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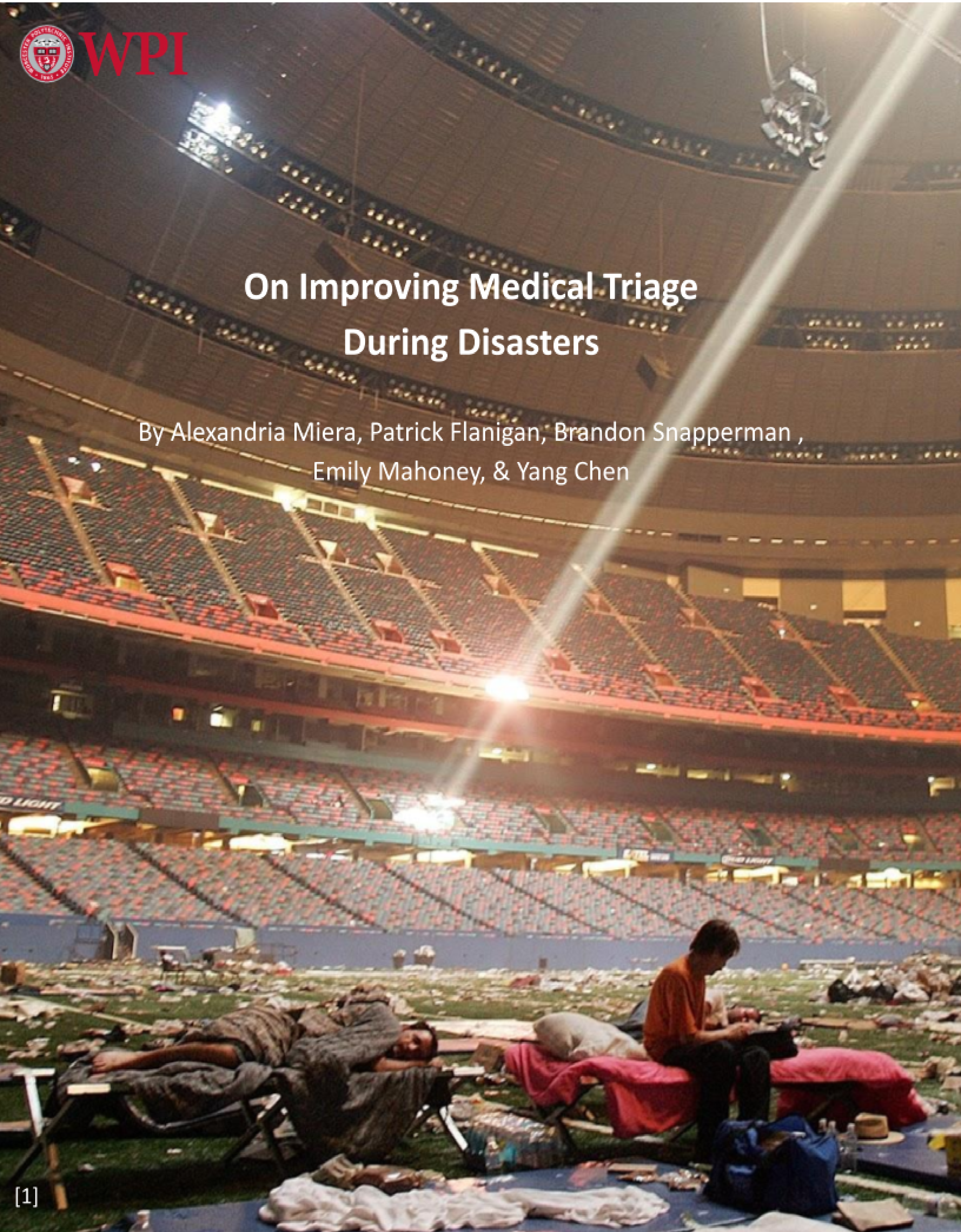
On Improving Medical Triage During Disasters

By Alexandria Miera, Patrick Flanigan, Brandon Snapperman ,
Emily Mahoney, & Yang Chen



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On Improving Medical Triage During Disasters

An Interactive Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

Submitted by Yang Chen, Emily Mahoney, Alexandria Miera, Patrick Flanigan, & Brandon Snapperman

Advised by Professor Therese Mary Smith

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Abstract
In response to ongoing man-made disasters like war and increasing natural disasters like hurricanes and tsunamis, the traditional emergency medical system may become overwhelmed resulting in constrained medical resources such as supplies, hospital beds, and healthcare workers. To combat this, health care workers use triage to sort patients based on the severity of their condition to ensure that high priority or critical patients get the care and supplies they need before lower priority patients. Despite its clear advantages, triage is susceptible to failure, leaving patients vulnerable. We worked to understand why triage fails and identify technological and non-technological ways to prevent triage from failing.

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Table of Contents

Table of Figures

Terminology

(DT) Disaster Triage

Executive Summary

Introduction

Around the world, ongoing man-made disasters and increasing natural disasters have resulted in health crises [“...escalating health crisis in Ukraine”, 2022] [“Afghanistan crisis”, n.d.] [Kherallah et. al., 2012] [Klein et. al. 2013] [Herreros et. al., 2020] that have overwhelmed temporary and traditional emergency medical systems. In response, health care workers have used disaster triage (DT) to sort patients based on the severity of their condition to ensure that high priority or critical patients get the care and supplies they need before lower priority patients. Despite its clear advantages, DT is susceptible to failure, leaving patients vulnerable.

Background

DT is a process used to sort patients from most (red tag) to least critical (green tag) using physical tags to indicate the patient's priority. However, the way in which patients are sorted varies based on the availability of medical resources and the typical conditions amongst patients. If such factors are not considered, DT can fail as shown in case studies of previous disasters.

Results

In previous disasters, DT failed because the algorithm used to triage patients was not appropriate for their condition, medical resources were overwhelmed, or communications were inadequate. Some of these concerns have been addressed in current triage technology which tends to focus on automatically triaging patients using a computer algorithm, improving communications amongst healthcare workers, and managing medical resources such as healthcare workers or supplies. Technologies that are relevant to these areas include but may not be limited to: near field communication, vitals collection devices, triaging algorithms, hospital matching algorithms, and patient dashboard applications. Our findings suggest that there is a market as well as a need to create and implement these technologies in order to help manage the influx of patients after man-made or natural disasters. Alternatively, our findings suggest that there are non-technical ways to support triage such as teaching triage to healthcare workers and creating triage algorithms catered to specific types of disasters before the disaster strikes. Based on this, we believe that IQP centers focused on disaster management should investigate and integrate technical or non-technical ways to support triage.

Conclusion & Future Work

With ongoing man-made disasters and increasing numbers of natural disasters, mass-casualty disasters may continue to rise. Future IQP groups should therefore consider investigating and or integrating triage technology, educating healthcare workers across the world on the structure and benefits of triage, and integrating triage algorithms in disaster management plans to better prepare for natural and man-made disasters.

Chapter 1: Introduction

Around the world, ongoing man-made disasters and increasing natural disasters [National Academies of Sciences, 2016] have resulted in health crises ["...escalating health crisis in Ukraine", 2022] ["Afghanistan crisis", n.d.] [Kherallah et. al., 2012] [Klein et. al. 2013] [Herreros et. al., 2020] that have overwhelmed temporary and permanent emergency medical systems. In response, health care workers have used disaster triage (DT) to sort patients based on the severity of their condition to ensure that high priority or critical patients get the care and supplies they need before lower priority patients. Despite its clear advantages, DT is susceptible to failure, leaving patients vulnerable.

The goal of this project is to identify:

1. Why triage fails
2. Technological and non-technological ways to prevent triage from failing

Additionally, we hope that the information provided in this IQP can be utilized by other IQP's who are working on disaster management preparedness or are at or near countries who have experienced or are in danger of experiencing natural or man-made disasters.

Chapter 2: Background

2.1 Understanding emergency medicine

2.1.1 History

Civilian emergency medicine is a field of medicine that was first begun around the 1960s to treat acute, rapid onset, conditions [Suter, 2012]. At the time, emergency rooms were staffed by physicians of all specialties and about half of the ambulance services were run by funeral homes who had special vehicles that could transport patients in various positions of comfort. In a few areas, the police or fire department used station wagons to transport patients to the hospital. A driver was always present but an attendant who watched over the patient may not have been. If present, the attendant may have had some formal first aid training, though there was no guarantee. Overall, the early emergency medical system was uncoordinated and followed no standard. It was not until 1966 when the National Academy of Sciences presented *Accidental Death and Disability: The Neglected Disease of Modern Society*, also known as the *White Paper*, which outlined the inadequacy of the state of emergency medicine in the United States (U.S.). Following the release of the paper were a series of legislative acts and organizational efforts that began to form today's emergency medical system in the U.S.

Organized military emergency medicine dates back to the 19th century during the Napoleonic Wars [Way, 2016]. Conflicts that followed such as World War I and II, Korean War, and the Vietnam War helped develop the standards of care for trauma patients that are still used today [Pollak et. al., 2016]. Even more recent military conflicts have contributed to improving modern medicine [France & Handford, 2021]

Foreign-supported emergency medicine is a relatively newer system in comparison to the civilian and military systems. However, system is a loose term. Various organizations such as the North Atlantic Treaty Organization (NATO), World Health Organization (WHO), and the United Nations have their own foreign-supported emergency medical systems in place. However, in 2003, WHO attempted to create a set of guidelines for foreign field hospitals (FFHs) [“...Guidelines for the Use of foreign Field Hospitals…”, 2003], although adherence to the guidelines was limited. In 2013, the guidelines were reviewed after the concerns were raised regarding the medical practices of foreign medical teams (FMTs) [“...Foreign Medical Teams in Sudden Onset Disasters”, 2013]. In 2015, the term FMT was abandoned and emergency medical team was adopted and in 2016 WHO launched a website where teams could register to be internationally deployable [“About Us”, n.d.].

In the conceptualization of the civilian, military, foreign emergency medicine, the structures of the systems also began to take shape.

2.1.2 Structure

The traditional emergency medical system in the U.S. is a pre-hospital care system focused on responding to, caring for, and transporting a patient to a hospital. It is typically made up of permanent medical facilities like hospitals but, in times of disaster, temporary structures may be used [Klein et. al. 2013]. The system is generally organized into 3 parts [Pollak, 2011]:

1. Dispatch
2. EMS
3. Hospitals

Dispatch is a system of professional communicators who receive 911 calls and activate emergency medical services (EMS) who are a group of healthcare workers focused on assessing, stabilizing, and transporting the patient to an appropriate hospital. There are 4 types of EMS providers where each type is defined by their scope of practice [Pollak et. al., 2016]:

1. Emergency medical responders (EMRs)
2. Emergency medical technicians (EMTs)
3. Advanced EMTs (AEMTs)
4. Paramedics

The scope of practice is the set of services that each type of EMS provider can provide to a patient. Paramedics have the greatest scope, followed by AEMTs, EMTs, and EMRs. Regardless, each medical provider plays an important role in EMS.

The U.S. The Army's emergency medical system is structured differently than its civilian counterpart and has both temporary and permanent structures. It is organized into 5 levels of medical care where each level is defined by its capabilities [Bagg et. al., 2006]:

1. Level 1 care provides immediate first aid on-scene and the patient is triaged, stabilized, and evacuated to the next appropriate level
2. Level 2 care provides continued treatment in a temporary and limited inpatient area within a combat zone and basic medical capabilities such as lab tests and dental work are available
3. Level 3 care provides continued treatment in a temporary and larger inpatient area within a combat zone and advanced medical capabilities like surgery and intensive care units (ICU) are available
4. Level 4 care provides intensive rehabilitation or special care which is given outside of a combat zone, likely within a permanent medical facility.
5. Level 5 care provides long-term care which is again given outside of a combat zone and likely in a permanent medical facility.

The types of EMS providers are similar to the civilian system with the exception that the scope of practice and naming conventions are intended for combat medicine. In the U.S. Army, EMR, EMTs, and AEMTs are considered to be roughly equivalent to a 68W combat medic specialist and paramedics are roughly equivalent to 300-F1 combat paramedics [“300-F1 Combat Paramedic…”, n.d.]. However, the Navy and Airforce have different naming conventions and scopes [“Pararescue”, n.d.] [“Hospital Corpsman”, n.d.] .

A similar tiered emergency medical system was established in areas inflicted with a sudden and substantial medical emergency such as a natural disaster or war [“...Foreign Medical Teams in Sudden Onset Disasters”, 2013]. According to the world health organization (WHO), foreign medical teams (FMT) are organized into 4 levels of medical care where each level is defined by its capabilities:

1. Outpatient emergency care provides roughly the same scope of care as level 1 care in the U.S. Army.
2. Inpatient surgical emergency care provides continued treatment in an existing or deployable facility and surgical triage, advanced life support, wound and fracture care, damage control surgery, and basic medical capabilities such as x-rays, blood transfusions, and lab tests.
3. Inpatient referral care provides continued treatment in a larger and more capable existing or deployable facility and reconstructive wound and orthopedic care, anesthesia, intensive care, and advanced medical capabilities.
4. Additional specialized care provides specialized care such as burn care, facial surgery, intensive rehabilitation, and maternal health. Such services are only available on request.

However, there are 8 other ways in which FMTs are organized according to the organization. For example, the North Atlantic Treaty Organization (NATO) organizes FMTs into 4 levels of medical care, again, where each level is defined by its capabilities [“...Foreign Medical Teams in Sudden Onset Disasters”, 2013] [“Multinational Logistics”, 1997]:

1. Echelon 1 provides medical support for patients who are minorly sick or injured in addition to supporting disease prevention.
2. Echelon 2 provides medical care in war vessels or mobile facilities and supports triage, resuscitation, evacuation, and emergency dental treatment.
3. Echelon 3 provides specialized medical support in hospital ships, mobile facilities, and permanent facilities and supports diagnosis and treatment.
4. Echelon 4 provides continued medical care, typically within the country of origin, and supports highly specialized surgical and medical procedures.

Another example is the United Nations (UN) whose FMT organization is similar to the U.S. Army’s. The types of EMS providers are the same as the civilian system in addition to various types and levels of nurses, doctors, and surgeons.

If either civilian, military, or foreign emergency medical systems become overwhelmed, then triage must be used to ethically sort patients based on the severity of their condition and available supplies.

2.2 Understanding triage

2.2.1 History

Triage dates back to the Napoleonic Wars and is often credited to Napoleon's surgeon, Baron Dominique-Jean Larrey who created a classification system that prioritizes patients for evacuation [Mitchell, 2013]. Previous triage attempts often put the highest priority on patients who could be easily cared for and returned to duty. In Larrey's memoirs on the Russian campaign, he described how patients should be triaged: "Those who are dangerously wounded should receive the first attention, without regard to rank or distinction. They who are injured in a less degree may wait until their brethren in arms, who are badly mutilated, have been operated on and dressed, otherwise the latter would not survive many hours; rarely, until the succeeding day." [Larrey, 1814]. It was not until World War I (WWI) that the term "triage" was widely adopted [Iverson & Moskop 2004]. However, the WWI military surgical manual offered an approach to triage that was counter to Larrey's recommendations stating that if a case may "absorb a long time" then it "may have to wait" [Keen, 1917]. In 1964, triage was adopted into civilian emergency departments and has since been refined [Weinerman, 1966]

2.2.2 Types

There are 5 types of triage within the medical field [Iverson & Moskop 2004]:

1. Emergency Department (ED) triage
2. Inpatient intensive care unit (ICU) triage
3. Mass casualty triage (MCT)
4. Military triage (MT)
5. Disaster triage (DT)

For the purposes of this paper, only disaster triage will be discussed. DT is aimed to respond to the effects of natural or man-made disasters that overwhelm the local ability to meet the demand for health care.

Generally in DT, a patient's condition can be categorized in 4 ways. The most critical patients are red tags because they require immediate care. The least critical patients are green tags because they do not require immediate treatment. Yellow-tagged patients are in-between red and green tags and black tagged patients are considered deceased or expectant deceased [Pollak et. al., 2016]. During the triage process, all relevant patient data, including the color categorization, is typically kept on physical patient tags as shown in figure 2.2.

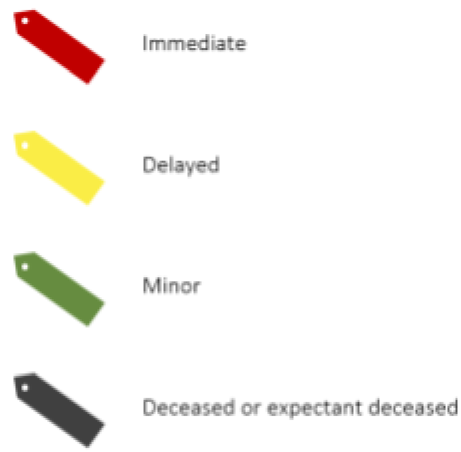


Figure 2.1 Triage tags where a red tag indicates the highest priority followed by yellow, green, and black

Algorithms are used to determine which patients belong into which category. DT generally uses the Simple Triage and Rapid Transport (START) and JumpSTART triage algorithms. However, these algorithms are not universal. The START algorithm was developed at the Hoag Hospital in Newport Beach, California and was meant to assist minimally trained healthcare workers in identifying the most critical patients [Iverson & Moskop 2004]. The JumpSTART algorithm was created to meet the needs of patients younger than 8 years old or who appear to weigh less than 100 lbs [Pollak et. al., 2016]. One study (n = 148) found that the START algorithm results in acceptable (100% red sensitivity and 89% green sensitivity) levels of undertriage but substantial (53%) amounts of overtriage [Kahn et. al., 2007]. In a counter correspondence, the Sacco Triage algorithm was introduced as a more accurate alternative [Navin et. al., 2010]. The cited study found that the Sacco algorithm outperformed the START algorithm in accuracy by 21% [Sacco et. al., 2010]. This claim is further backed by Aoyu et. al. [Aoyu et. al., 2019]. However, both studies test the Sacco algorithm in trauma related incidents. Because the Saco algorithm is relatively new, its implementation into emergency medicine is to be determined.

Figure 2.2 An example of a triage tag ["Triage Tags", n.d.]

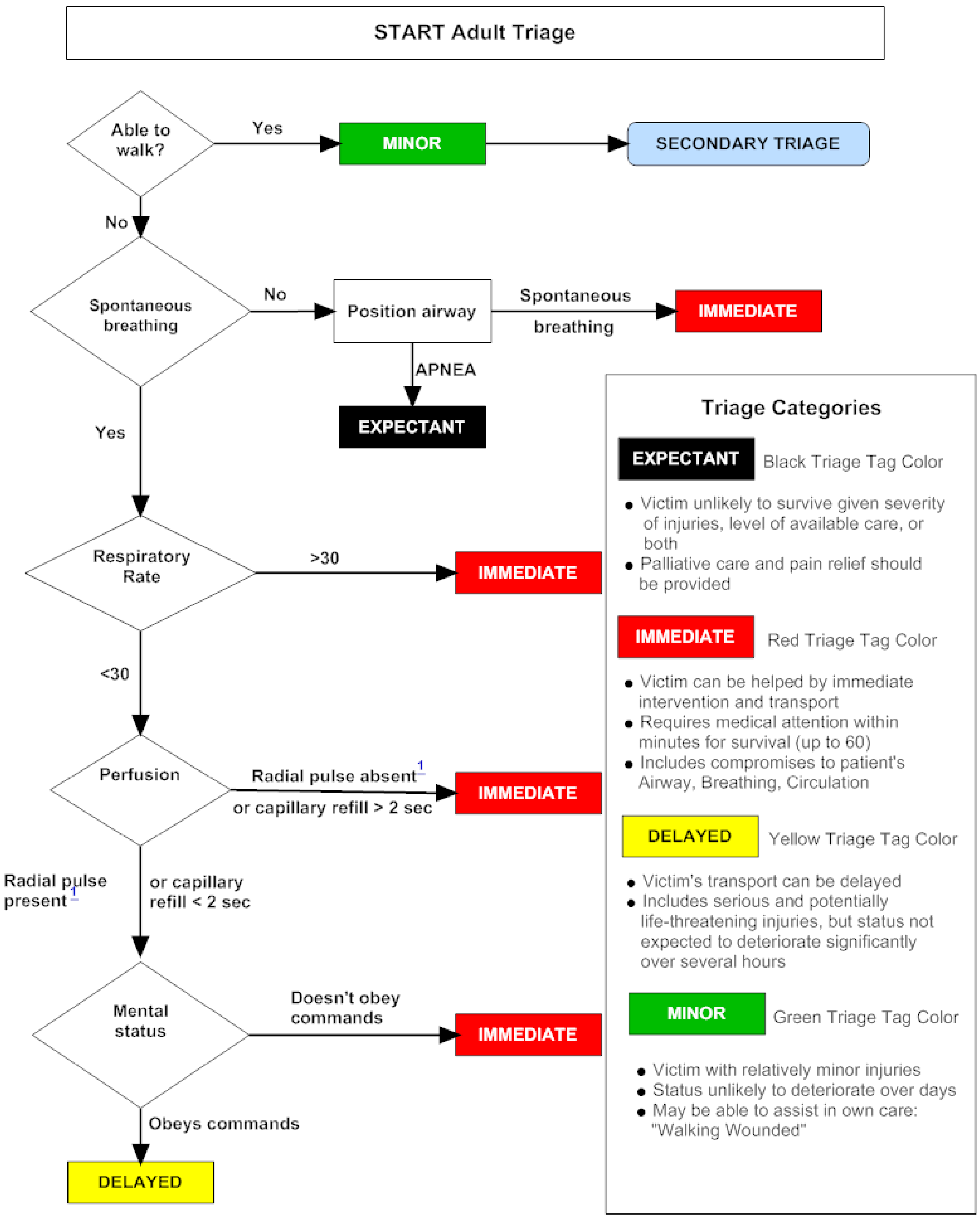


Figure 2.3 START triage algorithm [“START Adult…”, 2021]

Sacco and START triage have proven to be beneficial in trauma-related DT, with some exceptions, but these algorithms may not be adequate for patient conditions after all disasters. For example. If a large number of patients are yellow, then which patients should receive care first? Additionally, START triage fails to account for the scarcity of medical resources after a disaster, which may cause the algorithm to fail.

2.3 Triage in context

On August 23, 2005, Hurricane Katrina made landfall and over the next 8 days it would become one of the most devastating natural disasters to hit the U.S ["Hurricane Katrina", n.d.]. Before the hurricane made landfall, the Federal Emergency Management Agency (FEMA) activated Disaster Medical Teams (DMATs) to stage field hospitals in non threatened areas, including the Louis Armstrong International Airport (MSY) [Klein et. al. 2013]. 12 hours after the hurricane struck, the field hospital was unable to accommodate new patients. Additionally, between 125 and 175 helicopters were landing and off-loading 600 patients every hour at the various DMAT field hospitals causing the DMAT system to collapse. As a result, accurate medical records could not be kept and the ability to triage patients was exhausted. Klein et. al. alluded to the idea that nontraumatic triage guidelines for natural disasters should be developed. More than 1,500 people died in the hurricane and 7,500 were injured [Sullivent et al 2006] ["Hurricane Katrina…Unprepared", 2006].

On March 11, 2020, WHO declared COVID-19 a pandemic [Cucinotta & Vanelli, 2020]. Just one day before, the Department of Clinical Bioethics of the University Hospital Infanta Elena in Valdemoro Madrid called for a need to establish common criteria for triage. Soon after, in April 2020, the community of Madrid had been particularly hard hit with over 47,000 cases causing local hospitals to become overwhelmed with patients [Herreros et. al., 2020]. As a result, available ICU beds and advanced life support (ALS) supplies were limited. The call for a common criteria for triage was never met, causing hospitals to create independent triage protocols or even triaging without any structured protocol in place. Generally, healthcare workers had to make decisions on which ALS candidates would be admitted to the ICU. Some factors that may have contributed to this decision were age, social value, and order of arrival, all of which are ethically controversial [Herreros et. al., 2020]. Overall, Madrid had about 1.6 million cases and 17, 450 related deaths ["COVID-19 Data Repo…", 2020]

The Syrian Civil War began in 2011 [Kahn & Kahn, 2017] and has continued since. As a result of the crisis, the UN reported back in 2021 that 350,000 people have died ["Syria: 10 years of war…", 2021]. Additionally, medical infrastructure has been compromised or destroyed causing restricted access to healthcare and due to sanctions, there is also a shortage of medical supplies [Kherallah et. al., 2012]. Healthcare workers report that the triage process was relatively new and was only taught to emergency doctors before the conflict [Fardousi et. al., 2019]. After the conflict, there is a rising need for training in triage either in person or online. A Doctors Without

Borders group reports that they are working to support triage efforts in Raqqa Syria [“How we’re helping in Syria”, n.d.].

With ongoing man-made disasters [“...escalating health crisis in Ukraine”, 2022] [“Afghanistan crisis”, n.d.] [Kherallah et. al., 2012] and increasing numbers of natural disasters [“Climate and weather related disasters…”, 2021], mass-casualty disasters may continue to rise [“Mass Casualty Management Systems”, 2007].

2.4 Summary of Background

DT is a process used to sort patients from most (red tag) to least critical (green tag) using physical tags to indicate the patient's priority. However, the way in which patients are sorted varies based on the availability of medical resources and the typical conditions amongst patients. If such factors are not considered, DT can fail as shown in case studies of previous disasters.

Chapter 3: Methodology

3.1 Identify what causes triage to fail

To identify why triage may fail, we used Google Scholar to research how triage failed in three unique disasters, two of which were natural and one of which was man-made. Hurricane Katrina and the COVID-19 pandemic were natural disasters while the Syrian Civil War was man-made. In analyzing these three case studies, we identified three ways in which triage can fail.

3.2 Identify what technology is being used to support triage

After we identified why triage may fail, we looked to identify technology that may be used to help prevent triage failures by

1. conducting literature reviews on triage technology and
2. reviewing articles and literature on what technology is used in medicine today

3.3 Identify key technologies that can be used to support triage

Based on our findings from the previous two sections, we identified five technologies that can be used to support triage. We then generally described how each technology could be used to support any of the three trige failures. Additionally, we detailed specific ways each technology could be used.

3.4 Consider the market size and needs for the technology

Assuming the five technologies identified in the previous section generally fit under the category health information technology (HIT), we looked at the market size to understand the feasibility of creating the technology. We also looked at the market needs that would need to be addressed when creating and implementing the technology.

3.5 Identify IQP sites that may be able to benefit from such technology

Understanding that technology may not be the answer, we also identified ways in which triage can be improved in non-technical ways. We then identified the lack of triage integration in IQP's on disaster management and suggested ways in which this could be addressed.

Chapter 4: Results

4.1 What causes triage to fail

Based on the background research, there are 3 reasons that DT fails:

1. Resources are depleted
2. The algorithm fails
3. Communications fail

In all cases of DT, triage is subject to failure when the local ability to meet the demand for healthcare is overwhelmed. That may be due to the number of available healthcare workers, available supplies, and or available beds.

In the case of Hurricane Katrina and COVID-19, DT failed because there was no standard algorithm available that was specific to the disaster. Meaning, algorithms like Sacco or START did not apply. During Hurricane Katrina, a non-traumatic triage algorithm was needed [Klein et. al. 2013] while during the COVID-19 surge in Madrid, an algorithm that took into account the available ALS-supplies and the patient's condition was needed [Herreros et. al., 2020].

In all cases, DT also failed because of a lack of communication. During Hurricane Katrina, the lack of communication was between the DMATS and FEMA commanders in Baton Rouge, Louisiana and resulted in the saturation of local field hospitals at MSY and thus a collapse of the triage process [Klein et. al. 2013]. During COVID-19, the lack of communication was between hospitals where each hospital surged with patients operated under independent triage algorithms or none at all [Herreros et. al., 2020]. Finally, during the ongoing Syrian crisis, the lack of communication was between emergency medical doctors, the rest of healthcare workers, and foreign medical support. Triage was a topic limited to emergency doctors prior to the crisis. However, soon after the crisis began, there became a need to teach triage to all healthcare workers [Fardousi et. al., 2019].

4.2 Triage technologies used today

4.2.1 Triage technology and research

The Medical Hands-free Unified Broadcast system (MEDHUB) is a HIT system for the U.S. army military that collects, stores, and transmits non-personally identifiable information from the point of injury to the receiving field hospital [Soares, 2020]. The system is intended to help document triage and streamline communications on other medical interventions [Soares, 2021]. To maintain security, it utilizes the military's Blue Force Tracker tactical satellite network. Overall, it has received praise from the 30th Medical Brigade in Sembach, Germany, the 44th Medical Brigade at Fort Bragg, North Carolina, and is currently being tested at the University of Maryland-Baltimore Shock Trauma Center [Soares, 2021]

Masimo is a medical technology company that offers HIT solutions for EDs and EMS. For the ED, Masimo offers vital signs monitors with automated data transfer to patients' EHR [“Emergency Department”, n.d.]. Additionally, they offer supplemental remote monitoring and a clinician notification system which is intended to display real time patient data, including triage tags, and alert clinicians from any device connected to the Masimo system, including phones. For EMS, Masimo offers vital sign monitors specifically for carbon monoxide levels breath-by-breath ventilation data that alerts hospitals of the incoming patient's status [“Emergency Medical Services”, n.d.]. It is unclear how large this market is for Masimo.

In 2021, a team of 6 John Hopkins undergraduates paired up with NATO to create the digital triage assistant (DTA) that helps triage patients by continuously monitoring soldier’s vitals and “transmitting this information to a centralized location for the medic” [Kallem, 2021]. The system currently measures heart rate, oxygen saturation, and blood pressure and uses this data to compute a numerical output indicative of the urgency of care a soldier requires. Research has since been handed off to the Czech Technical University in Prague (CTU) who continues to develop the DTA.

Another group from John Hopkins based in the Center for Data Science in Emergency Medicine is working on connecting emergency care, applying machine learning to triage, and optimizing resource allocation. In the Connected Emergency Care Patient Safety Learning Lab, the team is working to close the loop on patient outcomes in the ED [“Connected Emergency Care”, n.d.]. Meaning that clinicians can easily follow up on what happened to their patients after they left the ED. In the machine learning triage group, a triage tool was developed to automatically triage patients admitted to the ED based on their presenting complaint, vital signs, and demographic information [Levin et. al., 2018]. However, a triage nurse can override the triage decision. The tool has since been acquired by the digital health company StoCastic and is currently being used in three EDs at John Hopkins [“Stocastic”, n.d.]. In the optimized resource allocation group, the team is working to develop mathematical models to optically transfer patients within the Johns Hopkins Health System in response to COVID-19 surges [Graham, 2020].

4.2.2 Relevant technology widely used or emerging in medicine today

Back in 2005, RFID was at its infancy in healthcare [“Radio Frequency Identification in Healthcare…”, 2016] but has since began to become more widely adopted [Dey, 2016]. However, there are still concerns with cost and security [Haddara & Staaby, 2018]. Regardless, RFID has been implemented to prevent newborns from being abducted or accidentally switched at birth [Wong, 2021], improve operating room and emergency room workflow management [Wong, 2021] [Pasupathy & Hellmich, 2015], prevent surgical supplies from being left in the body [Grillman, 2018], track staff and patients [Arunachalam et. al., 2017], track patient specimens [Will, 2021], among a variety of other reasons.

In 1887, Augustus Desiré Waller was the first to record the electrical activity of the human heart and in 1925, James Machkenzie emphasized the need to graphically display pulse rate and blood pressure [Stewart, 1970]. Vital sign monitors have been widely marketed and integrated in hospitals [“Vital Signs Monitors”, n.d.] and EMS [“Vital Sign Monitors”, n.d.] but are now even being integrated into the home [Oestreich, 2020]. Traditionally, vital sign monitors are wired, but wireless monitors have been investigated by the U.S. Department of Homeland Security [“Wireless Patient Monitoring, n.d.] and approved by the U.S. Food and Drug Administration (FDA) [“...FDA Clearance of Radiu PCG…”, 2021] [“...MyHomeDoc receives FDA approval…”, 2021].

Back in 2009, the health information technology for economic and clinical health (HITECH) act was established to promote the adoption of HIT, including electronic health records (EHR) [“HITECH Act Enforcement…”, 2017]. As a result, hospitals began to widely adopt EHR and companies like Epic and Cerner, among others, became leaders in EHR software [Phaneuf, 2020]

With the widespread adoption of HIT, large amounts of data are now available for analysis. Big companies like IBM [“Data-driven insights…”, n.d.] and Microsoft [Microsoft, n.d.] are working towards building various healthcare analytics solutions but companies like Flatiron Health have catered their analytics services to specific areas in healthcare like oncology [Flatiron, n.d.]. However, there are still challenges that data analytics companies and researchers face like a lack of interoperability between EHR platforms, security concerns, and data quality [Rehman et. al., 2021]

4.3 Technologies that can be used to support triage

Based on the technologies mentioned in 4.2 and the case studies mentioned in 2.3, we identified five technologies that may be able to help support the three failures of triage identified in 4.2:

1. Near Field Communication (NFC)
2. Vitals collection device
3. Triaging algorithms
4. Hospital matching algorithms
5. Patient dashboard application for healthcare workers

NFC, similar to RFID, may be utilized in DT management to quickly identify patients throughout the different levels of treatment and quickly pull and edit their EHR. That way, rather than triage tags, patient data can be directly logged to the EHR. As a result, this solution would attempt to support the triage communication failure.

Vitals collection devices can be utilized in DT management to capture patient data over time while the patient is not being seen by a healthcare worker. In the event that the patient's condition rapidly changes, for example a yellow tagged patient begins to rapidly deteriorate, the vital collection device in conjunction with a computational algorithm can alert the healthcare worker. This solution would attempt to support triage communication and algorithm failure.

A triaging algorithm can be used in conjunction with a vitals collection device to semi-automatically triage patients based on their vitals and healthcare worker inputs. The algorithm should not automatically triage patients because it should take into account the experience the healthcare worker has by allowing them to override the triage decision. This solution would attempt to support the triage algorithm failure

A hospital matching algorithm can be used by EMS to identify which field hospital is most appropriate for the patient based on a variety of factors like the level of care the patient requires, available supplies, available capacity, and current location. This solution would attempt to support the triage resource depletion failure.

Finally, the patient dashboard application which can be used to organize and visualize patient data into one cohesive system. If used in conjunction with the NFC tag, healthcare workers can quickly identify and pull the patient's EHR in the application. The dashboard can also be used to visualize a triage list which may help healthcare workers quickly identify which patients need to be prioritized. This may help in identifying which patients require certain medical supplies over others. As a result, this solution would attempt to support the triage resource depletion and communication failure.

These technologies and the way in which they are proposed to be used for triage, generally make up aspects of a HIT system. In the following paragraphs, we propose specific ways in which the five technologies can be utilized but we recognize that there are alternative methods.

4.3.1 NFC

NFC is similar to radio frequency identification (RFID) in that they both transmit data through radio frequency waves. NFC operates at 13.56 MHz and is meant for short distance readings (20 cm) while RFID operates at 125kHz and 13.56 MHz [Mareli et. al., 2013] and is meant for long distance readings (100 m). Because RFID operates on the same frequency as NFC, an RFID reader can also be used as an NFC reader. The two components of the NFC technology are the NFC tag itself and the NFC reader. There are 2 types of NFC tags, active and passive. An active NFC tag requires internal power so that the tag can actively broadcast a signal. A passive NFC tag does not require internal power because it uses the electromagnetic field supplied by the NFC reader to power the internal circuit [Chawla & Ha, 2007]; the same is true for RFID. Phones like the iPhone (7th gen and up) and Samsung Galaxy are NFC enabled meaning that they can be used as NFC readers. However, RFID is not as easily integrated and therefore typically requires external hardware. We propose a patient identification NFC system that utilizes a healthcare worker's phone to quickly pull the patient's EHR as shown in figure 4.2.

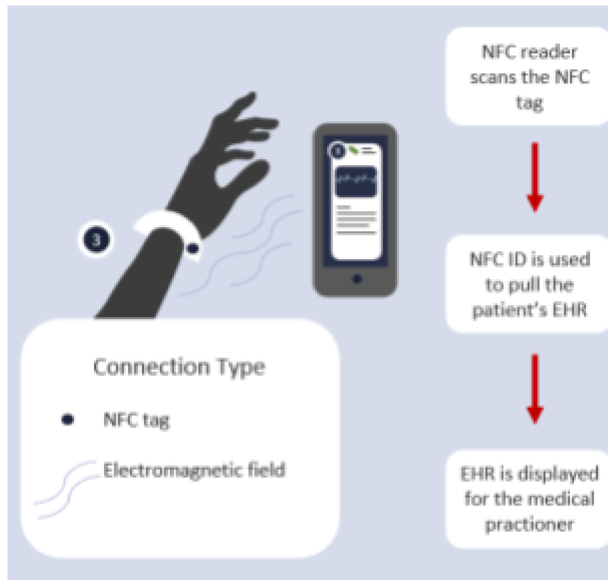


Figure 4.2 shows the flow of information of the NFC patient identification system

4.3.2 Vitals collection device

The purpose of the vitals collection device is to autonomously collect, process, and transmit patient vitals. Vital signs allow for a variety of ways to measure the current condition of a patient. These readings are critical to providing effective care to a patient, both in-hospital and pre-hospital, and can be used to assess injuries that may not be visually obvious. Current in-hospital vital sign monitoring provides very accurate readings, however, it is commonly stationary and expensive and may not be as easily implemented in disaster scenarios. Vital-sign monitoring in disaster scenarios may be far less accurate and much more manual. Professionals working in the field often have to manually and quickly take, and sometimes estimate, vital signs such as pulse rate, blood pressure, breathing rate, oxygen saturation, and temperature. On average, it takes roughly 215 seconds, or 3 minutes and 35 seconds, to measure a complete set of vital signs in a hospital setting (Wong et at 2017). In disaster scenarios, minutes and accurate data matter. If any of the vital signs are low, inconsistent, or irregular, they can often indicate an issue on the scene (Brekke et al 2019). There are a number of ways to collect this data from a patient. Currently vital conditions of a patient can be monitored manually by counting the number of breaths and heartbeats in a minute, as well as using a thermometer to measure temperature and a blood pressure monitor to measure systolic, as well as diastolic blood pressure (Sapra 2021). This method is extremely manual and time-consuming, with each vital sign being measured over a minute. As a result, manual vitals collection is used most commonly where time is ample, or equipment is scarce. There are methods that allow for easier, semi-automated vital sign collection. The most common, and least expensive, of these devices is a finger mounted pulse oximeter. A spring holds the pulse oximeter onto the finger of a patient while the device records oxygen saturation (SpO2), perfusion index, pulse rate, and pulse strength. These devices have proven to be an easy and inexpensive way to collect accurate readings on oxygen saturation and pulse rate, however, the device (by nature of being on the finger) is unable to measure any data regarding the respiratory and breathing rate. Some in-hospital devices are capable of measuring respiratory and breathing rates through the use of an oxygen mask and while very accurate, they are typically large and fixed to a stand, require substantial amounts of power, and are extremely expensive. These devices are well suited for use in hospitals, where space, power, and funding are ample. This leaves an industry gap for a lightweight, portable vitals collection device that can monitor a wide range of vitals (Weenk 2020). There are a series of oxygen masks that are designed for field use such as non-rebreather and big valve masks (BVMs), however, these masks tend to be technically difficult to mount properly to the patient. This results in high training and retraining costs, as well as providing technical difficulties to the medical professionals during rescue procedures. Additionally, we consider it to be a novel idea to embed our vitals collection device into one of these field-ready oxygen masks. By combining these systems, we would create a single unit, easy to administer, and self contained automated vitals collection device. We believe this combination of properties would lower technical aptitude standards, increase time efficiency, increase patient care quality and accuracy, and reduce strain on medical professionals.

To maximize the effectiveness of our vital signs collection device we want to measure pulse rate and strength, blood oxygen saturation levels, breathing temp and rate, carbon dioxide levels, and total volatile organic compounds (TVOCs) using a system that is portable, accurate, easy to use, and ergonomic. To accomplish this, we propose embedding a pulse oximeter and gas analyzer into an oxygen mask to measure a wide breadth of data. Both devices will upload data to a central database over the internet while also storing data locally on an SD card. The mask system would be a fully self-contained apparatus to minimize in-field setup and organization time while maximizing simplicity and ease of use. We believe this is absolutely critical to the design of our vitals collection device. Although we expect medical professionals to be well trained, our proposed mask design is very straightforward to fit, and would most likely be administered correctly by a completely untrained individual. This is not to remove the necessity of training but instead to minimize the time and cognitive load of mounting the unit to the patient and act as a fail-safe if a condition occurs where an untrained individual has to administer a vitals collection device.

With this combination of sensors embedded into a mask, the total mounting time for the system should be under twenty seconds and record a plethora of accurate data in regards to cardiovascular and respiratory systems. Additionally, each of these sensors is extremely inexpensive and energy-efficient. By prioritizing ease of use, flexibility, and simplicity while maintaining data breadth and accuracy, we believe our vital signs collection system could collect more data, save significant amounts of time, and make medical professionals more effective, especially in disaster scenarios.

4.3.3 Triaging algorithm

Using data retrieved from the vital signs collection device, and an algorithm to compute expected treatment time interval, we can apply modern computer science techniques to produce a recommended sequence of patient treatments to maximize recovery. Recent advances in the field of computer science include research into what is known as 'time-utility scheduling'. Time-utility scheduling is the sequencing of multiple complicated tasks, often with limited resources, with each task returning a different (usually positive) result. In the case of pre-hospital triaging, especially in a disaster scenario, the sequence in which patients are treated is critical to maximize the final outcome of the total recoveries combined across all involved casualties. By implementing algorithms to direct effort towards areas that will produce maximal utility, complex tasks have proven to be completed more quickly, or return better results if they are time or resource limited (Jensen et al 2006). By using these algorithms to schedule patient treatment during disaster medical care, we expect to increase the effectiveness of a medical team in the field and ensure effort is directed where it will produce the best results.

There are a number of different time-utility functions which produce results based on different levels of available resources and environmental constraints. Energy bounded utility accrual algorithms (EBUAs) produce a sequence in which the maximal utility, or best results, are returned given a situation with multiple tasks that must be performed by a system with limited energy. EBUAs function by calculating a utility energy ratio (UER) for each task such that the system may understand and apply the relation between required effort/energy and returned utility (Jensen et al 2006). Following the UER assignments, an algorithm is able to compute the sequence in which the maximal utility may be returned given a system with limited resources. Applying these algorithms to disaster triage, we expect the health care system to achieve maximal utility when facing multiple casualty scenarios with similarly limited resources such as medical professionals, equipment, vehicles, and time.

4.3.4 Field hospital matching algorithms

The hospital matching algorithm can be used to optimize the way that patients are distributed to field hospitals based on a variety of factors like distance to the location and what level of care the field hospital will need to provide. It has three subcomponents that allow it to perform its operation: the distance calculator, the weighted sum calculator, and the top three field hospitals calculator. There are two distance calculators that are available for use, but currently the algorithm is finding the Euclidean distance between the patient location and the field hospital locations. The weighted sum calculator takes in the factors that the EMS worker enters and the importance of each for a given hospital and returns the weighted sum. The top three field hospitals calculator takes in a list of field hospitals, a list of factors given by the EMS worker, and the importance of each factor and gets the weighted sum for how well each field hospital meets the needs. The top three field hospitals are those with the lowest weighted sums, and are returned to the user in order of ranking, with the first hospital having the best services for the patient.

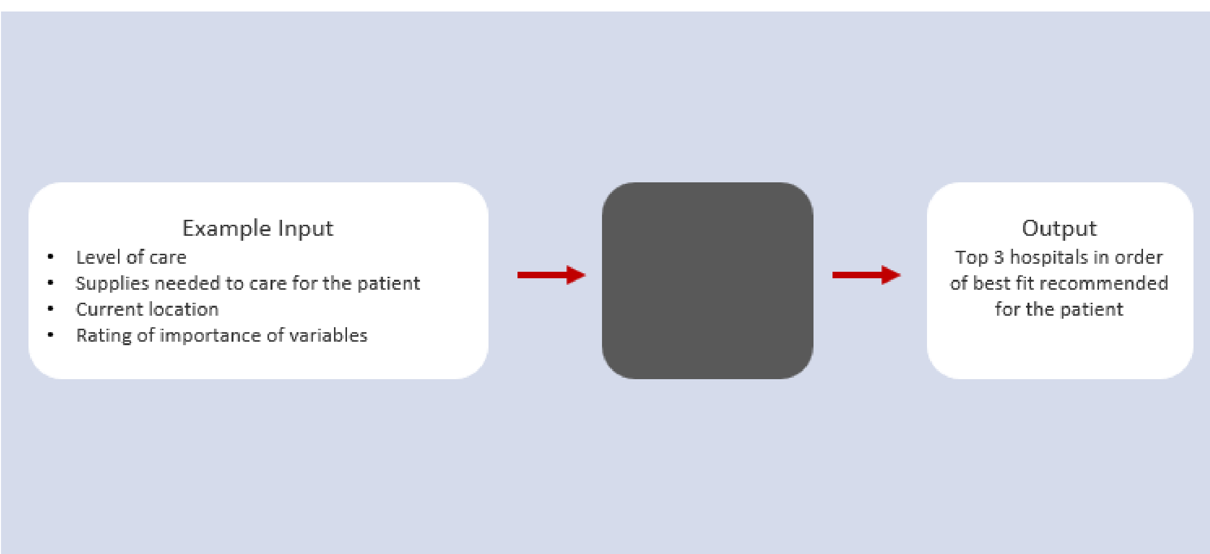
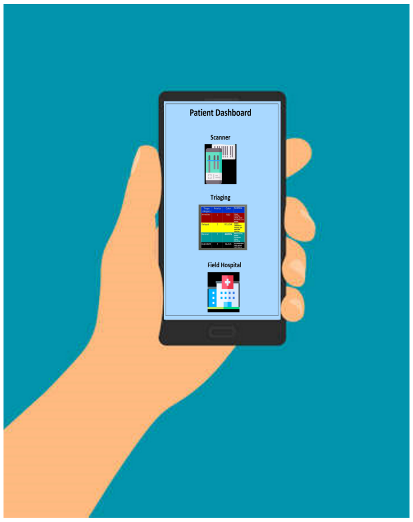


Figure 4.3 shows the flow of information of the hospital matching algorithm

An EMS worker can be responsible for inputting the patient's preferences information, such as what their state of health or injuries suggest for what level of care or what tools should be available at an ideal hospital. The location of the patient should also be provided in any case. The variables of distance and level of care should also be rated by importance, or provided as 0 if not applicable. The program will then take the variables, their levels of importance, and hospital information related to the variables and calculate three hospitals in order of suitability that it would recommend the patient go to.

4.3.5 Patient dashboard application for medical practitioners

The patient dashboard mobile app allows for the gathering of medical information, triaging of patients, and choosing which hospital is most appropriate. The dashboard app can be used as a guest or be signed in with their own account. Having a personal account can verify if the user has any advanced training, is a medical professional or military personnel. This can allow greater access to the app's functions to update and view patient data. The app will have a home page consisting of three icons: a scanner, a triaging table and a field hospital. When selected, the scanner icon will take the user to a loading screen that will continuously scan until it reads/scans a patient's NFC tag. The scanner icon allows those with little to no medical training the ability to assist in a crisis. After registering the patient's tag, the user can pull up the patient's EHR and have it displayed in the app. After viewing and or editing the patient's data, depending on clearance, the user can also upload the data to either the triaging algorithm, the field hospital algorithm, or both. After uploading and updating the patient's data the user can navigate back to the home page via back buttons located in the bottom right. The triage icon will open up to a new page with a couple of options. The first option will be to record patent data manually and have it uploaded to the triaging algorithm. The second option will be to view the priority of treatment by the triaging algorithm. A ranking of patients to transport/evacuate can be included. This will allow anyone on the scene to prioritize helping the most severe cases first. The third option will also be a scanner to collect patient data on the scene. This may seem redundant as the first icon discussed above is the scanner icon. However, this allows personnel with access to the triaging functions to scan without having to back out and select the scanner icon. Then it will upload it to the triaging algorithm and update their respective EHRs. The last option will be a home button to get back to the home page. The field hospital icon will take the user to another submenu where they can follow a series of steps to get the three best hospitals for the patient or patients. The first step is to choose if it is a military or a civilian operation. The second step will be to record the current location and circumstances surrounding the area for the field hospital matching algorithm. The third step will be to upload the patient data which can be inputted manually or scanned. The data is analyzed by the field hospital matching algorithm. The fourth step will bring up the top three hospitals that the field hospital matching algorithm chose based upon the previous step's data. The last option will be a home button to go back to the home page. This app will give a new level of functionality to medical personnel allowing them to treat more people quickly.



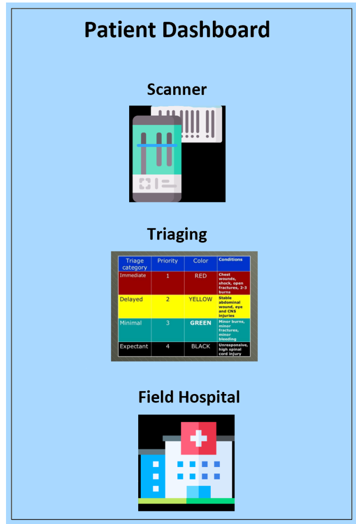


Figure 4.4 & 4.5 Shows a possible home screen for the Patient Dashboard app.

4.4 The market size and needs for the technology

There are two areas of HIT investment: research, and market. Within the research area, various government agencies and foundations such as the Agency for Healthcare Research and Quality, the National Science Foundation, and the Department of Defense are offering research grants for HIT systems or related work [“Using Innovative Digital…”, 2021] [“Communications, Circuits…”, 2018] [“Army Applications Lab…”, 2019]. Within the market area, companies like GE IBM have branches that work on health IT solutions [“GE Healthcare Systems”, n.d.]. Additionally, there are HIT-focused companies like Cerner Corporation and McKesson Corporation. Some of their investors include The Vanguard Group with $2.8 billions of dollars in shares, BlackRock Fund Advisors with $1.4 billion, and SSgA Funds Management with $1.3 billion [“Cerner Corp”, n.d.]. Even hospitals like the Mayo Clinic and the Baptist Hospital of Miami are investing millions into HIT systems [Anastasijevic, 2021] [“Baptist Health Announces…”, 2021]. This is no surprise because, according to various market research consulting groups, the HIT market is on the rise and expected to rapidly increase due to pressures placed on the healthcare system in response to the Covid-19 pandemic. In 2019 alone, US health care spending reached $3.8T which accounts for 17.7% of the nation’s gross domestic product [“National Health Expenditure Data: Historical”, 2021]. Of the $3.8T, 5% or $190B was spent on noncommercial research, structures, and equipment [“National Health Expenditure Data: Historical”, 2021]. Grand View Research states that health IT market investments are up 11.9% from 2019 and that the 2020 market size was valued at USD $96.5B. Additionally, the market size is expected to grow at a compound annual growth rate (CAGR) of 15.1% from 2021 to 2028 [“Digital Health Market Size…”, 2021]. Similarly, Global Market Insights states that the HIT market size was valued at over USD $187B in 2019 and is expected to grow at a CAGR of 15.6% [Ugalmugle et. al., 2020]. With regards to venture funding, U.S. HIT companies raised $14.1B in 2020 which was the largest amount of capital Rock Health has measured since 2011 [DeSilva et. al., 2021]. Additionally, equity funding of HIT companies was up to $26.5B in 2020 which is an all-time high [CBInsights, 2021]. As funding increases, more deals are being closed and Rock Health mentions that the dollar value per deal has increased [DeSilva et. al., 2021].

Despite all of the current and anticipated growth in the HIT market, it is important to note that in the past, technological advancements have come with an overall increase in healthcare costs [Clemens. 2017] [Callahan, 2015] [Ginsburg et. al. 2008]. As a result, investors and the government are shifting their focus to support HIT innovation that lowers direct medical costs in addition to technical, clinical, and usability benefits, which is particularly true of HIT systems as outlined by the "Digital Health ScoreCard" [Mathews et. al., 2019]. In general, the digital health scorecard highlights the major concerns of HIT systems including energy usage, communication mechanisms, scalability, security, and heterogeneous interconnectivity [Kranenburg & Bassi, 2012] [Goyal et. al., 2020]. On the other hand, telehealth systems are generally secured video and audio communication applications typically hosted via phone or laptop. Such platforms have been well established as shown with applications like Microsoft Teams and Zoom and as a result, telehealth systems do not face the same concerns as HIT systems. If any of the 5 technologies identified in 4.3 are utilized in DT, the following expectations should be considered [Colakovic & Hadzialic, 2018].

- *Standardized* - the systems architecture, technology, and protocols follow well-established standards
- *Interoperable* - the system must be able to take on an increasing number of different sensor inputs, interface with a wide variety of current EMS and ED/hospital communication systems and software, and adapt to the needs specific to each healthcare team.
- *Available & Reliable Coverage* - the networks that the HIT system relies on must be available and reliable.
- *Scalable* - the system must be able to take on an increasing number of inputs, whether that be patient profiles or sensor devices, without failure.
- *Easy to use* - the system properly stores information in a way that it can be easily retrieved, processed, and visualized for the end user.
- *Manageable* - system failures are easily identified and certain system functions are automated.
- *Optimal performance* - network traffic loads are efficiently managed to reduce the effects on the networks' performance and quality of service (QoS).
- *Identifiable* - each HIT object needs to have a unique identifier so that the object may be monitored, controlled, or managed.

- *Energy-efficient* - the system must be able to efficiently work off of finite battery power
- *Transparent* - the development team must be able to clearly state what data is being collected, how is the data being collected, transmitted, processed, organized, and stored, and who has access to the data at what points in time.
- *Secure* - the system must be able to effectively protect patient data during collection, transmission, processing, organization, and storage.
- *Cost-effective* - the return on investment is positive

Additionally, to meeting the expectations of healthcare providers [Mathews et. al., 2019]:

- *Clinically effective* - the system positively impacts clinical outcome, is comparable to the clinical gold standard, and has undergone real world testing or simulation.
- *Technically effective* - the system is comparable to the technical gold standard, is secure, and interoperable.
- *Usable* - the end users rate the system as helpful, effective, learnable, and likable
- *Cost-effective* - the return on investment is positive and training, setup, and implementation time is reasonable.

4.5 Recommendations for IQP sites

It may not be feasible to create or implement the five technologies identified in 4.3. Based on the case studies in 2.3, non-technical alternatives may include:

1. Holding on-line or in-person courses on triage
2. Developing triage algorithms as part of disaster preparation

Oftentimes, IQP reports that focus on emergency preparedness [Garza et. al., 2020] [Cooper et. al., 2021] [Nowtash & Kashef, 2007] [Girardo et. al., 2013] [Brainard et. al., 2019] either do not account for emergency medical preparedness after the disaster has struck or do not outline a triage plan in the case that medical resources are scarce. Based on our findings, we suggest that IQP sites that are at or near countries that may or have experienced man-made or natural disasters should investigate and integrate technical and non-technical ways to support triage. These sites include but are not exclusive to: Puerto Rico, Iceland, Israel, Thailand, Taiwan, and Japan.

4.6 Summary of results and analysis

In previous disasters, DT failed because the algorithm used to triage patients was not appropriate for their condition, medical resources were overwhelmed, or communications were inadequate. Some of these concerns have been addressed in current triage technology which tends to focus on automatically triaging patients using a computer algorithm, improving communications amongst healthcare workers, and managing medical resources such as healthcare workers or supplies. Technologies that are relevant to these areas include but may not be limited to: near field communication, vitals collection devices, triaging algorithms, hospital matching algorithms, and patient dashboard applications. Our findings suggest that there is a market as well as a need to create and implement these technologies in order to help manage the influx of patients after man-made or natural disasters. Alternatively, our findings suggest that there are non-technical ways to support triage such as teaching triage to healthcare workers and creating triage algorithms catered to specific types of disasters before the disaster strikes. Based on this, we believe that IQP centers focused on disaster management should investigate and integrate technical or non-technical ways to support triage.

Chapter 5: Conclusion & Future Work

5.1 Limits and future work

Our IQP team was limited to online research which does not account for the perspectives and advice drawn from healthcare professionals who have been directly impacted by man-man or natural disasters. We recognize this and suggest that future work should revolve around interviewing and working with such healthcare professionals. This can be more easily achieved at IQP sites that work directly with those involved in disaster management.

5.2 Conclusion

With ongoing man-made disasters and increasing numbers of natural disasters, mass-casualty disasters may continue to rise. We should therefore consider investigating and or integrating triage technology, educating healthcare workers across the world on the structure and benefits of triage, and integrating triage algorithms in disaster management plans to better prepare for natural and man-made disasters.

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