Region-Based Bed Capacity mHealth Application for Emergency Medical Services: Saudi Arabia Case Study

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***Abstract*—One of the major causes of death in trauma cases is ambulance diversion due to the unavailability of resources (bed and specialists) in the closest hospital. To date, there are no solutions in the literature that link Emergency Medical Services (EMS) with trauma centers in Saudi Arabia to avoid Emergency Departments (EDs) crowding and shortages in terms of inpatient bed capacity. Therefore, this study aims to bridge the gap by helping paramedics deliver patients to the nearest trauma center with available resources in the shortest possible time, as well as to monitor ambulance diversion data. This is achieved by regionalizing the availability of resources in the nearest hospitals using a mobile health (mHealth) application and two algorithms: Dijkstra and Fusion. The former helps route the ambulance's path taken, while the latter predicts inpatient bed capacity. The solution is an effective and time-optimizing application for the rescuer or paramedic, ED Support Officer (EDSO), and EMS administrator. It should help optimize EMS resources, reduce ED crowding, and increase the quality of urgent care services**.

Keywords- Emergency medical services; Operating room; Emergency department; Electronic health record; mHealth.

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 due to inefficient processes or environmental disaster, often have to divert ambulances to another hospital. In this case, the targeted hospital notifies the ambulance to go to another ED at any other hospital. This increases 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. This is evidenced in trauma treatment guidelines which state that to reduce risks, it is strictly suggested that the total time should be under 60 min for trauma victims. In research published in the Journal of the American Medical Association [1], researchers found that victims of a heart attack are more likely to die when their nearest hospital had high diversion rates of more than 12 hours diversion per day in contrast to other heart-attack victims who happened to be near a hospital and without any need for diversion [1]. Therefore, to eliminate the need for ambulance diversion and 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 to accommodate the patient in the unit. 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. From the hospital's perspective, the potential revenue is either lost or delayed, which may lead to some financial inefficiencies. 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.

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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 WannaCry Virus. WannaCry is a malware of Trojan virus called 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 even all of the files on a user's computer. Hence, the software demands that a ransom be paid in order to have the files decrypted. The episodes of Ransomeware attacks [2] have had a massive scale effect on around 150 countries, targeting not only home computers but also healthcare, communications infrastructure, logistics, and government entities for financial gain. This challenged healthcare providers' deployment of their computerized complex systems to maintain and keep patients' records and patient diversion data at critical times and so paralyzing healthcare services totally in some targeted health trusts in many countries, such as the British's National Health Service (NHS) [2]. Hospitals across England and Scotland's NHS reported that the cyber attack was causing disruptions to their health services by "affecting X-ray imaging systems, pathology test results, phone systems and patient administration systems" [2].

This project aims to address ambulance diversion issues in Emergency Medical Services (EMS) and monitors ambulance diversion data. Therefore, it focuses on finding a practical solution to facilitate the delivery of EMS across all EDs without ambulance diversion to reduce the time it takes them to reach the nearest ED with the available inpatient beds and the right resources for treating the patient. The remainder of this paper is organized as follows. Section II describes the background, while Section III discusses related work. Section IV presents our methodology, and conclusions are drawn in Section V.

II. BACKGROUND

The Saudi Arabian government has accorded high priority to healthcare services. According to the Basic Law of Saudi Arabia Rights of the Saudi Citizen, the government guarantees the right to healthcare for citizens and their families and the government is responsible for providing public health care services to all Saudi citizens [3]. In recent years, healthcare services in Saudi Arabia have improved tremendously in terms of both quantity and quality, and this is evident in the literature and government white papers in general, and reflected in the total number of hospitals in Saudi Arabia in particular. Back in 2015, there were 462 hospitals in Saudi Arabia with a capacity of 69,394 beds, with an increment of 49 hospitals in comparison with their number in 2011. The governmental sector owns nearly 70 percent of hospitals and the rest are owned by the private sector [4].

A. ED Crowding

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

> "*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.*" [5]

Instead of managing ED crowding as a standalone problem in order to eliminate it, contributing factors must also be examined. First, patients' long wait until an inpatient bed becomes available and the increased inpatient waiting time for care are also indications of ED crowding. Second, the lack of hospital inpatients bed capacity could lead to ED boarding, which is a significant cause and one of the main reasons for ED crowding [6]. 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 [7]. 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 speedy 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 a 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 Capacity Planning

Hospital bed capacity planning is crucial in healthcare because 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 its 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"* [8]. 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, the 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 its 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

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the hospital, as well as the factors that can cause delays in patients' treatment and this could be displayed in the form of a bottleneck [10].

Therefore, the key to successful capacity planning is to try to eliminate any possible future cause of a bottleneck; 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 this might affect others. Guaranteeing that there are as few bottlenecks as possible will, in turn, result in minimizing the delay in patients' treatment, separating patients into two streams based on complexity rather than urgency, and creating a fast-track patient stream for patients who can be treated and discharged more or less immediately [9].

C. International Hospital Statistics

Despite hospital planning strategies, this section highlights some international statistics for acute hospital bed shortages around the globe [11], along with a definition of hospital beds in such countries [11] (summarized below in Table I). In Austria, hospital beds have an average length of stay of 18 days or less. This includes some day care beds. In Germany, acute hospital beds are those other than psychiatric and long-term beds, and that exclude any day care beds. In Iceland, acute hospital beds are calculated from bed-days, assuming 90% occupancy rate; beds in medicine and surgeries of main hospitals and mixed facilities are available in small hospitals that do not include any day care beds. In Italy, acute hospital beds include in-patient beds of psychiatric hospitals and in-patient beds of psychiatric wards of other hospitals; these do not include any day care beds. In Spain, acute hospital beds include general hospitals, maternity, other specialized hospitals, and health centers; no day care beds. Last but not least, in the UK, acute hospital beds include NHS acute medical, surgical, and maternity beds (excluding Northern Ireland).

TABLE I. DEFINITIONS OF HOSPITAL BEDS IN SELECTED COUNTRIES [11]

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 centers
Sweden	Beds for short term care run by county councils and 3 independent communities (short-term includes medical, surgical, miscellaneous medicine/surgery, admission department and intensive care)
Turkey	Public hospitals, health centers, maternity hospitals, cardiovascular and thoracic surgical centers orthopaedic surgery hospitals

III. LITERATURE

A. Bed Capacity Planning Approach

Healthcare, like any other industry, faces huge pressure to improve efficiency and reduce costs. A study by McKinsey [5] 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 [13]. DES has been widely applied in healthcare services [13] to study the interrelationships between admission rates, hospital occupancy, and several different policies for allocating beds to MCUs. Lewis [14] studied bed management in Germany's hospitals, and decision support systems were presented depending on mathematical approaches and computer-based assistance designed to improve efficiency and effectiveness of admission planning and bed assignment. The study interviewed 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 [14]. Patient admission and assignment is based on up-to-date and flexible length of stay estimates, being taken into aggregated contingents of hospital beds, treatment priorities, patient preferences, and a linkage between clinics and wards [14].

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 [14]. Such flows are usually in emergency rooms, where patients can be seen without appointments, and require treatment for various sets of ailments and conditions [14]. 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 [15].

In emergency rooms, to reduce waiting times of low priority patients, Schmidt et al. [15] 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 [15]. A simulation model was 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 being transferred to ward beds in a timely manner [19]. Most experts agree that a greater inpatient capacity is required in order to relieve access block and decrease ED overcrowding

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[15]. Schmidt et al. 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, Schmidt et al. proposed in [15] 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.

Lin [16] 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 [16]. The throughput component of the model identifies 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 includes triage, room placement, and the initial provider evaluation. While the second phase of the throughput component includes diagnostic testing and ED treatment. The triage phase is used to objectively identify patients suitable for treatment by emergency nurse practitioners [16]. Since emergency nurse practitioners show high diagnostic accuracy, the emergency nurse practitioner model of care is considered an important strategy in reducing the length of stay of ED patients and may prevent ED crowding [16].

The input-throughput-output conceptual model of ED crowding may be useful for organizing research, policy, and operations management agenda to alleviate the problem [16]. This model illustrates the need for a systems approach with integrated, rather than piecemeal, solutions for ED crowding [16]. 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 important 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.

Infective allocation of existing bed capacity among different medical service units can lead to service quality problems for the patients along with operational and/ or financial inefficiencies for the hospitals [16]. Most health care managers apply relatively simple approaches, such as the use of target occupancy level with average length of stay, to forecast bed capacity required for a hospital or an MCU [16]. Yet, 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 [16].

Other research considers the hierarchical relation 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 [16]. If the ability downstream is insufficient, patients must stay within the current care units with typically more costly equipment, thereby meaning the full capacity is reached at these upstream care units [16]. To take the interactions among care units in a hospital into account, Lin [16] first applies queuing network methodology (without blocking) to discover a balanced bed allotment, which is obtained through trial-and-error work. Then, Lin uses simulation analysis to estimate the blocking behavior and patient sojourn times. The authors [16] 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 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 [16]. 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 provides critical benefits to both patients and staff; indeed, by using the system, patients' waiting times have been decreased by 30 percent [17]. 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, and 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 action immediately.

The way this system works is as follows: when the patient is admitted to the hospital, they receive a Radio

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Frequency Identification (RFID) tag with a unique identifier that will identify and track the patient's location during their stay at the hospital. The system then searches for a bed that best fits the patient's needs, based on their 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 Liquid Crystal Display (LCD) panels that display 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 Personal Digital Assistant (PDA) to clean and prepare the vacated bed, and once the bed is ready, the housekeeping staff updates the bed status [18].

C. Nature of Trauma

In physical medicine, major trauma is an injury or a damage to a biological organism caused by physical harm from an external source [28]. Major trauma is also an injury that can potentially lead to serious long-term outcomes, such as chronic pain or other lifelong ailments. There are different types of trauma [28]:

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 [28].

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 [28].

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 a challenging task 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 [27]. 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 [27]. 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 [27]. 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 important to find beds prior to trauma cases [28], and therefore, our proposal strives to address this matter.

D. Hospital Bed Capacity Globally and Saudi Vision 2030

Hospitals' provision for accommodating the increasing numbers of emergency admissions is a matter of considerable public and political concern and has been the subject of widespread debate [25]. When discussing a hospital's bed capacity, a number of questions are often raised. First, what is a hospital bed? A bed is merely 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 [12].

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 (i.e. Annual Islamic pilgrimage to Mecca, Saudi Arabia) [25]. 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 [20]. Many countries now struggle to provide cost-effective, quality healthcare services to their citizens [23]. Saudi Arabia has experienced high costs along with concerns about the quality of care in its public facilities [26]. 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 [26]. These changes provide an interesting 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 [26]. The complexity of changing a healthcare system is discussed with the many challenges associated with the change.

According to Saudi Vision 2030 [22], 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 [24]. 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 [24]. During the current fiscal year, 1437/1438, 23 new hospitals (4,250 beds) in various regions across Saudi Arabia were built [24].

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 energy consuming and hard to handle data). Alternatively, pointers to electronic health 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 with automation, including integrated interfaces with Hospital Information System (HIS) "*as an element of health informatics that focuses mainly on the administrational needs of hospitals*."
- Centralized query capabilities for both head quarters and regional administrators.
- Operational support to hospitals and primary health care practitioners providing patient referrals.
- Support full inpatient bed management cycle-interface with multiple systems, including registries, HIS, and communication systems. Generate messages to hospital housekeeping.
- Emergency bed requirements and other hospital departments across Saudi Arabia's regions to inform of status - full reporting and analytical capability [24] (See Table II below).

TABLE II. HOSPITALS ESTABLISHED IN SAUDI ARABIA (2010-2013) [24]

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
Tabuk	3	350
Jouf	5	550
Baha	2	100
Jazan	6	400
Najran	3	150
New	45	6,521
Upgraded/Replacement	65	2,470
Total	**175**	**17,982**

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 further away or kept at the hospitals where they currently are that yet may not be able to provide adequate service. For a critical trauma victim, the consequence of divert status can be the difference between life and death. Therefore, the healthcare service facility needs to construct a facility location model that can simultaneously determine the number of facilities opened, their particular locations, and their capacity levels. This should ensure that the probability of all servers in a facility gets busy does not exceed a pre-determined level.

To achieve such capabilities in a facility location model, some solutions in the literature incorporate queuing systems into facility location models to consider the chance of servers' availability and focus on reducing the demand lost due to the shortage of capacity or system congestion. However, to date there are no available region-based bed-capacity systems in the literature for Saudi Arabia. Therefore, this project aims to bridge this gap by locating ER services across Riyadh City on a network and determine their respective capacity levels such that the probability of diverting patients is not larger than a particular threshold. This proposal should enhance the performance of EMS in Saudi Arabia in general, and Riyadh City in particular. In Addition, it should reduce the total number of deaths resulting from trauma diversion.

IV. METHODOLOGY

This research uses a mixture of qualitative research methods for data collection and system design. First, a total of 34 hours of semi-structured interviews with 23 multi-disciplinary experts were conducted. The sample of interviewees included 1 trauma surgeon, 1 physician, 2 health informatics experts, 4 information security experts, 8 computer scientists, and 7 Saudi Red Crescent Authority (SRCA) representatives with information technology and medical backgrounds, including the General Manager of Emergency Medical Services, SRCA. Through those interviews, primary data was collected about all trauma centers in Riyadh, the number of states in emergency, the data assessment sheet EMS personnel uses today (in paper format) that needs to be sent to hospitals with notification along with patient ID number, and the challenges faced by the ED. Second, soft systems methodology was used to design the proposed system and produce an architectural design (See Figure 1).

A. *Region-Based Bed-Capacity System Framework*

The SRCA EMS personnel interviews (mainly with the Business Analyst [30]) provided substantial evidence that hospital beds can reduce deaths during emergencies and delay treatment of many patients in emergency by devolving the bed capacity system. Therefore, this research aims to devolve web services (See Figure 1) that connect the proposed mHealth application with any Electronic Health Record (EHR) in any hospital to show the bed capacity. Furthermore, to learn more about ED process, we interviewed Dr. Thamer Nouh [31], Trauma Surgeon at King Khalid University Hospital, to identify the criteria relating to emergency department bed capacity in trauma care in one of the large tertiary hospitals in Riyadh (namely King Khalid University Hospital).

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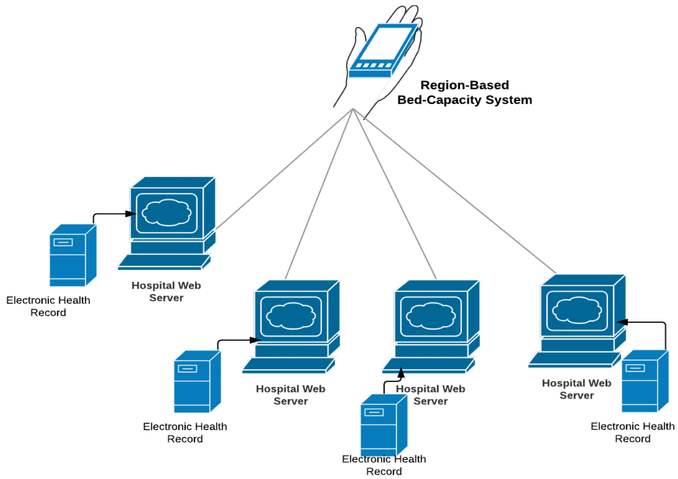

Figure 1. Proposed System Overview.

B. System Functional Requirements

Based on two sets of interviews the following solution is proposed:

- The EMS rescuer/paramedic can view information about hospitals across the city of Riyadh.
- The information available in the application must be dynamic and in real-time, which means that the paramedic can see the available and current information about the hospitals at any time and anywhere across Riyadh.
- The EMS rescuer/paramedic can view each hospital's exact location, bed capacity and the available medical resources to suit a patient's case.
- The EMS paramedic can view available inpatient bed capacity in real-time for the hospitals.
- The EMS 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.
- The Emergency Department Support Officer (EDSO) [32] receives notification of the new patient and can view their assessment information.
- The administrator of EMS can view reports about every EMS rescuer/paramedic case and patient information.

C. Workflow Design

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

- Available bed in radiology department,
- Available bed in Intensive Care Unit (ICU)
- Available bed for inpatient
- Available bed in Operation Room (OR)

A final criterion would be existing specialists in one of the three fields (Orthopedic surgery, Neuro surgery, and 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, then the EMS rescuer/paramedic can choose a suitable hospital. Accordingly, ER can be available if there are enough beds in the radiology department, ICU, inpatient and OR (See in Figure 2). The system has two components:

- 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.
- 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.

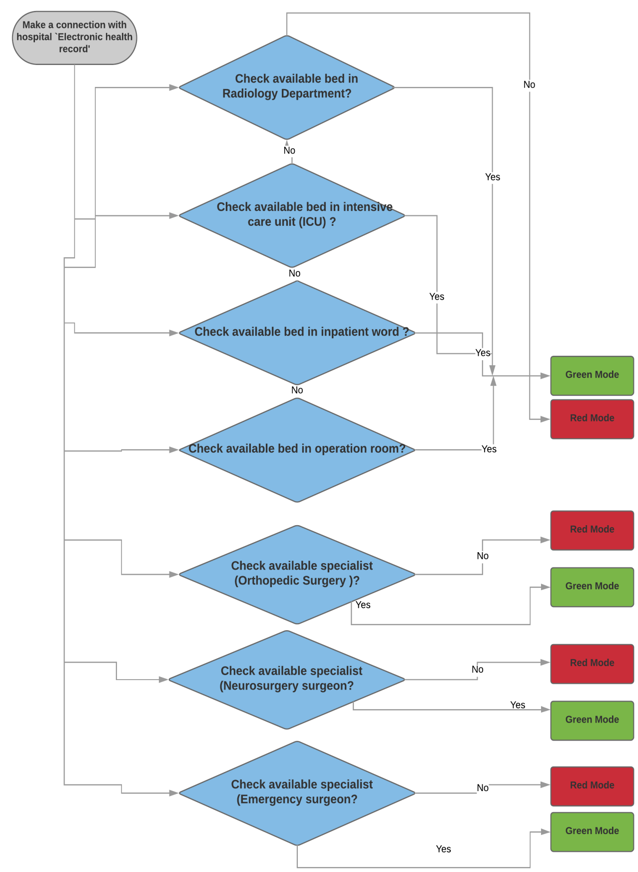

Figure 2. Proposed System workflow.

D. Process Algorithms

The goal of this phase is to build a decision support model that is powerful, robust, comprehensible, optimal, and effective. There are many different search algorithms that can 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.

On the one hand, Fusion Algorithm [33] 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].

On the other hand, Dijkstra's Algorithm [34] finds the shortest path from a starting node to a target node in a weighted graph. This algorithm is a graph search one that solves the single-source shortest path problem for a graph with nonnegative edge path costs, producing a shortest path tree. It 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]

- Existence of a widespread roads 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.
- Existence of an updated database of the roads and hospitals.
- Existence of Road Side Units (RSU) at suitable locations that might be inaccessible due to restrictions for propagation of signal.

E. 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 main 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-victim's assessment sheet containing key information on patients to the chosen hospital. On the other hand, the EDSO can view the assessment sheet of patients before they arrive (See Figure 3). An EMS dashboard administrator can view reports about every rescue/ paramedics operations and we can also search by rescue/ paramedics name, code number or hospital name (See Figure 4).

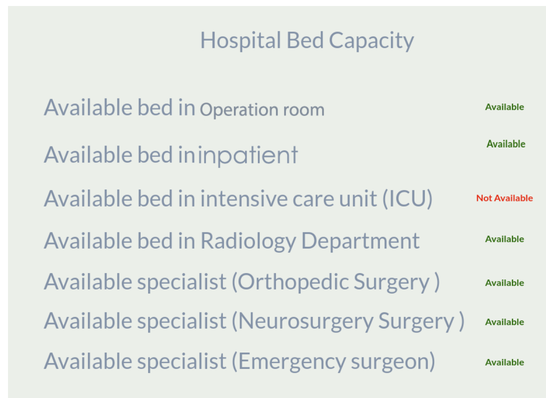

Figure 3. Hospital Bed Capacity Webpage Interface.

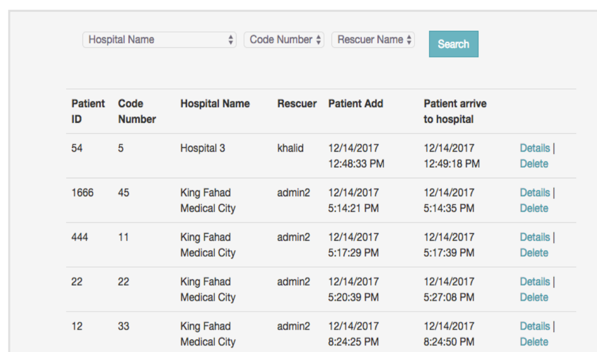

Figure 4. Emergency Dashboard Interface.

A menu in Figure 4 below shows all suitable hospitals arranged by location and available beds. This is a color-coded scheme of availability: Red icon: Not Available, and Green icon: Available.

- 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*.

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- Fourth icon from right is: *Available Emergency Surgery specialist.*

The screen in Figure 5 appears after choosing suitable hospitals from the previous screen. A *"field 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.

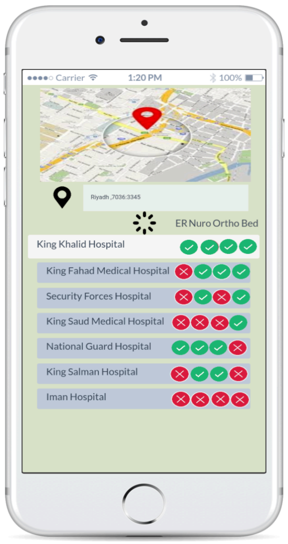

Figure 4. mHealth Application Interface (1st Screen).

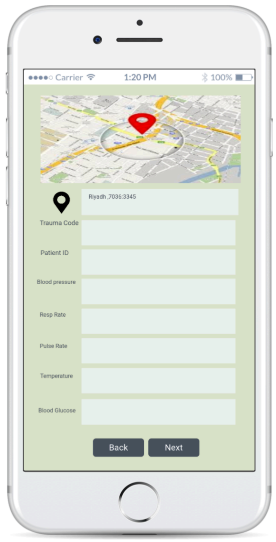

Figure 5. mHealth Application Interface (2nd Screen).

V. DISCUSSION AND CONCLUSION

The work presented in this paper described the proposed solution to a major problem facing healthcare services. The proposed mobile health (mHealth) application solution is an attempt to solve the issue of major causes of deaths in trauma cases: ambulance diversion due to the unavailability of resources (namely beds and specialists) in the nearest hospital. The proposed application focuses on linking Emergency Medical Services (EMS) to trauma centers in Riyadh to help the paramedic to deliver the patients to the nearest trauma center with available resources in the shortest possible time to save the lives of patients. The evaluation results of the application have shown that the proposed solution provides regional-based availabilities of resources in nearest hospitals in order to avoid Emergency Departments (ED) crowding and shortages in inpatient bed capacity. The proposed application uses two algorithms: Dijkstra Algorithm for routing the ambulance path taken and Fusion Algorithm for predicting inpatient bed capacity. Results show an effective mHealth application to be used by 3 system users. First, EMS rescuer/ paramedic user to view a list of suitable nearest hospitals then chooses one of them; they also send the trauma-victim's assessment sheet containing key information on patients to the chosen hospital. Second, EDSO user to view the patients' assessment sheet before they arrive to the nearest trauma center that is ready to reduce the average time of 1 hour it takes for preparation prior to trauma victim arrival [31]. Finally, EMS administrator user to view a dashboard that reports about all EMS rescue/paramedics' actions. This mHealth application should optimize resources in EMS in Riyadh city to improve the ambulance diversion issue in particular and the quality of urgent care service delivery to Saudis in general.

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