, can have negative consequences on the patient's health and safety, especially in cases of urgent care when every second is crucial and could mean life or death. Shen and Hsia, in the Journal of the American Medical Association [2], report that heart attack victims are more likely to die when their nearest hospital has high diversion rates for more than 12 hours per day, in contrast to other heart attack victims who happen to be near a hospital without diversion or with diversion for less than 12 hours per day [2]. Therefore, to reduce the time it takes to reach the nearest available emergency department, there is an urgent need for a continuous, stable process that connects both the ED and the ambulance services together.

Furthermore, an arriving patient may be declined or placed on hold by Medical Care Utilization (MCU) if there is no bed available. In such cases, the patient may be subject to similar health risks due to the necessity of finding an alternative health care provider or waiting until a bed becomes available. Similarly, an arriving patient may be accepted for treatment but can be accommodated in another MCU (e.g., an arriving obstetrics patient can be boarded in neurosurgery), and hence there is the chance that it may not be possible to move admitted patients from the ED due to an inpatient bed problem. This forces the ED to board admitted patients until inpatient beds are available, effectively reducing the ED's capacity to care for new patients. Boarding of inpatients in the ED has also been cited as the most important determinant of ambulance diversion.

In addition to time and systems integration factors, cyber attacks on healthcare infrastructure for a deliberate interruption of healthcare services could leave hospitals no choice but to divert ambulances. Global attacks on electronic service providers in healthcare, business, and government sectors have been witnessed in recent times, and there has been a wave of deliberate attacks using the WannaCry virus. WannaCry is a Trojan malware virus known as "ransomware." The virus holds the infected computer hostage and demands that the victim pays a ransom to regain access to the files on his/her computer. Ransomware, like WannaCry, works by encrypting most or all of the files on a user's computer. demanding that a ransom be paid in order to have the files decrypted. The episodes of Ransom ware attacks [3] have had a massive scale effect on roughly 150 countries, targeting not only home computers but also healthcare, communications infrastructure, logistics, and government entities for financial gain. This has challenged healthcare providers' deployment of their computerized complex systems to maintain patient records and patient diversion data at critical times, so as to paralyze healthcare services in some targeted health trusts in European countries, such as England's National Health Service (NHS) [3]. Hospitals across England's National Health Service reported that the cyberattack was causing huge problems to their services by affecting X-ray imaging systems, pathology test results, phone systems and patient administration systems" [3].

This article is an extended version of preliminary work published in [1] that aims to address ambulance diversion challenges in Emergency Medical Services (EMSs) in Saudi Arabia by connecting siloed information systems to make informed decisions in a timely fashion. The preliminary work [1] identified the decentralization challenges faced in Saudi's EMS ecosystem due to the fragmentation of data, a lack of communication among stakeholders, and a lack of interoperability between the information systems. This article proposes mEmergency, a practical solution that can reduce ambulance diversion and the time it takes to reach the nearest appropriate ED: one with available inpatient beds and the right resources for that patient's care.

The rest of this paper is organized as follows. Section II introduces the background, while Section III discusses related work. Section IV describes our methodology and structure, and Section V draws our conclusions.

II. Background

The Saudi Arabian government has accorded high priority to healthcare services. According to the Saudi Arabian "Basic Law of Governance" [4], the government guarantees the right to healthcare for its citizens and their families. It is responsible for providing public health care services to all Saudi citizens. In recent years, healthcare services in Saudi Arabia have improved tremendously in terms of quantity and quality. This is evident in the literature and government white papers in general, and reflected in the total number of hospitals in Saudi Arabia. The governmental sector owns nearly 70 percent of hospitals, with the rest being operated by the private sector [5]. The number of government hospitals in Saudi increased by 49 hospitals between 2011 and 2015 with a capacity of 69,394 beds.

A. *ED Crowding*

ED crowding and inpatient bed capacity are pressing problems facing healthcare worldwide. ED Crowding is defined as [6]:

> "*A situation in which the ED function is impeded by the number of patients waiting to be seen, undergoing assessment and treatment, or waiting for departure, exceeding the physical or staffing capacity of the department.*"

Ed crowding should not be managed as a standalone problem. Contributing factors must be examined in order to eliminate the problem. The lack of hospital inpatient bed capacity could lead to ED boarding, which is a significant cause of ED crowding [7]. ED boarding is the practice of keeping patients in the ED waiting area due to the lack of available inpatient beds, even after their admission to the hospital. This results in many issues, including ambulance diversion, extended patient waiting periods, delays in treatment, and longer waiting times for other patients who do not require admission to be treated [8]. Finally, there is an urgent need for a solution to eliminate ED crowding and ambulance diversions resulting from unavailable inpatients bed capacity and ED boarding. This is to provide emergency patients with fast and reliable healthcare and reduce the time it takes the ambulance to reach the nearest available emergency department. To address the above issues, there is a need for a continuous, stable process that requires system-wide support among all healthcare related parties, in order to connect and work with both the emergency departments and the ambulance services together.

B. *Hospital Bed-Ecosystem*

A hospital bed is not simply a piece of furniture; it is a vital part of hospital infrastructure that enables patient treatment. A hospital bed is an ecosystem that enables delivery of care via trained professionals, managerial staff, equipment and pharmaceuticals (see Figure 1).

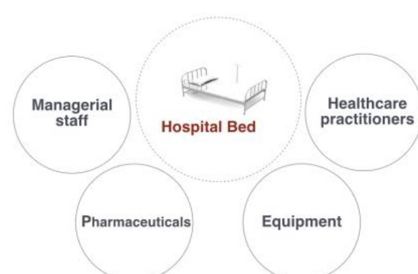

Figure 1. Hospital Bed EcoSystem.

C. *Hospital Bed Capacity Planning*

Hospital capacity planning is crucial in healthcare. It is essential for managing hospital resources and hospital staff and personnel. In addition, it could be the deciding factor between a patient's life and death. In some countries, such as Finland, New Zealand and Germany, the unit for measuring hospital care and capacity is bed occupancy rate [9], which is defined as "the number of hospital beds occupied by patients expressed as a percentage of the total beds available in the hospital" [10]. This rate remains an essential unit in hospital capacity planning. Nevertheless, using bed numbers and occupancy as a measurement in hospital capacity planning will not foretell the hospital's future demand; neither will it provide a valid estimate of hospital services [9].

In research published by the World Health Organization, researchers propose using strategies that focus on the benefits of using systematic processes in hospital capacity planning. They argue that it is not beneficial to look at the hospital from the perspective of beds and occupancy rates, but rather it is necessary to focus on processes and the path taken by the patients inside the hospital. One of the strategies mentioned is to design hospital flows around "care pathways" instead of counting beds; the strategy works by identifying the variety of pathways the patients take inside the hospital, as well as the factors that can cause delays in patients' treatment, thus identifying bottlenecks [11].

Therefore, the key to successful capacity planning is to try to eliminate any possible future cause of bottlenecks. Sometimes this could be the number of inpatients' available beds, ineffective allocation of existing patients among different medical service units. and sometimes it could be other hospital departments attempting to enhance their performance without realizing how such actions might affect others. Guaranteeing that there are as few bottlenecks as possible will, in turn, result in minimizing delays in patient treatment, separating patients into two streams based on complexity rather than urgency, and as a result creating a fast track for patients who can be treated and discharged more or less immediately [10].

D. *International Hospital Statistics*

Despite hospital planning strategies, this section highlights some international statistics for acute hospital bed shortages around the globe. In Austria [12], hospital beds have an Average Length of Stay (ALoS) of 18 days or less. This includes some daycare beds. In Germany, acute hospital beds are the beds other than psychiatric and long-term beds. It does not include any daycare beds. In Iceland, acute hospital beds are calculated from bed-days, assuming 90% occupancy rate; beds in medicine and surgeries of leading hospitals and mixed facilities are available in small hospitals that do not include any daycare beds. In Italy, acute hospital beds include inpatient beds of psychiatric hospitals and in-patient beds of psychiatric wards of other hospitals; these do not include any daycare beds. In Spain, acute hospital beds include general hospitals, maternity, other specialized hospitals, and health centers -- no daycare beds. In the UK, acute hospital beds include NHS acute medical, surgical and maternity beds (excluding Northern Ireland) [12] (see Table I below for others country).

TABLE I. DEFINITIONS OF HOSPITAL BEDS IN SELECTED COUNTRIES [12]

Country	Content
Austria	Beds in hospitals with average length of stay of 18 days or less
Germany	Beds other than psychiatric and long term beds
Italy	In-patient beds of psychiatric hospitals and in-patient
United Kingdom	National Health Service acute medical, surgical and maternity beds (excluding Northern Ireland)
Spain	General hospitals, maternity, other specialized hospitals, health centres
Sweden	Beds for short term care run by county councils and three independent communities (short-term includes medical, surgical, miscellaneous medicine/surgery, admission department and intensive care)
Turkey	Public hospitals, health centres, maternity hospitals, cardiovascular and thoracic surgical centres, orthopaedic surgery hospitals

III. LITERATURE REVIEW

A. *Bed Capacity Planning Approach*

Like any other industry, healthcare faces enormous pressure to improve efficiency and reduce costs. A study by McKinsey [6] points out that the U.S. spends at least $600 - $850 billion on healthcare annually. One area that can be leveraged in healthcare is the support of informed decision-making processes. This is to allow the end user (namely, hospital administrators or clinical managers) to assess the efficiency of existing healthcare delivery systems.

Discrete-Event Simulation (DES) is a widely used technique for the analysis of systems with complex behaviors [14]. DES has been widely applied in healthcare services [14] to study the interrelationships between admission rates, hospital occupancy, and several different policies for allocating beds to MCUs. Lewis D [15] studied bed management in Germany's hospitals, and decision support systems were presented depending on mathematical approaches and computer-based assistance designed to improve the efficiency and effectiveness of admission planning and bed assignment. The study starts by interviewing professionals in bed management to identify aspects that must be respected when developing the decision system, ensuring that patients' treatment priorities and individual preferences are respected [15]. Patient admission and assignment are based on up-to-date and flexible Length of Stay (LoS) estimates, being taken into aggregated contingents of hospital beds, treatment priorities, patient preferences, and a linkage between clinics and wards [15].

The main reason for using DES for modeling a healthcare clinic instead of other mathematical modeling tools (such as linear programming and Markov chain analysis) is the ability to simulate complex patient flows through healthcare clinics, and to play "what if" games by changing the patient flow rules and policies [15]. Such flows are usually in emergency rooms, where patients can be seen without appointments and require treatment for various sets of ailments and conditions [15]. These disorders can range from mild injuries to serious medical emergencies. Although the number of patients is unpredictable, medical staff can control the treatment by minimizing patient waiting times and increasing staff utilization rates [16].

In emergency rooms, to reduce waiting times of low priority patients, Schmidt et al. [16] analyzed the effects of using a fast track lane. As emergency rooms are prioritized according to the level of patient sickness, low priority patients may have to wait for exceedingly long periods of time [16]. A simulation model is used to classify daily occupancy distributions; it helps in studying the swapping of overflow and bed capacity levels, and it investigates the effects of various changes. ED overcrowding principally results from the incapability of admitted patients to be transferred toward beds in a timely manner [17]. Most experts agree that a greater inpatient capacity is required in order to relieve access block and decrease ED overcrowding [16]. The authors in [16] collected real data from a single month at a single hospital, and a computer model was developed to examine the relationship between admissions, discharges and ED overcrowding (the number of hours admitted patients waited in ED before transfer to an inpatient bed). Meanwhile, authors in [16] proposed a facility location model to locate ER services on a network and determine their respective capacity levels, such that the probability of diverting patients is not larger than a particular threshold.

Author Chin-I Lin in [17] presents a conceptual model of ED overcrowding to help administrators, researchers, and policymakers. The ED conceptual model recognizes at least three general categories of care delivered in the ED: Emergency care, Unscheduled urgent care, and Safety net care. The outputs are patients who are unable to obtain follow-up care and often return to the ED if their condition does not improve or deteriorates [17]. The throughput component of the model identifies the patient length of stay in the ED as a potential contributing factor to ED crowding. The ED crowding is then measured based on two phases; the first phase includes triage, room placement, and the initial provider evaluation. The triage phase is used to objectively identify patients suitable for treatment by emergency nurse practitioners [17]. Since emergency nurse practitioners show high diagnostic accuracy, the emergency nurse practitioner model of care is considered an essential strategy in reducing the LoS of ED patients and may prevent ED crowding [17]. Meanwhile, the second phase of the throughput component includes diagnostic testing and ED treatment.

The input-throughput-output conceptual model of ED crowding may be useful for organizing research, policy, and operations management agenda to alleviate the problem [17]. This model illustrates the need for a systems approach with integrated, rather than piecemeal, solutions for ED crowding [17]. In the study, there are four general areas of ED crowding that require future research.

First, research must consider developing valid and reliable measures of ED crowding. These measures should be sensitive to changes throughout time. Second, research in the field should identify the most critical causes of ED crowding from each component of the model. Third, the effect of ED crowding on the quality of patient care must be assessed. Finally, interventions to reduce ED crowding need to be evaluated.

Ineffective allocation of existing bed capacity among different medical service units can lead to service quality problems for the patients, along with operational and financial inefficiencies for the hospitals [17]. Most health care managers apply relatively simple approaches, such as the use of target occupancy level with an average length of stay, to forecast bed capacity required for a hospital or an MCU [17]. The failure to adequately consider uncertainties associated with patient arrivals and the time needed to treat patients by using such simple approaches may result in bed capacity configurations where a large proportion of patients may have to be turned away. The application of queuing theory allows for the evaluation of the expected (long-run) performance measure of a system by solving the associated set of flow balance equations [17].

Other research considers the hierarchical relationship between care units. For example, after a mother-to-be delivers her child in the labor and delivery unit, she should be moved to the postpartum unit for recovery [17]. If the capability downstream is insufficient, patients must stay within the current care units with typically more costly equipment, thereby reaching capacity limits at these upstream care units [17].

To take the interactions among care units in a hospital into account, C Lin [17] first applies queuing network methodology (without blocking) to discover a balanced bed allotment, which is obtained through trial-and-error work. Then, they use simulation analysis to estimate the blocking behavior and patient sojourn times. The authors [17] develop a mathematical programming formulation to address this problem, and the system uses a different approach by integrating results from queuing theory into an optimization framework. Specifically, the model with each MCU in a hospital has an M/M/c/c queuing system to estimate the probability of rejection when there are beds.

B. *International Bed Management System (BMS)*

Hospitals should use a BMS that provides a real-time display of hospital occupied beds, along with the available beds, as well as the current status of each one [17]. Therefore, by using a BMS system, the hospital staff would be able to view the status of each bed, whether the bed was occupied, vacant or being prepared for a patient. Also, the hospital staff would be able to view the patient's status; if the patient was going to be discharged, had already left, or was being transferred. Moreover, by using the system, nurses can utilize more of their time in caring for the patient, instead of handling bed assignment tasks manually. This Bed Management Unit used at Alexandra Hospital has provided critical benefits to both patients and staff; indeed, by using the system, patients' waiting times have been decreased by 30 percent [18]. Singapore General Hospital (SGH) is another hospital that has benefited from the use of technology to manage hospital beds.

The SGH uses BMS technology to help improve hospital capacity and care. BMS is a web-based system that allows hospital staff and administration to access information related to patient flow anywhere in the hospital. The BMS user interface has been configured to display the location of patients in the hospital as well as the primary physician. The system also allows the hospital staff to view and track information, records and any specific actions related to the patient's needs, as well as any follow-up movements required. The system gives nurses and bed management staff a full overview of the bed status and patient needs, which allows them to take immediate action.

The way this system works is as follows: when the patient is admitted to the hospital, he/she will receive a Radio Frequency Identification (RFID) tag with a unique identifier that will identify and track the patient's location during his/her stay in the hospital. The system will then search for a bed that best fits the needs of the patient, based on his/her condition before assigning that bed to the patient. The system also uses a real-time location system to help identify the location of the patient through the tag and display; this creates a workflow related to the patient's movements. Hospital departments are also provided with LCD panels that display the BMS dashboard with real-time patient RFID location, which shows the patient's' information and bed statuses automatically in real-time. Once the patient is discharged, the BMS system will notify the housekeeping staff through their PDA to clean and prepare the vacated bed, and once the bed is ready, the housekeeping staff update the bed status [19].

C. *Nature of Trauma*

In physical medicine, major trauma is an injury or damage to a biological organism caused by physical harm from an external source [29]. Major trauma is also an injury that can potentially lead to long-term severe outcomes, such as chronic pain or other lifelong ailments. There are different types of trauma [29]:

1. Birth trauma: an injury to the infant during the process of being born. In some psychiatric theories, the psychic shock is produced in an infant by the experience of being born [29].
2. Psychic trauma: a psychologically upsetting experience that produces an emotional or mental disorder or otherwise has lasting negative effects on a person's thoughts, feelings, or behavior [29].
3. Risk for trauma: a nursing diagnosis accepted by the North American Nursing Diagnosis Association, defined as accentuated risk of accidental tissue injury, such as a wound, burn, or fracture.

The initial evaluation of a trauma patient is challenging and time-critical, as every minute could be the difference between life and death. Over the past 50 years, the assessment of trauma patients has evolved because of an improved understanding of the distribution of mortality and the mechanisms that contribute to morbidity and mortality in trauma [28]. On the one hand, early deaths may occur in the minutes or hours after the injury. These patients frequently arrive at a hospital before death, which usually occurs because of hemorrhage and cardiovascular collapse [28]. On the other hand, late trauma mortality peaks in the days and weeks after the injury and is primarily due to sepsis and multiple organ failure [28]. Therefore, systems supporting trauma care focus on the treatment of a patient from early trauma mortality, whereas critical care is designed to prevent late trauma mortality. This is the reason why it is essential to find beds prior to trauma cases [29], and therefore, our proposal strives to address this matter.

D. *Hospital Bed Capacity Globally and Saudi Vision 2030*

Hospitals' provisions for accommodating the increasing number of emergency admissions is a matter of considerable public and political concern and has been the subject of widespread debate [26]. When discussing a hospital's bed capacity, a number of questions are often raised. First, what is a hospital bed? As discussed earlier, a bed is more than an item of furniture on which a patient can lie. For a bed to make any meaningful contribution to a healthcare facility's ability to treat someone, it must be accompanied by an appropriate hospital infrastructure, including trained professional and managerial staff, equipment and pharmaceuticals [13].

For several years, hospital managers have been under pressure to reduce bed capacity and increase occupancy rates for operational efficiency, especially in the Hajj season [26]. More recently, public concern has arisen in cases where patients could not gain access to a local hospital or were subjected to extended delays for the availability of vacant beds [21]. Many countries now struggle to provide cost-effective, quality healthcare services to their citizens [24]. Saudi Arabia has experienced high costs along with concerns about the quality of care in its public facilities [27]. To address these issues, Saudi Arabia is currently restructuring its healthcare system to privatize public hospitals and introduce insurance coverage for both its citizens and foreign workers [27]. These changes provide an exciting and insightful case for the challenges faced when radically changing a country's healthcare system. The situation also demonstrates a unique case in the Middle East for greater reliance on the private sector to address rapidly escalating healthcare costs and deteriorating quality of care [27]. The complexity of changing a healthcare system is discussed with the many challenges associated with the change.

According to Saudi Vision 2030 [23], the healthcare system has benefited from substantive investment in recent decades. As a result, we now have 2.2 hospital beds for every 1,000 people, world-class medical specialists and an average life expectancy rising from 66 years to 74 years in the past three decades [25]. Work is currently underway to build and develop 38 news hospitals with a total capacity of 9,100 beds, in addition to two medical sites accommodating 2,350 beds [25]. During the current fiscal year, 1437/1438, 23 new hospitals (4,250 beds) in various regions across the Kingdom were built [25].

E. *Availability of Beds in Saudi Hospital ED*

Implementing a Saudi Arabia-wide system would allow a patient's referral from one healthcare provider/facility to another. This includes the ability to electronically transfer patient-related data in either a structured (namely, organized and well-maintained information that can be obtained in a simple click) or non-structured fashion (namely, data which is laborious to handle). Alternatively, pointers to eHealth accessible data could be used, including patient diagnosis and treatment, referral notes, medication lists, laboratory test results, radiology reports, digital images, audio and video files. This solution would enable integration of information on the availability of the facility, bed, provider or specialty. In addition, such a solution supports optimizing the search for best-fit resource utilization. The proposed work supports:

- Riyadh hospital's bed management program, including automated interfaces with a hospital information system (HIS) "as an element of health informatics that focuses mainly on the administration needs of hospitals."
- Centralized query capabilities for Headquarter and Regional Administrators.
- Operational support for the hospital and PHC practitioners providing patient referrals.
- Support for full inpatient bed management cycle-interface with multiple systems, including registries, HIS and communication systems. Generation of messages to hospital housekeeping.

  Emergency bed requirements and other hospital departments to inform of status - full reporting and analytical capability [25] (see Table II below).

TABLE II. HOSPITALS ESTABLISHED IN SAUDI ARABIA (2010-2013) [25]

Regions	No. of Hospitals Established	No. of Beds
Riyadh	8	1,400
Makkah	8	2,386
Eastern	7	1,150
Al Madinah	5	650
Hail	3	180
Qassim	4	475
Northern Border	3	400
Asir	8	800

F. *Regionalization Vs. Bed Capacity*

In a healthcare service facility, when an ER is full or all intensive care beds are occupied, hospitals send out a divert status. When a hospital is on divert status, incoming patients might be sent to hospitals which are farther away or kept at the hospitals where they are currently that may not be able to provide adequate service. For a critical trauma victim, the consequence of diverting status can be the difference between life and death. The healthcare service facility attempts to construct a facility location model, which simultaneously determines the number of facilities opened and their particular locations, as well as the capacity levels of the facilities so that the probability that all servers in a facility are busy does not exceed a pre-determined level. In other words, we want to locate ER services on a network and determine their respective capacity levels such that the probability of diverting patients is not larger than a particular threshold. To address the issue, some papers incorporate queuing systems into facility location models to consider the chance of availability of servers and focus on reducing the demand lost due to the shortage of capacity or system congestion.

It is worth mentioning that we try to find similar solutions in this field to compare with our proposal. mEmergency is expected to enhance performance of emergency service as well as to reduce number of deaths number of trauma diversion.

IV. METHODOLOGY

This research uses a mixture of qualitative research methods for data collection and system design. First, a set of semi-structured interviews with different stakeholders (ED and EMS) were conducted to collect data about: a) all Trauma Centers in Riyadh, b) the number of states in emergency and c) data assessment sheet that needs to be sent to hospitals with notification along with patient ID number. After conducting interviews, information about the challenges faced by the ED was collected. Second, soft systems methodology was used to design the proposed system and produce an architectural design.

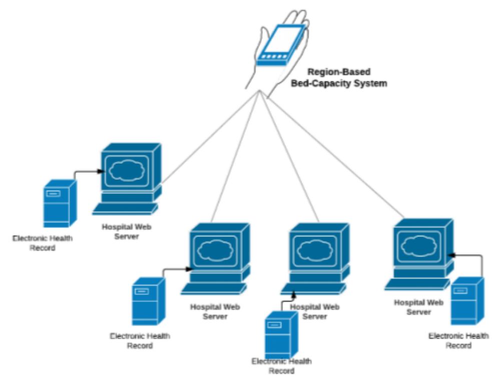

Figure 2. Prposed System Overview.

A. *mEmergency System Framework*

After interviewing five Saudi Red Crescent Authority representatives (with information technology and medical backgrounds), we came to learn that there is substantial evidence that supports the assertion that hospital beds can reduce deaths during emergencies, and enable treatment of many patients in an emergency by developing the bed capacity system. Therefore, this research decided to develop web services (see in Figure 2) that connect the proposed mobile application with any Electronic Health Record (EHR) in any hospital to show the bed capacity. Furthermore, to learn more about ED process, we met with Dr. Thamer Nouh [30], and discussed eight questions, so that we could then decide criteria relating to emergency department bed capacity in trauma care. We started by basing the criteria on one of the large tertiary hospitals in Riyadh (namely, King Khalid University Hospital).

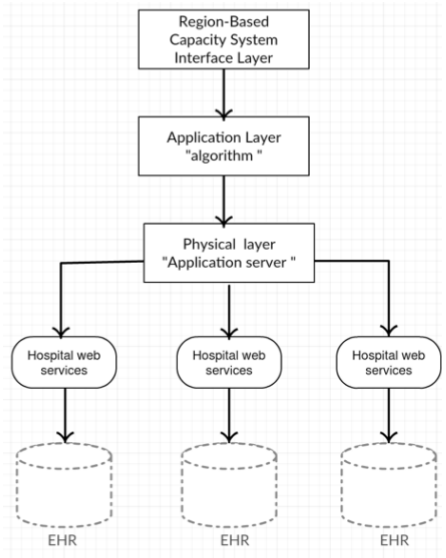

Figure 3. Proposed System Architecture

B. mEmergency System Architecture

mEmergency solution is structured as a multi-layered application (See in Figure 3) consisting of:

- **Interface layer:** This is the top level of the application. The presentation tier displays information related to nearest hospitals. It communicates with the next layer (application layer) by which it puts out the results to the EMS rescuer/ paramedic. In simple terms, it is a layer which users can access directly system's GUI.
- **Application layer:** The algorithm layer is pulled out from the Interface Layer and, as its own layer, it controls an application's functionality by performing detailed processing through follow criteria in section C.
- **Physical layer:** The physical layer includes the data persistence mechanisms (database hospitals servers) and the data access layer that encapsulates the persistence mechanisms and exposes the data. An API is generated by the data access layer to the application layer to find out different methods for managing the available data without creating dependencies on the data storage mechanism.

1) mEmergency Functional Requirements

Based on two interviews with a trauma surgeon who works in King Khalid hospital and workers in EMS [31], the following solutions were proposed:

a) The EMS rescuer/paramedic can view information about hospitals across the city of Riyadh.

b) The information available in the application must be dynamic and in real-time, which means that the paramedic can see the available and current

c) Anywhere across Riyadh.

d) The EMS rescuer/paramedic can view each hospital's exact location, bed capacity, and the available medical resources to suit a patient's case.

e) The paramedic can view available inpatient bed capacity in real-time for the hospitals.

f) The paramedic can find the nearest suitable hospital location for a patient's case with the right medical services for this patient's emergency situation, to guarantee a transfer in a speedy manner that would prevent negative implications to the patient and, at the same time, provide the right health care at the right time in a speedy manner.

g) The Emergency Department Support Officer (EDSO) [32] receives notification of the new patient and can view his/her assessment information.

h) The administrator of EMS can view reports about every EMS rescuer/paramedic case and patient information.

C. mEmergency Workflow Design

Based on the collected data, four criteria are used to decide on bed availability:

1) *Available bed in Radiology department*
2) *Available bed in Intensive Care Unit (ICU)*
3) *Available bed for inpatient*
4) *Available bed in OR*

Another criterion is the availability of specialists in one of the three fields (Orthopedic surgery, Neurosurgery, Emergency surgery; however, the EMS cannot decide which patient needs to go to the radiology department for examination unless the specialist visits the radiology department. Hence, the system will be in green mode, and then the rescuer/paramedic can choose a suitable hospital. Accordingly, ER can be available if there are enough beds in the Radiology department, ICU, inpatient and Operation Room (OR) (see Figure 2).

The system has two components:

1) *In the first part of the system, an attempt is made to construct module web services integration with each internal hospital system to decide ability of ER to receive the new patient; this depends on the criteria that are mentioned above.*

2) *On the other hand, EMS regenerates bed capacity of Riyadh hospitals in trauma cases to decide on a suitable hospital, depending on the following:*

- Shortest way from the hospital location that guarantees a speedy transfer that would prevent negative implications.
- Hospitals have the medical resources to treat the patient's case.

- Hospitals have specialized personnel to treat the patient’s case.

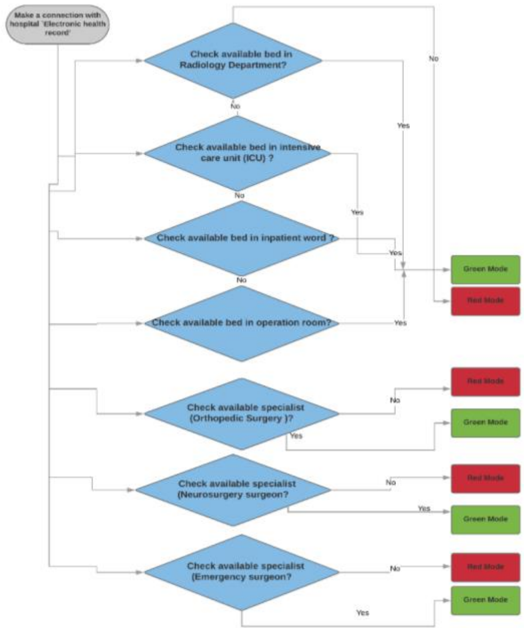

Figure 4. System Framework

D. mEmergency Process Algorithm

The goal of this phase is to build a decision support model that is powerful, robust, comprehensible, optimal, and effective. There is a large number of different search algorithms that can be chosen to run the best diction support model (for example, Fusion [33] and Dijkstra's [34]). The best algorithm to be chosen depends on the collected data.

Fusion Algorithm is used in many tracking and surveillance systems. One method for the design of such systems is to employ a number of sensors (perhaps of different types) and to fuse the information obtained from all these sensors on a central processor. Past efforts to solve this problem required the organization of feedback from the central processor to local processor units. This can be used by the hospitals for proper surveillance of accidents on the roads. It can also reduce the time necessary for bringing the patient to the hospital [32].

Dijkstra's Algorithm is an algorithm for finding the shortest path from a starting node to a target node in a weighted graph. Dijkstra’s Algorithm is a graph search algorithm that solves the single-source shortest path problem for a graph with nonnegative edge path costs, producing a shortest path tree. This algorithm is used in routing and as a subroutine in other graph algorithms. It can also be used for finding the costs of shortest paths from a single vertex to a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined. For example, if the vertices of the graph represent cities and edge path costs represent driving distances between pairs of cities connected by a direct road, then Dijkstra’s Algorithm can be used to find the shortest route between one city and all other cities. It can also be used by hospitals for ambulances in case of emergency to find the shortest available path. The algorithm creates a tree of shortest paths from the starting vertex, the source, to all other points in the graph. The algorithm exists in many variants; Dijkstra's original variant found the shortest path between two nodes, but a more common variant fixes a single node as the “source” node and finds the shortest paths from the source to all other nodes in the graph, producing a shortest-path tree [33]. For this, the following are points which are necessary for Dijkstra's Algorithm in hospitals [34]:

- The existence of a widespread road system that connects all parts of the city.
- Availability of sufficient VANET modules in the routes in order to detect traffic congestion.
- Infrastructure, such as GPS, communication links and two-way radio are provided.
- Presence of a Dispatch Centre (DC) that serves the purpose of information exchange.
- The existence of an updated database of the roads and hospitals.
- The existence of Road Side Units (RSU) at suitable locations which might be inaccessible due to restrictions for the propagation of the signal.

Algorithm of Decision Support Model

```
Initialize arrivaltime to time start to enter
data
Initialize senddatatime to time submit
assessment sheet
Initialize responsetime to time hospital receive
data
Initialize location to location of patient
Initialize Empty Nearestlist
Initialize Empty Availablelist
Initialize Empty Availablespecialistlist
   For each hospital around Location value
   Collocate distance
Set all Hospital to Nearestlist Item arrange by
Short distance
   For each Hospital In Nearestlist
   Connect with Bed Capacity Web Service
Call and set value of Available Bed
Call and set value of  available  Orthopedic
Surgery specialist
Call and set value of  available  Neuro surgery
specialist
Call and set value of available Emergency
surgeon specialist
   For each hospital in Nearestlist
        If Available Bed is Not False
        Set Hospital in Availablelist
        Print Availablelist
        Delete Hospital from Nearestlist
   For each Hospital In Availablelist
        If available Orthopedic Surgery
        specialist OR available Neuro surgery
        specialist OR Emergency surgeon
        specialist
        Set Hospital in Availablespecialistlist
        Delete Hospital from
        Availablespecialistlist
        Print Availablespecialistlist
        Else
        Print Nearestlist
```

Algorithm of Bed Capacity Web Service

```
Initialize available bed to False
Initialize available Orthopedic Surgery
specialist to False
Initialize available Neuro surgery specialist to
False
Initialize available Emergency surgeon
specialist to False
Connect Electronic Health Record
Call Available bed in Radiology department
Call Available bed in  intensive care unit (ICU)
Call Available bed for inpatient
Call Available bed in OR
Call available Orthopedic Surgery specialist
Call available Neuro surgery specialist
Call available Emergency surgeon specialist
   If Available bed in Radiology department is
   Not False AND Available bed in intensive care
   unit (ICU) is Not False AND
   Available bed for inpatient is Not False AND
   Available bed in OR is Not False
   Set available bed True
   Print available bed
   Else
   Set available bed False
   Print available bed
   If Orthopedic Surgery specialist is Not False
   Set Orthopedic Surgery specialist True
   Print available Orthopedic Surgery specialist
   Else
   Set Orthopedic Surgery specialist False
   Print available Orthopedic Surgery specialist
   If Neuro surgery specialist is Not False
   Set Neuro surgery specialist True
   Print available Neuro surgery specialist
   Else
   Set Neuro surgery specialist False
   Print Neuro surgery specialist
   If Emergency surgeon specialist is Not False
   Set Emergency surgeon specialist True
   Print available Emergency surgeon specialist
   Else
   Set Emergency surgeon specialist False
Print available Emergency
```

E. *mEmergency Interface Design*

In the proposed mHealth application, there are three potential users: rescuer or paramedic front-end, EDSO, and EMS administrator for the back-end. The rescuer or paramedic is the primary user of the mHealth application. They can view a list of suitable nearest hospitals then choose one of them; they can also send the trauma victims assessment sheet containing vital information on patients to the chosen hospital. An EMS dashboard administrator can view reports about every rescue/paramedics, and we can also search by rescue/paramedics name, code number or hospital name (see Figure 5). On the other hand, the EDSO can view the assessment sheet of patients before they arrive (see Figure 6).

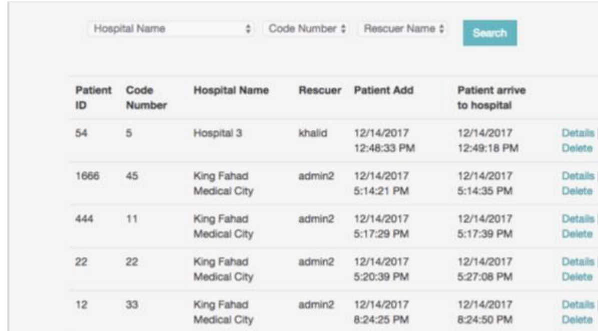

Figure 5. Hospital Bed Capacity Webpage Interface.

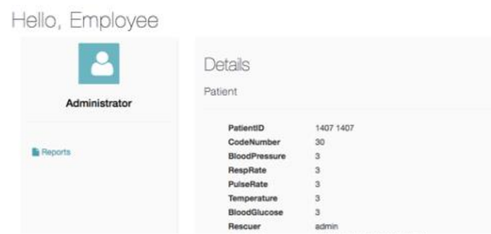

Figure 6. mEmergency Dashboard Interface.

An aggregated result illustrated in Figure 7 below shows all suitable hospitals prioritization by location and available beds. This is a color-coded scheme of availability: Red icon: Not Available, and Green icon: Available.

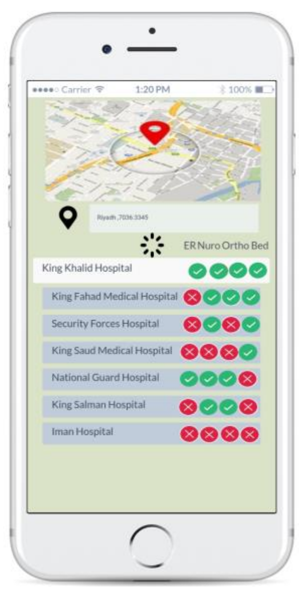

Figure 7. mEmergency prioritisation of nearest and most-equipped trauma EDs to the patient's case.

- First icon from the right is: Available bed.
- Second icon from right is: Available Orthopedic Surgery specialist.
- Third icon from right is: Available Neuro Surgery specialist.
- Fourth icon from right is: Available Emergency Surgery specialist.

The screen in Figure 8 appears after choosing the suitable hospital in Figure 7, so the EMS paramedics can record the patient's assessment data for sharing with the selected hospital prior to arrival to optimize its resources and enhance its readiness.

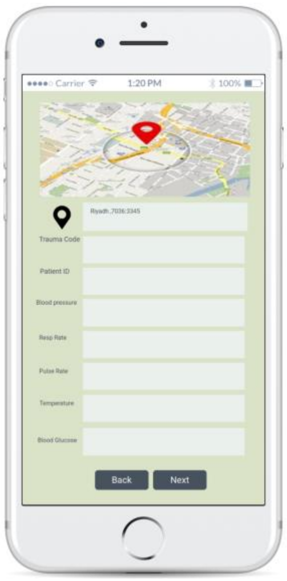

Figure 8. mEmergency records the patient's assessment data for sharing with the selected hospital prior to arrival.

- A "fields set" of patient's attributes should be completed.
- A Next button transfers the user to the next page (confirmed page).
- A Back button transfers the user to the previous screen.

V. Discussion and Conclusion

Overcrowded hospitals with limited resources in Saudi Arabia are left with no option but to divert ambulances, which can be the leading cause of death in some trauma cases. The work presented in this article proposes an effective mEmergency solution to this problem. First, it links Emergency Medical Services (EMSs) with trauma centers in Riyadh to help the paramedic deliver patients to the nearest trauma center's Emergency Department (ED) with available resources based on informed decisions in the shortest possible time to save their life. This is achieved by predicting inpatient bed capacity in real-time using Fusion Algorithm, while routing the EMS ambulance path taken using Dijkstra's Algorithm. In addition, mEmergency, optimizes the selected trauma center's resources and enhances its readiness by the sharing of patient's vital signs and physical assessment data prior his/her arrival to reduce the time for preparation prior to trauma victim arrival. The evaluation results of the solution show the capability of providing regional-based availabilities of resources in nearest hospitals in order to avoid ED crowding and shortages in inpatient bed capacity. Ultimately, mEmergency should help optimize EMSs resources in Riyadh city to improve the ambulance diversion issue in particular and the quality of urgent care service delivery to Saudis in general.

References

[1] K. Alghamdi, S. Alsalamah, G. Al-Hudhud,T. Nouh, I. Alyahya and S. Alqahtani. "Region-Based Bed Capacity mHealth Application for Emergency Medical Services: Saudi Arabia Case Study", *eTELEMED*, 2018, p.114

[2] Y. Shen, "Association Between Ambulance Diversion and Survival Among Patients With Acute Myocardial Infarction", *JAMA*, vol. 305, no. 23, p. 2440, 2011.

[3] "WannaCry ransomware: Everything you need to know", CNET, 2018. [Online]. Available: https://www.cnet.com/news/wannacry-wannacrypt-uiwix-ransomware-everything-you-need-to-know/. [Accessed: 23-Nov- 2018].

[4] Ministry of Foreign Affairs. "The Basic Law of Governance" Kingdom of Saudi. 1992.

[5] Ministry of Health, "Kingdom of Saudi Arabia - Ministry of Health Portal", 2017. [Online]. Available: http://www.moh.gov.sa/en/Ministry/Statistics/book/Pages/default.aspx. [Accessed: 29- Nov- 2018].

[6] Indexmundi. "Hospital bed density - Country Comparison", 2017. [Online]. Available: http://www.indexmundi.com/g/r.aspx?v=2227. [Accessed: 29-Nov- 2018].

[7] Van der Linden, M. C. "Emergency department crowding: Factors influencing flow", 9789461089007, 2015.

[8] National Association of EMS Physici, "Ambulance Diversion and Emergency Department Offload Delay", Prehospital Emergency Care, vol. 15, no. 4, pp. 543-543, 2011.

[9] Encyclopedia. "bed occupancy - Dictionary definition of bed occupancy", Encyclopedia.com, 2017. [Online]. Available: http://www.encyclopedia.com/caregiving/dictionaries-thesauruses-pictures-and-press-releases/bed-occupancy. [Accessed: 23- Nov- 2018].

[10] ACEP, "Definition of Boarded Patient", 2017. [Online]. Available: https://www.acep.org/Clinical---Practice-Management/Definition-of-Boarded-Patient-2147469010/. [Accessed: 23- Nov- 2018].

[11] B. Rechel, S. Wright, J. Barlow and M. McKee, "Hospital capacity planning: from measuring stocks to modelling flows," Bulletin of the World Health Organization, vol. 88, no. 8, pp. 632-636, 2010.

[12] World Health Organization, "Millennium Development Goals (MDGs), 2017. [Online]. Available: http://www.who.int/mediacentre/factsheets/fs290/en/. [Accessed: 23- Nov- 2018].

[13] M. McKee, "What are the lessons learnt by countries that have had dramatic reductions of their hospital bed capacity?" HEN synthesis report on reduction of hospital beds", Health Evidence Network (HEN), 2003.

[14] Jun, S. Jacobson and J. Swisher, "Application of Discrete-Event Simulation in Health Care Clinics: A Survey", The Journal of the Operational Research Society, vol. 50, no. 2, p. 109, 1999.

[15] Dawn M. Lewis," A Qualitative Case Study: Hospital Emergency Preparedness Coordinators' Perspectives Of Preparing For And Responding To Incidents", Capella University, 2015

[16] R. Schmidt, S. Geisler and C. Spreckelsen, "Decision support for hospital bed management using adaptable individual length of stay estimations and shared resources", BMC Medical Informatics and Decision Making, vol. 13, no. 1, 2013.

[17] Chin-I Lin. "Optimization Models For Capacity Planning In Health Care Delivery." (Doctoral Dissertation). University of Florida, Gainesville, USA. 2008.

[18] B. Asplin, D. Magid, K. Rhodes, L. Solberg, N. Lurie and C. Camargo, "A conceptual model of emergency department

crowding", Annals of Emergency Medicine, vol. 42, no. 2, pp. 173-180, 2003.

[19] Cisco Systems. "Singapore Hospital Modernizes Bed Management." [Accessed: 7- Nov- 2018] [Online]. Available: http://www.cisco.com/c/dam/en_us/solutions/industries/docs/healthcare/AlexandraHospital.pdf. 2006.

[20] Groundbreaking Bed Management Technology Helps SGH Improves Capacity and Care. [Online]. Available: https://www.sgh.com.sg/about-us/newsroom/news-release/2010/Pages/GroundbreakingBedManagementTechnologyHelpsSGHImprovesCapacityandCare.aspx. [Accessed: 30- Nov- 2018].

[21] M. Ribbe, G. Ljunggren, K. Steel, E. Topinkova, C. Hawes, N. Ikegami, J. Henrard and P. JONnson, "Nursing Homes in 10 Nations: A Comparison Between Countries and Settings", *Age and Ageing*, vol. 26, no. 2, pp. 3-12, 1997

[22] Kerr E, Sibrand V. Health care systems in transition: Belgium. Copenhagen, European Observatory on Health Care Systems, 2000.

[23] S. Hussain, "Full Text of Saudi Arabia's Vision 2030 | Saudi Gazette", Saudi Gazette, 2017. [Online]. Available: http://saudigazette.com.sa/saudi-arabia/full-text-saudi-arabias-vision-2030/. [Accessed: 23- Nov- 2018].

[24] Ministry of Finance. "Ministry of Finance 2017 Budget of Kingdom of Saudi Arabia." [Online]. Available: https://www.mof.gov.sa/en/budget2017/Documents/The_National_Budget.pdf. [Accessed: 23- Nov- 2018].

[25] Ministry of Health. "Achievement of Ministry of health 2013", 2017. [Online]. Available: http://www.moh.gov.sa/en/ministry/statistics/book/documents/1433.pdf [Accessed: 21- Nov- 2018].

[26] Ministry of Health. "News - Ajyad Hospital in Makkah Shows Continuous Readiness for the Hajj Season", Moh.gov.sa, 2017. [Online]. Available: http://www.moh.gov.sa/en/hajj/news/pages/news-2014-09-22-002.aspx. [Accessed: 23- Nov- 2018].

[27] S. Walston, Y. Al-Harbi and B. Al-Omar, "The Changing Face of Healthcare in Saudi Arabia", Annals of Saudi Medicine, vol. 28, no. 4, pp. 243-250, 2008.

[28] A. Bagust, M. Place and J. Posnett, "Dynamics of bed use in accommodating emergency admissions: stochastic simulation model", BMJ, vol. 319, no. 7203, pp. 155-158, 1999.

[29] Emedicine.medscape. "Initial Evaluation of the Trauma Patient: Overview, Triage and Organization of Care, Initial Assessment", Emedicine.medscape.com, 2017. [Online]. Available: http://emedicine.medscape.com/article/434707-overview. [Accessed: 23- Nov- 2018].

[30] Dr. Thamer Nouh, King Khaild Hospital,Riyadh, 2017.

[31] M. Aouad,Saudi Red Crescent Authority, Riyadh, 2017.

[32] "Emergency Department Support Officer", Nswhealth.erecruit.com.au, 2017. [Online]. Available: http://nswhealth.erecruit.com.au/ViewPosition.aspx?Id=270427. [Accessed: 23- Nov- 2018].

[33] Yuemin Li, Renbiao Wu, Tao Zhang, "Multi-scale fusion and estimation for multi-resolution sensors", Signal Processing (ICSP) 2012 IEEE 11th International Conference on, vol. 1, pp. 193-197, 2012, ISSN 2164-523X.

[34] P. Singal and R. R.S.Chhillar, "Dijkstra Shortest Path Algorithm using Global Position System", International Journal of Computer Applications, vol. 101, no. 6, pp. 12-18, 2014.