Dissertation

Improving the Air Force Medical Service's Expeditionary Medical Support System: A Simulation Approach

Analysis of Mass-Casualty Combat and Disaster Relief Scenarios

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Abstract

Research finds minor changes to the Air Force's Expeditionary Medical Support System (EMEDS) that produce significant impacts on patient outcomes in mass-casualty events.

The Air Force presently deploys a modular medical treatment facility (MTF), the EMEDS, to provide emergency care to patients around the globe. A fully developed EMEDS consists of twenty-five medical and surgical beds. The EMEDS is not designed to treat large numbers of critically wounded patients or individuals needing advanced trauma surgery. However, the Air Force has previously employed an EMEDS to assist with the emergency medical care provided in large-scale operations.

This research uses a simulation tool to answer three questions. First, how well does the EMEDS currently perform across three types of mass-casualty events: fixed-based missile strikes, earthquakes, and hurricanes? What changes can be made within an EMEDS that might allow it to better serve large numbers of patients? Finally, across the indicated changes, what are the specific impacts on overall patient outcomes (evacuations, returns-to-duty, and mortality) for different patient streams?

This research confirms that the EMEDS is not well-suited to handle patient surges. Though large-scale changes to the EMEDS structure are impractical, two small changes were found that each produce beneficial and statistically significant impacts on patient outcomes. Increasing the size of one of the EMEDS's functional areas, the Critical Care Ward, by adding two beds alleviates patient bottlenecks and improves patient throughput by 50% in some scenarios. Prioritizing certain low mortality risk patients increases evacuations by an average of 200% while increasing return-to-duty rates significantly. When combined, these two adjustments further improve the productivity of the MTF.

This research recommends that the Air Force conduct operational tests of modified EMEDS to confirm that the proposed changes have the beneficial impacts measured and thus strengthen the ability of EMEDS to respond to mass-casualty events.

Table of Contents

Abstract iii
Figures ix
Tables xiii
Contact Information xvii
Acknowledgments xix
Abbreviations xxi
1. Introduction 1
Policy Objective 1
What is an Expeditionary Medical Support System? 1
Research Questions 2
Policy Relevance 3
Organization 4
2. EMEDS Background and Existing Medical Tools and Research 5
Roles of Medical Care 5
Role 1 Medical Care 5
Role 2 Medical Care 6
Role 3 Medical Care 6
Role 4 Medical Care 6
Patient Prioritization and Movement 7
Patient Prioritization 7
Patient Movement 9
Historic EMEDS System 10
When Was the EMEDS System Designed? 10
When Are EMEDS Used? 10
Combat Operations 11
Current Deployable Medical Assets 13
EMEDS Health Response Team 13
EMEDS+10 14
EMEDS+25 14
58 Bed Air Force Theater Hospital 14
Existing Analytic Tools 15
Medical Planner's Toolkit (MPTk) 15
Joint Medical Planning Tool (JMPT) 16
Theater Air Base Models 17
Existing Literature 17
Expeditionary Medical Support (EMEDS) and Air Force Theater Hospital (ATFH) 17
How Should Air Force Expeditionary Medical Capabilities Be Expressed? 18

Timelines for Reaching Injured Personnel in Africa 19
A Chance in Hell: Evaluating the Efficacy of US Military Health Systems in Foreign Disaster Relief 19
Conclusion 20
3. Threat Environment 21
Missile Strike Attack Strategies and Requirements 21
Missile Class Nomenclature 22
Current State of Affairs 23
Adversary Introduction 23
Country Profile: China 24
Country Profile: Russia 26
Country Profile: North Korea 28
Country Profile: Iran 30
Conclusion 33
4. Model Formulation 34
Research Question 1 35
Research Question 2 35
Research Question 3 36
Research Question 4 36
Data Requirements 36
MPTk Data Requirements 37
JMPT Medical Network 38
Data Collection 40
Attack Scenario Data Collection 40
Natural Disaster Data Collection 45
Conclusion 47
5. Assessing Alternative EMEDS Configurations 48
MPTk Patient Streams 48
Exporting the MPTk results to JMPT 50
Simulated Medical Network 51
Patient Outcomes 55
Baseline EMEDS+25 Patient Outcomes 56
Initial Comparisons 57
Comparison of Alterative EMED Systems 59
Confidence Intervals 60
Paired T-Test 61
Conclusion 61
6. EMEDS Improvements for Fixed Base Attacks 62
A Closer Look at an Individual Patient Stream 62
Comparing the EMEDS's Capacity to the AFTH's Capacity 64
The value of the First Additional Bed in Combat Casualty Scenarios 68
The value of the Second Additional Bed in Combat Casualty Scenarios 74

Increasing Capacity and Equipment 81
Triage Protocol 86
Design 88
Patient Outcomes from Adjusted Priority Strategy 90
Combing Adjusted Priority Strategy and Expanded Critical Care Ward Capacity 97
Design 97
Combined Effect of Different EMEDS Adjustments on Evacuations in Combat Casualty Scenarios 98
Combined Effect of Different EMEDS Adjustments on Returns-to-duty in Combat Casualty Scenarios 100
Combined Effect of Different EMEDS Adjustments on Mortality in Combat Casualty Scenarios 102
Conclusion 104
7. EMEDS Improvements for HA/DR Events 106
Scenarios 106
Design 107
Hurricane Findings 107
Patient Types 107
Mortality Risk Outcomes 107
The Value of an Additional Bed for Hurricane Scenarios 108
Patient Outcomes from an Adjusted Priority Strategy in Hurricane Scenarios 115
Hurricane Conclusions 120
Earthquake Findings 121
Patient Types 121
Mortality Risk Outcomes 121
Critical Care Ward Adjustments 122
Patient Outcomes from an Adjusted Priority Strategy in Earthquake Scenarios 126
Earthquake Conclusions 129
HA/DR Conclusions 129
8. Research Limitations and Additional Considerations 131
Research Limitations 131
MPTk Scenarios 131
JMPT Network 132
CONUS Effects 134
Resource Management 134
9. Conclusions and Recommendations 136
Improving the EMEDS system 136
Accurate Patient Estimates 136
Triage Protocol 137
Critical Care Ward 137
Uniform Triage Policies 138
Recommendations for JMPT 139
Definitions 140

Missing KIA Patients 140
EMEDS Buildup 142
Patient Mortality Control 142
Further Research 142
Additional MTFs 142
Alternative Patient Streams 142
Improved Self-Buddy Aid and First Responders Care 143
Chance of Treatment and Quarantined Care 143
10. Appendix 145
JMPT User-Defined Query 145
11. References 146

Figures

Figure 1.1 Research Question Flow 3
Figure 2.1 NATO Triage and Evacuation Categories 8
Figure 2.2 START Triage Flowchart 8
Figure 2.3. En Route Care Procedure during OEF and OIF 12
Figure 3.1 Chinese Missile Estimates 25
Figure 3.2 US air base vulnerability to Chinese Missiles, 1996-2017 26
Figure 3.3 North Korean Missile Launches 28
Figure 3.4 North Korean Missile Range 30
Figure 3.5 Iranian Missile Launches 32
Figure 4.1 Two Stage Simulation Modeling Process 34
Figure 4.2 Example JMPT Medical Network 39
Figure 4.3 Modeling Casualty Flow from Point of Injury to Aeromedical Evacuation 40
Figure 4.4 Isolated EMEDS+25 JMPT Medical Network 40
Figure 4.5 Representative Air Force Base ArcGIS Projection 41
Figure 4.6 EMEDS deployment timeline 46
Figure 5.1 EMEDS+25 Patient Flow and Maximum Casualty Load 53
Figures 5.2 and 5.3 Mean Baseline Patient Outcomes Across Patient Streams 56
Figure 5.4 Mean Evacuate Rate Across Patient Streams 58
Figure 5.5 Mean RTD Rate Across Patient Streams 59
Figure 6.1 Patient Outcome Rates for 1042 Trauma Patients Treated in an EMEDS+25 62
Figure 6.2 Patients Seeking Care in an EMEDS+25 Over Time 63
Figure 6.3 Patients within Functional Areas Over Time 63
Figure 6.4 Patient Seeking Care in an EMEDS+25 and AFTH Over Time During Thirty Day Scenario 65
Figures 6.5 and 6.6 EMEDS+25 and AFTH Average Cumulative Mortality Distributions in Combat Casualty Scenarios 66
Figure 6.7 Patient Evacuations and RTDs from an EMEDS+25 and AFTH in Combat Casualty Scenarios 68
Figure 6.8 Patient Stream a4 Evacuations from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios 70
Figure 6.9 Patient Stream a9 Evacuations from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios 71
Figure 6.10 Patient Streams a2, a13, and a9 RTDs from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios 73

Figure 6.11 Patient Streams a2, a13, and a9 Deaths from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios 74
Figure 6.12 Patient Streams a2 and a13 Evacuations from an EMEDS+25 with up to Two Additional Bed in Combat Casualty Scenarios 75
Figure 6.13 Patient Streams a4, a9, a12, and a17 Evacuations from an EMEDS+25 with up to Two Additional Bed in Combat Casualty Scenarios 76
Figure 6.14 Evacuations from an EMEDS+25 with Two Additional Critical Care Beds with and without Additional Equipment in Combat Casualty Scenarios 82
Figure 6.15 RTDs from an EMEDS+25 with Two Additional Critical Care Beds with and without Additional Equipment in Combat Casualty Scenarios 83
Figure 6.16 Mortality from an EMEDS+25 with Two Additional Critical Care Beds with and without Additional Equipment in Combat Casualty Scenarios 85
Figure 6.17 EMEDS+25 Patient Flow and Maximum Casualty Load 87
Figure 6.18 Evacuation Rate from a Baseline EMEDS+25 and an EMEDS using an Adjusted Priority Strategy in Combat Casualty Scenarios 92
Figure 6.19 RTD Rate from a Baseline EMEDS+25 and an EMEDS using an Adjusted Priority Strategy in Combat Casualty Scenarios 93
Figure 6.20 Mortality from a Baseline EMEDS+25 and an EMEDS using an Adjusted Priority Strategy in Combat Casualty Scenarios 95
Figures 6.21 and 6.22 EMEDS+25 and Adjusted Triage EMEDS+25 Average Cumulative Mortality Distributions in Combat Casualty Scenarios 96
Figure 6.23 Patient Streams a13 and a12 Evacuations from an EMEDS using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios 99
Figure 6.24 Evacuations Rates from an EMEDS with and without using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios 100
Figure 6.25 RTD Rates from an EMEDS with and without using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios 102
Figure 6.26 Mortality from an EMEDS with and without using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios 104
Figure 7.1 Patient Stream Mean Mortality Risk Distributions 107
Figure 7.2 Patient Streams h7, h10, h8, and h11 Evacuations from an EMEDS+25 with up to Two Additional Beds in Hurricane Scenarios 111
Figure 7.3 Patient Streams h7, h10, h8, and h11 RTDs from an EMEDS+25 with up to Two Additional Beds in Hurricane Scenarios 113
Figure 7.4 Patient Streams h7, h10, h8, and h11 Deaths from an EMEDS+25 with up to Two Additional Beds in Hurricane Scenarios 115

Figure 7.5 Patient Streams h7, h10, h8, and h11 Evacuations from an EMEDS using an Adjusted Priority Strategy with and without Two Added Critical Care Beds in Hurricane Scenarios 116
Figure 7.6 Patient Streams h7, h10, h8, and h11 RTDs from an EMEDS using an Adjusted Priority Strategy with and without Two Added Critical Care Beds in Hurricane Scenarios 117
Figure 7.7 Patient Streams h7, h10, h8, and h11 Deaths from an EMEDS using an Adjusted Priority Strategy with and without Two Added Critical Care Beds in Hurricane Scenarios 119
Figure 7.8 Patient Streams e8, e5, e11, and e2 Evacuations from an EMEDS+25 with up to Two Additional Critical Care Beds in Earthquake Scenarios 123
Figure 7.9 Patient Streams e8, e5, e11, and e2 RTDs from an EMEDS+25 with up to Two Additional Critical Care Beds in Earthquake Scenarios 124
Figure 7.10 Patient Streams e8, e5, e11, and e2 Deaths from an EMEDS+25 with up to Two Additional Critical Care Beds in Earthquake Scenarios 125

Tables

Table 3.1 Missile Range Classes 22
Table 3.2 Chinese Historic Defense Spending 24
Table 3.3 Russian Missile Estimates 27
Table 3.4 Russian Historic Defense Spending 27
Table 3.5 North Korean Missile Estimates 29
Table 3.6 North Korean Historic Defense Spending 29
Table 3.7 Iranian Missile Capabilities 30
Table 3.8 Iranian Historic Defense Spending 31
Table 4.1 Notional Sector Specific Geographic and Personnel Distribution Data 37
Table 4.2 Representative Adversary Missile Inventory 42
Table 4.3 Maximum Notional Adversary Payloads by Base and Distance 43
Table 4.4 Notional Bases Missile Attack Allocation 44
Table 5.1 MPTk Casualty Results for Attack Scenarios 48
Table 5.2 MPTk Casualty Results for HA/DR Scenarios 49
Table 5.3 EMEDS+25 Baseline Personnel: Quantity, Skill Level, and Assigned FA 52
Table 5.4 EMEDS+25 Baseline FA Holding and Treatment Capacity 53
Table 6.1 Baseline Functional Area Casualty Limits Across MTFs 64
Table 6.2 Mean Number of Patients After 30 replications 69
Table 6.3 Patient Stream a4 Mean Difference in Patient Evacuations with One Additional Bed 70
Table 6.4 Comparison of Adding a Critical Care Bed vs. the Baseline EMEDS on Evacuations from an EMEDS+25 in Combat Casualty Scenarios 72
Table 6.5 Comparison of Adding 1 vs. 2 Critical Care Beds on Evacuations from an EMEDS+25 in Combat Casualty Scenarios 77
Table 6.6 Comparison of Adding 1 Critical Care Bed and Adding 1 Critical Care Bed + 1 Emergency Room Bed on RTDs from an EMEDS+25 in Combat Casualty Scenarios 78
Table 6.7 Comparison of Adding 1 vs. 2 Critical Care Beds on RTDs from an EMEDS+25 in Combat Casualty Scenarios 79
Table 6.8 Comparison of Adding 1 vs. 2 Critical Care Beds on Mortality from an EMEDS+25 in Combat Casualty Scenarios 80
Table 6.9 Change in Patient Outcome Rates from an EMEDS+25 in Combat Casualty Scenarios when Beds are added to the Critical Care Ward 80
Table 6.10 JMPT Critical Equipment Utilization in an EMEDS+25 in Combat Casualty Scenarios 81

Table 6.11 95% Confidence Intervals for the Mean Difference in Patient RTDs in Combat Casualty Scenarios between a Baseline EMEDS+25 and an EMEDS with 2 Additional Critical Care Beds and 3 Additional Patient Vital Signs Monitors 84
Table 6.12 95% Confidence Intervals for the Mean Difference in Patient Mortality in Combat Casualty Scenarios between a Baseline EMEDS+25 and an EMEDS with 2 Additional Critical Care Beds and 3 Additional Patient Vital Signs Monitors 85
Table 6.13 Comparison of Patient Priority Strategy on Evacuations from an EMEDS+25 in Combat Casualty Scenarios 91
Table 6.14 Comparison of Patient Priority Strategy on RTDs in Combat Casualty Scenarios 92
Table 6.15 Comparison of Patient Priority Strategy on Mortality in Combat Casualty Scenarios 94
Table 6.16 Combined Effect of Different EMEDS Adjustments on Evacuations in Combat Casualty Scenarios 98
Table 6.17 Combined Effect of Different EMEDS Adjustments on RTDs in Combat Casualty Scenarios 101
Table 6.18 Combined Effect of Different EMEDS Adjustments on Mortality in Combat Casualty Scenarios 103
Table 6.19 Change in Weighted Average Patient Outcomes from an EMEDS+25 in Combat Casualty Scenarios 105
Table 7.1 Hurricane Patient Stream Parameters and Mean Number of Trauma Patients..... 108
Table 7.2 Comparison of Baseline vs. 1 Additional Beds on Hurricane Evacuations..... 109
Table 7.3 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Hurricane Evacuations 110
Table 7.4 Comparison of Baseline vs. 1 Additional Beds on Hurricane Returns-to-duty..... 111
Table 7.5 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Hurricane RTDs... 112
Table 7.6 Comparison of Baseline vs. 1 Additional Beds on Hurricane Mortality 113
Table 7.7 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Hurricane Mortality 114
Table 7.8 Combined Effect of Different EMEDS Adjustments on Evacuations in Hurricane Scenarios 117
Table 7.9 Combined Effect of Different EMEDS Adjustments on RTDs in Hurricane Scenarios 118
Table 7.10 Combined Effect of Different EMEDS Adjustments on Deaths in Hurricane Scenarios 119
Table 7.11 Change in Patient Outcome Rates When Different Adjustments are used for Hurricane Scenarios 120
Table 7.12 Earthquake Patient Stream Parameters and Mean Number of Trauma Patients..... 122
Table 7.13 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Earthquake Evacuations 123

Table 7.14 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Earthquake RTDs124
Table 7.15 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Earthquake Mortality 125
Table 7.16 Change in Patient Outcome Rates When Beds are added to the Critical Care Ward for Earthquake Scenarios 126
Table 7.17 Combined Effect of Different EMEDS Adjustments on Evacuations in Earthquake Scenarios 127
Table 7.18 Combined Effect of Different EMEDS Adjustments on RTDs in Earthquake Scenarios 127
Table 7.19 Combined Effect of Different EMEDS Adjustments on Deaths in Earthquake Scenarios 128
Table 7.20 Change in Patient Outcome Rates When Different Adjustments are used for Earthquake Scenarios 129
Table 9.1 Change in Weighted Average Patient Outcomes from an EMEDS+25 when 2 Beds are added to the Critical Care Ward across Combat, Hurricanes, and Earthquake Casualty Scenarios 138

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The author invites comments on the information presented in this report and welcome modification as well as additional ideas for consideration as part of our current research effort. Comments should be directed to John Hamm as follows:

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Rursus Incipiemus Nunc et Semper.

Abbreviations

AFB	Air Force base
AFMS	Air Force medical service
AFRICOM	Africa Command
AFSC	Air Force Specialty Code
AFTH	Air Force theater hospital
AFTTP	Air Force Tactics, Techniques, and Procedures
ATH	Air Transportable Hospital
BOS	Base operating support
CODE	Combat Operations in Denied Environments
CONOPS	Concepts of operations
CREstT	Casualty Rate Estimation Tool
DAFSC	Duty Air Force Specialty Code
DoD	Department of Defense
DOW	Died-of-wounds
EMEDS	Expeditionary Medical Support
EMRE	Expeditionary Medical Requirement Estimator
ER	Emergency room
ESP	Estimating Supplies Program
FIFO	First-in first-out
FOC	Full operational capability
HA/DR	Humanitarian assistance / disaster relief
IHS	International Health Specialist
HRT	Health response team
HUMRO-OCP	Humanitarian Relief Operation – Operational Capability Package
ICD-9	International Classification of Diseases 9th Edition
JMPT	Joint Medical Planning Tool

JP	Joint Publication
MASCAL	Mass-casualty
MFST	Mobile Field Surgical Team
MPTk	Medical Planners' Toolkit
NHRC	Naval Health Research Center
OB/GYN	Obstetrics/gynecology
OEF	Operation ENDURING FREEDOM
OFDA	Office of US Foreign Disaster Assistance
OIF	Operation IRAQI FREEDOM
OPCON	Operational control
OR	Operating Room
PACAF	Pacific Air Forces
PAF	Project Air Force
PAFSC	Primary Air Force Specialty Code
PAR	Population-at-risk
PCOF	Patient Condition Occurrence Frequency
ROMO	Range of Military Operations
RTD	Return-to-duty
SME	Subject matter expert
TAB-ROM	Theater Air Base Resiliency Optimization Model
TAB-VAM	Theater Air Base Vulnerability Assessment Model
USAF	United States Air Force
USAF/SG	United States Air Force Surgeon General
USAID	US Agency for International Development
UTC	Unit Type Code

1. Introduction

Policy Objective

The following research presents ways to improve the Air Force's use of its Expeditionary Medical Support (EMEDS) system to handle the flow of patients during mass-casualty (MASCAL) combat and disaster relief situations. The EMEDS system is a medical capability maintained by the Air Force for the purpose of providing rapidly deployable, scalable health care throughout the world.

This research quantifies the benefits of various adjustments to the EMEDS system in terms of their ability to improve patient outcomes, such as increasing return-to-duty (RTD), increasing evacuation rates, or reducing overall mortality. When deployed, EMEDS personnel have the responsibility of caring for injured and ill airmen and other patients. However, their ability to supply medical care to match the patient population's medical demands is limited by the resources they have access to, the design of the EMEDS system's facility, and the policies which govern their treatment of patients. These resources and policies may not be optimally suited to handle MASCAL scenarios that would arise from missile strikes against military operating locations in a variety of theaters or from natural disasters in remote parts of the world.

In this dissertation, I analyze what the potential streams of patients are for such scenarios, identify and explore viable improvements that can be made to the existing EMEDS system, and quantify what the benefits of those adjustments would be for each of the potential patient streams. The primary focus of this research is to improve the EMEDS in cases of MASCAL combat events with a secondary focus on humanitarian assistance and disaster relief (HA/DR) events.

What is an Expeditionary Medical Support System?

An EMEDS system is a modular Air Force medical response system. It is comprised of medical equipment and personnel which can be rapidly deployed to a variety of geographic operating locations. EMEDS are used to respond to medical needs from a variety of situations including wartime missions and humanitarian relief efforts. They are made up of individuals who can provide a variety of medical care ranging from dental to surgical care. The system is designed to provide primary and trauma care at forward operating locations, and to stabilize patients with more severe injuries in preparation for their transport to higher echelons of care within the military medical system (AFTTP 3-42.71.2.1). The system is not designed to provide long-term or extensive care, but rather to serve as a temporary stabilizing facility for patients. As such, the system is designed to handle a relatively small number of patients at a time with a rapid

throughput rate. An EMEDS serves as one link in the larger theater and world-wide chain of patient movement and patient management.

Research Questions

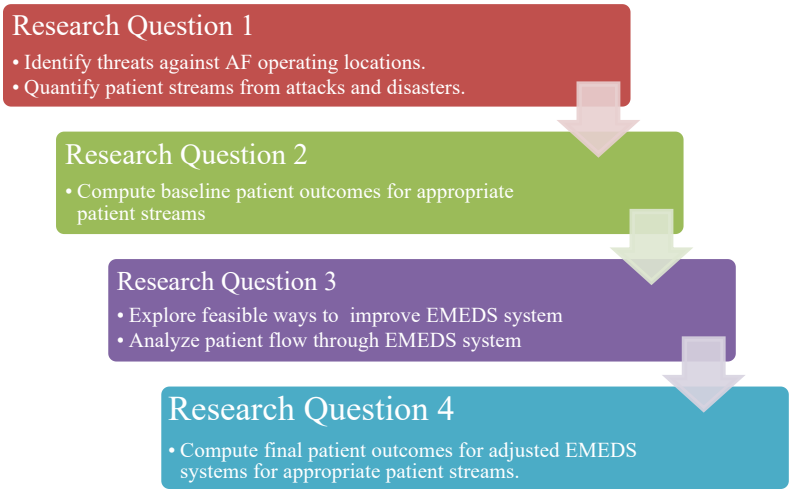
This research addresses the following questions.

1. What casualty streams can be expected as a result of conventional missile strikes against Air Force operating locations and natural disasters in locations with developing and emerging economies?
2. What are the patient outcomes for these streams based on the current EMEDS system?
3. What personnel, facilities, equipment or policies could be added to or changed within the existing EMEDS systems which may improve overall patient outcomes in MASCAL events?
4. What are the benefits to patient outcomes associated with these potential adjustments?

Addressing the first and second research questions was important in terms of validating the relevance of the subsequent questions and providing baseline data. In order to justify potentially complex, costly or controversial changes to the EMEDS system it was important to analyze whether or not the current EMEDS system can manage large-scale MASCAL patient loads. Answering the first question explored the potential patient streams and addressing the second established that the current medical system might not be capable of handling those streams.

Research questions one and two validated that changes may be necessary to address MASCAL combat or disaster relief scenarios. Therefore, it was important to explore what changes are feasible. The third question examines the levers the Air Force has at its disposal to amend the composition of the EMEDS. In the final research question, I explore whether or not changes to the EMEDS system could address gaps demonstrated by the second question and quantify the life-saving impacts corresponding to each adjustment. The flow of this research from one research question to the next is illustrated in figure 1.1.

Figure 1.1 Research Question Flow



Policy Relevance

The answer to the first research question depends on whether or not an adversary would use conventional strikes against an Air Force base and what size those attacks would be. Several nations, including North Korea, China, Russia, and Iran, maintain inventories of cruise and ballistic missiles which are capable of striking US operating locations (The Military Balance, 2017). A recent RAND analysis, Heginbotham et al., 2015, reported that China has expanded its conventional mission capabilities over the last two decades and that they can contest US operating locations within roughly a thousand miles of their territory. Many Chinese experts believe that there is a willingness in the Chinese government to target air bases with preemptive missile strikes as a logical initial war strategy prior to a declaration of war in order to control local airspace and prevent a US retaliation (Cliff et al., 2007). Additionally, as recently as November, 2017, another potential adversary, North Korea, tested long-range missiles which are capable of striking US bases (Star, 2017).

This research briefly analyzes the systematic growth of missile inventories by four potential adversaries to produce an unclassified estimate of the number of missiles within their respective inventories. That analysis showed that, in 2016, China, Iran, and Russia, for which there was data, invested 1.3%, 3.9%, and 3.7% of their GDP on defense spending respectively (The Military Balance, 2017). These nations have invested heavily in the development of cruise and ballistic missile inventories. While costly, this can be seen as less costly and challenging than maintaining a large conventional army. Between 1999 and 2017, these nations reduced the size of their active armed forces by 4.14% (Iran), 17.2% (Russia), and 22.6% (China) (The Military Balance, 2000; The Military Balance, 2017). With the ability to project power at a great distance from their national borders, their growing arsenals of ballistic and cruise missile capabilities pose a credible threat to US Air Force installations around the globe. Should the Air Force need to

rapidly support combat casualties at its forward operating locations, the EMEDS system is the most likely capability it would employ.

The EMEDS system is designed to provide individual bed-down medical support for deployed forces. The mission of the system is to provide forward stabilization, resuscitative care, primary care, dental services, and force health protection to patients. Furthermore, the system is intended to prepare patients for evacuation to higher levels of care. The system is designed to be modular so that teams of increasing sizes can be deployed to provide care to larger populations. However, according to policy, the most an EMEDS system can provide care for is a population of up to 6,500 individuals (AFTTP 3-42.71). Many bases, however, have populations which exceed 6,500 personnel. For instance, Kadena Air Base in Japan, within striking distance of both China and North Korea, has a base populace of over 8,000 (Kadena AB, 2017). Furthermore, the EMEDS is only designed to address the ongoing daily medial requirements of such a large population while temporarily addressing small emergency situations as they arise. It is not designed to provide advanced medical care to 6,500 critically wounded patients.

The realistic nature of the threat and the limited throughput and scale of the EMEDS system illustrate the policy relevance of an attempt to strengthen this medical asset. A MASCAL event could reasonably occur where the Air Force would depend on the medical capabilities of the EMEDS system. Therefore, the Air Force is strongly incentivized to ensure that it is as well-structured and as efficiently organized as possible.

Organization

This document presents the findings to each of the four aforementioned research questions. In the next chapter, I present background information on the EMEDS system and how it contributes to the larger Air Force Medical Service. In that chapter, I also provide a brief exploration into existing research and analytic tools on the subject of combat and medical modeling. Chapter 3 provides a more in-depth analysis of the potential threat facing US operating locations. Chapters 4 and 5 introduce the methodology and simulation designs used in this research. In this section, I also analyze the ability of the baseline EMEDS facility to address the patient streams produced by both cruise missile strikes and natural disaster scenarios. Chapters 6 and 7 present results quantifying the effects adjustments to EMEDS system will have on overall patient outcomes for attack and HA/DR scenarios respectively. Finally, the report ends with a presentation of limitations, additional considerations, and recommendations to stakeholders.

2. EMEDS Background and Existing Medical Tools and Research

This chapter introduces how the Air Force Medical Service (AFMS) classifies and manages patients, provides background as to how the EMEDS system has evolved and describes its current composition. It ends with a brief outline of existing research and analytic tools that have been used to address ways to improve the Air Force's ground medical assets.

Roles of Medical Care

The EMEDS consists of three, modular medical treatment facilities (MTFs): the EMEDS Health Response Team (EMEDS HRT), the EMEDS+10, and the EMEDS+25. These modular components build on one another to expand the capability of the MTF. They are designed to provide increasing amounts of rapidly deployable medical care. EMEDS+10 provides additional capacity and medical services on top on the EMEDS HRT. The "+10" indicates that the facility has ten total medical and surgical beds (AFTTP 3-42.71.2.5). Similarly, the EMEDS +25 also builds on top of the EMEDS HRT and EMEDS+10 and provides a total of 25 medical and surgical beds.

However, before delving too deeply into the EMEDS system's complexity or how EMEDS fits into the larger AFMS it is important to first understand how the Air Force classifies medical treatment facilities in general. Joint Publication 4-02 (JP 4-02) highlights four levels of medical care. These roles of medical care, Role 1 to Role 4, reflect the increasing amount of care that individuals can receive across different facilities. The process from a patient's point of injury through a series of medical networks and ultimately back to the United States is known as the continuum of care.

Role 1 Medical Care

Role 1 medical care consists of basic medical care provided by medical personnel during routine care or first-aid provided by nonmedical personnel during emergencies. There are two types of Role 1 care that should be noted.

Self-Aid and Buddy Care

Members of the Air Force are required to receive a basic level of first-aid training that can be used to treat themselves and their fellow airmen in the case of an injury. The amount of care that can be provided is minimum, particularly if resources such as bandages or medication are not available, but can be critical in stabilizing patients prior to the arrival of more advanced care or the ability to transfer the patient to a higher level of care (JP 4-02).

Combat Lifesaver

JP 4-02 states that a combat lifesaver, an individual who has received additional training beyond the minimum first-aid training, has an additional requirement of providing enhanced first-aid for injuries which individuals sustain prior to medical care arriving. This individual is not a member of the medical service and serves in a primary duty within his/her unit. Although such individuals have been given additional training, their ability to provide advanced medical care is still limited and therefore they are also categorized as providing Role 1 care (JP 4-02).

Role 2 Medical Care

Role 2 medical care expands on the care provided in Role 1. Both the aforementioned EMEDS HRT and EMEDS+10 are examples of Role 2 medical facilities. Role 2 facilities have capabilities such as the ability to resuscitate patients, transfuse red blood cells, or administer X-rays. However, Role 2 medical facilities are not intended to provide long-term sustained care to patients. The main purpose of a Role 2 facilities is to stabilize patients between Role 1 responders and Role 3 providers (JP 4-02).

Role 3 Medical Care

EMEDS+25

When the EMEDS system has been developed into its largest modular form, the EMEDS+25, it has become a Role 3 facility. Role 3 facilities are intended to provide care for all types of patients from resuscitation to surgery through post-operative care. However, the Role 3 facilities can also serve as a temporary holding facilities from which patients who are able are transported to higher levels of care, namely a Role 4 facility. All care can be provided to patients who are unable to make such a journey in a Role 3 facility such as an EMEDS+25 (JP 4-02). The EMEDS facility contains includes triage, flight medicine, emergency and operating rooms, and ICU and critical care functional areas.

Air Force Theater Hospital

The Air Force Theater Hospital (AFTH), the next largest medical capability beyond the EMEDS system, is also a Role 3 facility. They consist of a minimum of 58 beds. An AFTH was used at Joint Base Balad, Iraq from 2004 until 2011 as part of Operation IRAQI FREEDOM (AFTTP 3-42.71.1.2.3). The capabilities of the AFTH will be further addressed in the section on deployable medical assets.

Role 4 Medical Care

The largest and most capable military medical asset is a Role 4 facility. This type of facility mirrors the medical care available at largescale continental US (CONUS) base hospitals and established facilities outside of the US. These facilities provide definitive care to patients across

the entire spectrum of patient conditions. These facilities are often designed and located in a such a manner as to facilitate the arrival of patients from lower levels of care and thereby service a Population at Risk (PAR) beyond their immediate geographic area (JP 4-02).

Patient Prioritization and Movement

As mentioned, the AFMS maintains several types of MTFs which can provide progressing levels of care. However, within an individual MTF, decisions must be made in terms of how to prioritize and manage care. Unfortunately, scenarios can occur in which an individual facility is overwhelmed with patients. These events can occur as a result of enemy attacks or natural disasters such as earthquakes or hurricanes. When such events occur, patient prioritization is necessary for the constrained resources available. Example cases requiring patient prioritization will be explored in-depth in future chapters. However, first it is important to understand from a conceptual level how the AFMS would address these scenarios.

Patient Prioritization

In MASCAL scenarios, there can be more patients than a medical capability is immediately able to treat. Furthermore, even if there are enough medical providers to treat each patient, there may be a lack of the resources available to treat those patients. In such scenarios patients can be prioritized based on the types and severity of injuries they have, the likelihood they will survive, and the amount of resources, time, or effort it would take to treat them.

The military has traditionally adhered to the North American Treaty Organization's (NATO) triage protocol (Wiseman et al., 2002). This process is illustrated in figure 2.1 below. Figure 2.1 presents the *Delayed, Immediate, Minimal, Expectant* (DIME) NATO triage protocol. It is important to note that both *immediate* and e*xpectant* refer to patients who would require immediate medical attention in order to survive. However, due to the severity of their injuries or a lack of access to medical care it is anticipated that *expectant* individuals will not survive their injuries.

Figure 2.1 NATO Triage and Evacuation Categories

- Standard NATO nomenclature is recommended, often called "DIME"

– **Delayed** (yellow tag) – may be life-threatening, but intervention may be delayed for several hours with frequent reassessment – (fractures, tourniquet-controlled bleeding, head or maxillofacial injuries, burns)

– **Immediate** (red tag) – immediate attention required to prevent death – usually "AABC" issue – airway, arterial bleed, ventilation, circulatory

– **Minimal** (green tag) – ambulatory, minor injuries such as lacerations, minor burns or musculoskeletal injuries – can wait for definitive attention

– **Expectant** (black tag) – survival unlikely, such as extensive burns, severe head injuries

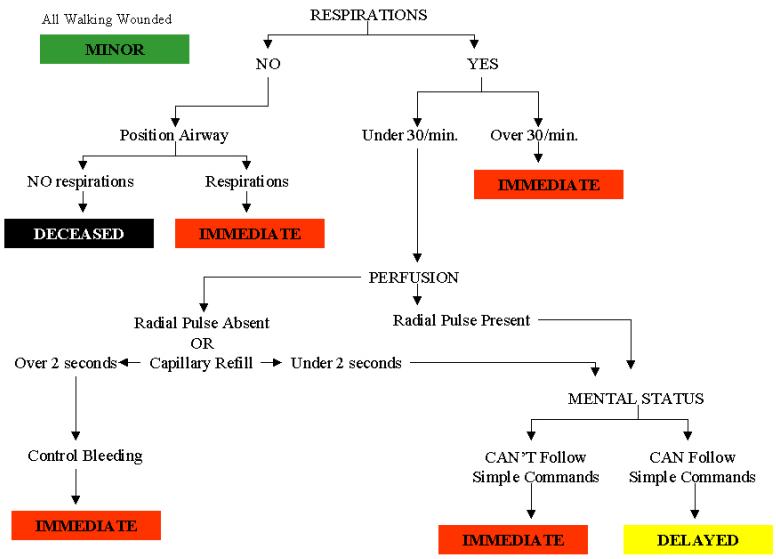
- Triage categories differ from Medical Evacuation categories :

– **Urgent** – save life or limb, evacuate within 2 hours
– **Urgent surgical** – same but must go to higher Level surgical capability
– **Priority** – evacuate within 4 hours, or may deteriorate into urgent
– **Routine** – evacuate within 24 hours to continue medical treatment
– **Convenience** – administrative movement

Source: Aydelotte et al. (2017), pp. 25

Many civilian institutions use a similar triage protocol known as START, which stands for Simple Triage and Rapid Treatment (Lerner et al., 2008). This process, illustrated in the flowchart below, is focused on progressively checking critical conditions to prioritize care for patients with the most exigent need for medical support. Unlike the DIME process, this flowchart is deliberately designed to give the triaging individual an easy to follow protocol on what to check for – and in what order – to discriminate between patient categories.

Figure 2.2 START Triage Flowchart



Source: Kouliev, Timur (2016) pp: 79

Note that both of these systems sort patients into four primary groups: deceased or expectant, immediate, delayed, and minor or minimal. Additional triage systems include the SALT (Sort, Assess, Life-saving interventions, treatment/transport)[1] and Homebush systems[2] use a similar categorization (Lerner et al., 2008).

Although the process of triage may appear straightforward in principle, it can be quite challenging during execution. A lack of experience, the number of patients, and the stress of the situation can make it very difficult to properly assign triage codes to individual patients. The process can take a long time and patients conditions can change while it is underway (Aydelotte et al., 2017).

Once the patients have been sorted, the general practice is to treat patients who are within the immediate category first prior to treating patients in the delayed category. Individual facilities, regional customs, and scenario challenges will dictate how to address the patients in the expedient category. One paper recommends a medical provider remain with them to ease their pain by either comforting them or providing pain medication while also having a chaplain or another professional present to help. An additional challenge presents itself in the form of where to put these patients and where to put those who ultimately expire (Aydelotte et al., 2017).

Patient Movement

This research did not look directly at patient movement, but it is important to consider how the military moves patients. Individual MTFs play a role in a larger theater evacuation process, especially in scenarios where simultaneous combat operations are ongoing or when a potential HA/DR scenario covers a geographically large area (JP 4-02). Furthermore, for the sake of this research it is important to consider the larger, theater-wide role of an EMEDS facility. The first two components of the EMEDS system are Role 2 facilities where patients can be stabilized and then moved elevated to the appropriate level of care. The JP 4-02 identifies four priority levels which govern patient movement:

1. Priority I – Urgent
   Priority Ia – Urgent-Surgical
2. Priority II – Priority
3. Priority III – Routine
4. Priority IV – Convenience

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[1] The SALT triage protocol consists of a more complex flowchart process in which individuals are sorted and assessed. The process uses voice commands to prioritize patients and focuses on instructing ambulatory patients to transition to the appropriate facility (not necessarily the nearest one) for their injuries. Unlike the START protocol, ambulatory patients are not inherently categorized as minor (Lerner et al., 2008).

[2] The Homebush method, designed in Australia, is built on the START protocol but adds an additional category for individuals who are dying but have not yet died. This category is similar to the *expectant* category in the DIME protocol. This is designed to identify a pool of individuals who may need or want non-medical assistance or comfort (Lerner et al., 2008).

The highest priority level, consisting of both Priority I and Ia, is comprised of patients who "should be evacuated as soon as possible … to save life, limb or eyesight and to prevent complications of serious illness and to avoid permanent disability" (JP 4-02 Appendix A.5.h.1, 2017). In particular, surgical patients require forward resuscitative care in order to save their life or a limb and will require stabilization for further evacuation.

The second priority level consists of patients who should be evacuated within four hours on a MEDEVAC asset or within twenty-four hours on an aeromedical evacuation asset to prevent the deterioration of their physical condition. These casualties may become urgent if they are not evacuated in time.

The last two patient priority levels consist of patients who do not require immediate medical attention. These patients can wait prior to being evacuated without their medical condition deteriorating to either priority or urgent. Routine patients must be evacuated within 24 hours on a MEDEVAC asset or 72 hours on an aeromedical evacuation asset. Convenience patients do not medically require an evacuation and are not put on aeromedical evacuation assets[3] (JP 4-02).

It is important to note that a patient's condition is a dynamic process that can change over time. The condition of patients in Priority II and Priority III can deteriorate to Priority Ia or Priority II respectively. For the MTF and evacuation assets this can mean that patients require more advanced medical teams to move individual patients and that fewer patients can be placed on individual transportation assets.

Historic EMEDS System

When Was the EMEDS System Designed?

In 1998, the 366th Medical Group at Mountain Home Air Force Base (AFB) developed a requirement-based medical package. The Medical Group developed the package in an effort to provide medical support to an operation in Iraq. This medical package laid the groundwork for what would become the modern EMEDS system. The Concept of Operations (CONOPS) for which was approved by the Air Force Surgeon General (USAF/SG) in 1999 (AFTTP 3-42.71.1.2).

When Are EMEDS Used?

Since 1999, the EMEDS system has been employed in a variety of combat scenarios including Operation ENDURING FREEDOM (OEF) and Operation IRAQI FREEDOM (OIF) as well as HA/DR settings.

[3] Convenience patients are typically transported on commercial aircraft. During a military conflict it is unlikely that these patients would be transported at all.

Combat Operations

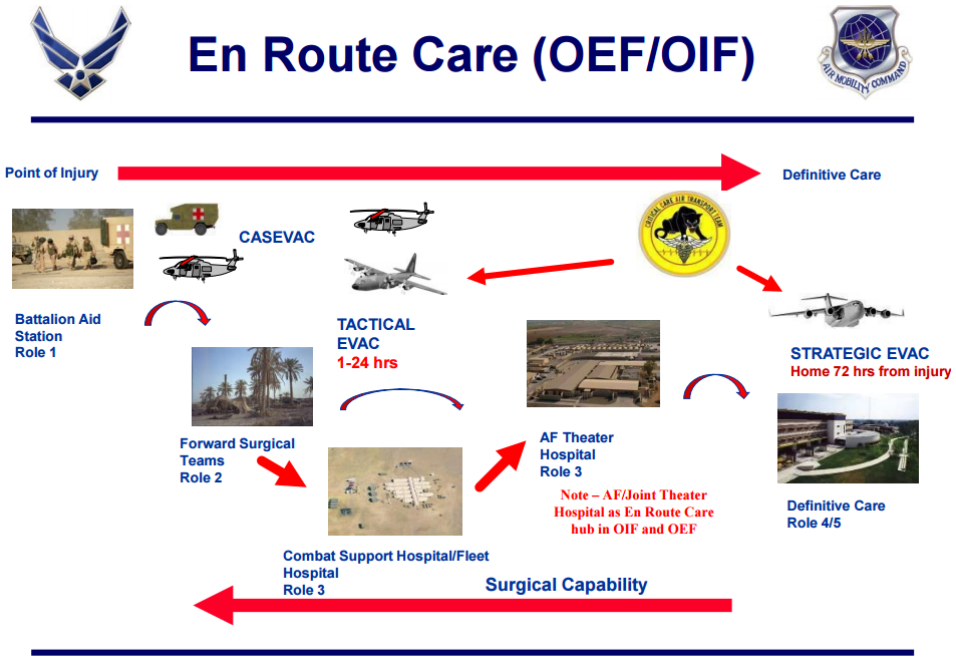
The Air Force Medical Service deployed an EMEDS configured medical capability to the Middle East in 2001 in support of OEF. A year later the capability was expanded to become an EMEDS+25. By 2003, there were five EMEDS and two aeromedical evacuation squadrons in the theater (AF/SG PA, 2003). The system incorporated improvements which had been made to medical capabilities since the Gulf War of the early 1990s. The configuration was two-thirds lighter and smaller than previous Air Transportable Hospitals (ATH). The Air Force continued to expand this capability during its time in Afghanistan, culminating with operational control (OPCON) of a 50-bed theater hospital at Bagram Airfield in 2007 (AFTTP 3-42.71.1.2.2).

While also supporting OEF, the AFMS deployed several EMEDS to provide medical capabilities in support of OIF. This support included assuming OPCON from the Army of a Role 3 trauma facility at Joint Base Balad north of Baghdad, Iraq in 2004. The trauma center was the largest surgical center in the theater and served as a hub for patient movement. The AFTH featured 20 critical care beds, 40 medical ward beds, and 8 operating tables and was in use until late 2011 (AFTTP 3-42.71.1.2.3).

A large challenge to providing medical care during OEF/OIF was the geographic distance and time it took to get a patient from the point of injury (POI) to the appropriate level of care. The continuum of care flows from POI through a variety of stages prior to arriving at an EMEDS or Theater Hospital. The initial stages include Self Aid and Buddy Care (SABC), First Responder care, and potentially treatment by a Forward Surgical Team. Once at the EMEDS, the objective is to stabilize patients so they can be evacuated to definitive care if needed. The following figure, figure 2.3, demonstrates how this process flowed during OEF/OIF.

The figure illustrates a basic premise of the AFMS's continuum of care process. In the figure, a minimum of medical care is available near the POI. As patients move along the continuum they receive access to increased amount of medical care at larger facilities. However, this process is predicated on the Air Force's ability to rapidly move patients through the network of MTFs. While the adversary in conflicts such as OEF and OIF did not significantly challenge the Air Force's ability to transport patients, a future conflict with a peer or near-peer adversary might not allow for such patient movement.

Figure 2.3. En Route Care Procedure during OEF and OIF



Source: HQ Air Mobility Command (2016)

This model deviates slightly from historic patient evacuation models as a result of several changes to the battlefield and war fighting dynamic. Battlefields are now more dynamic and fluid and medical care is able to follow the fight. However, because more medical care is available at the POI, more patients are surviving to the point where they require advanced surgical capabilities which are not available at lower levels of care. This and the fact that there is limited holding capacity within the theater increase the requirement for earlier evacuations. In order to address the challenge of distance and shrink the time it takes to provide operating room capabilities to patients, Air Mobility Command (AMC) has recommended the use of small pre-positioned or flyable surgical assets, depending on availability, to provide rapid access to a surgical Role 2 facility (HQ AMC, 2016). This is shown by the solid red line on the bottom of the figure. The closer surgical care can get to the POI, the higher probability of survival for patients requiring surgical care.

The above figure is predicated on two things. First, that there is a complete medical network of MTFs stretching from the POI to definitive care. Second, the process requires the ability to move patients throughout that medical network. The network focuses on the positioning and portability of forward medical assets. Access to forward care allows the majority of patients, those with minor injuries, to return to their missions while only the patients who require more comprehensive care move through the entire network. However, if the chain of medical networks is broken, transportation assets or transportation routes are unavailable, or forward assets are overwhelmed by patients the effectiveness of this system can be compromised.

Humanitarian Assistance and Disaster Relief

In 2006, a capability was approved by the Secretary of the Air Force in order to better provide medical responses to HA/DR scenarios. This capability was known as the Humanitarian Relief Operations – Operations Capability Package (HUMRO-OCP) and was designed to provide a stand-alone humanitarian medical package. The medical package included an EMEDS system and was designed to have diagnostic and surgical capabilities along with a 25-bed facility (Pacific Air Forces Public Affairs, 2007). This system was used in 2009 to assist relief efforts following an earthquake in Indonesia and in 2010 to respond to earthquakes in Haiti and Chile (AFTTP 3-42.71.1.2.4). After those experiences, the system was redesigned to better support a range of military objectives (ROMO) and to be more efficient. The Health Response Team (HRT) replaced what had been known as an EMEDS basic and provided additional, specialty care to include medical and dental care, obstetrics/gynecology (OB/GYN), and pediatrics. Furthermore, an international health specialist was added and tasks previously assigned to the second EMEDS level, including radiology and pharmacy, were also included into the basic HRT design (AFTTP 3-42.71.1.2.5). These changes, and changes that have occurred since EMEDS was first designed in 1999, demonstrate the evolutionary approach the Air Force has taken to improving its medical response capabilities.

Current Deployable Medical Assets

As was stated earlier, EMEDS is a modular system comprised of increasingly larger, more capable units known as the EMEDS HRT, EMEDS+10, and EMEDS+25. The Air Force also deploys a larger medical capability known as the AFTH.

EMEDS Health Response Team

The HRT is designed for patient populations of less than 3000 and is capable of stabilizing and holding up to four patients for 24 hours. During a combat operation, this Population At Risk (PAR) of 3000 is assumed to be the "military population, emergency essential civilians, and contractors, additive forces, and mobilization augmentees on base and excludes local nationals" (AFTTP 3-42.17).[4]

Within the HRT, three of the four patients who can be treated at one time may be in critical condition. The HRT is designed to be rapidly mobile and quick to set up. The Air Force Tactics, Techniques, and Procedures (AFTTP) document governing the HRT states that the HRT can deploy within 24 hours of notification. Furthermore, it states that the HRT can establish emergency room (ER) capabilities within two hours of being onsite, an operating room two

[4] The HRT is designed to treat the ongoing basic medical requirements and periodic emergency demands of a base of 3,000 personnel and does not mean that the HRT is meant to be utilized for a surge of up to 3,000 patients particularly if a large number of those patients are critically wounded.

hours after that, and critical care in just six hours after arrival. Thus, the HRT can be fully operational half a day after arriving. Because the HRT provides low level, Role 2 care (JP 4-02) it is aimed at stabilization and evacuation. Patients are intended to be stabilized and then transitioned to higher levels of care along the Air Force's continuum of care. An HRT does not come fully operational in terms of individual support. In fact, the HRT requires the support and services of additional Air Force units or military personnel. The unit arrives with personnel and equipment to provide medical care for the initial ten days but after that period it requires resupply. An HRT requires 40 personnel across 39 Unit Type Codes (UTC) (AFTTP 3-42.17).

EMEDS+10

The next medical capability within the EMEDS system is the EMEDS+10. This system must be added to an already existing EMEDS HRT. The new capability augments the existing HRT with the capacity of ten surgical beds. The EMEDS+10 is still a Role 2 facility (JP 4-02), but can now support a PAR of up to 5,000. The EMEDS+10 provides many additional services to the HRT including laboratory service, as well as additional bioenvironmental engineering, public health, administration, and medical logistics support. EMEDS+10 can reach full capacity within a day and a half of arrival and requires an additional 27 personnel (AFTTP 3-42.17.2.5).

EMEDS+25

The final increment of the EMEDS system is the EMEDS+25. This system is built on top of an existing EMEDS+10. This capability provides 25 total surgical beds and can service an increased PAR of up to 6,500. An EMEDS+25 upgrades the medical capability of the system to a Role 3 facility (JP 4-02). However, it takes much longer for a +25 to become fully operational. As compared to the HRT's 12 hour or the EMEDS+10's 36 hour set-up time, it takes an EMEDS+25 five days to be fully operational and requires 30 more personnel than an EMEDS+10, bringing the total manpower of an EMEDS+25 up to 97 (AFTTP 3-42.17.2.6).

58 Bed Air Force Theater Hospital

After the EMEDS+25, the next largest MTF within the Air Force is the 58-bed Theater Hospital. This asset is the largest deployable medical capability within the Air Force. Of its 58 beds, 46 are medical and surgical beds and the balance are critical care beds. The MTF is designed to be a Role 3 medical facility and is built on the EMEDS system. Air Force TTP 3-42.71 explains that these facilities are generally placed at air hubs in order to allow for patient movement back to the United States or other designated MTFs and are designed to service PARs of beyond the EMEDS+25 ceiling of 6,500. The number of personnel required to service this MTF, 261, is nearly three times as many as the 97 which are required for the EMEDS+25 to function (AFTTP 3-42.17.2.7).

Existing Analytic Tools

Extensive work has been done to model combat and humanitarian casualties over the last decade. In 2010, the Naval Health Research Center (NHRC) developed the Patient Condition Occurrence Frequency (PCOF) tool which was accredited by the DoD two years later. By 2013, the NHRC had added Expeditionary Medical Requirements Estimator (EMRE) and Casualty Rate Estimation Tool (CREstT) to PCOF to create the Medical Planner's Toolkit (MPTk) suite of tools. The package also consists of Estimating Supplies Program (ESP) which is used to calculate the amount of medical supplies a scenario and its corresponding patient load will require. In 2014, the entire suite joined the existing Joint Medical Planner's Tool (JMPT), developed by NHRC and Teledyne Brown Engineering, Inc., and was accredited by the DoD (MPT Course, 2017).

Medical Planner's Toolkit (MPTk)

MPTk includes four independent tools used by the joint medical planning community. The tools can be used in conjunction with one another during a process known as deliberate planning, a stage of planning which occurs prior to an emergency scenario in order to develop processes and procedures which will be utilized during an emergency, to provide an end-to-end solution for anticipated medical support requirements for a wide ROMO. These tools allow users to specify types of terrain attacks, population sizes, and distributions of injury rates to stochastically simulate combat engagements or HA/DR efforts. The accuracy of these estimates is critical in ensuring the proper resources and personnel are available in order to properly respond to potential scenarios. The tools used to accomplish this aim are:

1. Patient Condition Occurrence Frequency (PCOF) Tool
   - The outputs of the PCOF tool are baseline probability distributions for illness and injuries in the form of International Classification of Diseases 9th Edition (ICD-9) codes. These data are drawn from historical, empirical data of US military engagements dating back to the Korean War (MPTk Quick Start, 2016).
   - The tool consists of baseline PCOFs built and maintained by the NHRC which can be adjusted by users as well as unstructured PCOFs which may not be edited. Baseline PCOFs can be stored, edited, and manipulated to better serve future operations. The tool processes adjustments made by the user to create accurate expected probability distributions for patient ICD-9s, including combat patients and injuries and illnesses from HA/DR missions (MPTk Quick Start, 2016).
2. Casualty Rate Estimation Tool (CREstT)
   - In CREstT, planners are able to take an operational plan, consisting of personnel movement and combat engagements, and adjust on-going injury and illness rates throughout the operation. CREstT can be used to calculate results of a variety of engagements, including consistent force-on-force engagements or sudden missile strikes (MPTk Quick Start, 2016).

- The tool reads the distributions from PCOF and combines them with population changes and combat engagements to stochastically estimate overall patient streams.
- Outputs from CREstT have been used in a number of research projects, including a RAND Corporation study on injury distributions in Africa (Mouton et al., 2016).

3. Expeditionary Medical Requirement Estimator (EMRE)
   - EMRE uses CREstT estimates to predict the requirements for operating rooms (OR), ward space, evacuation, and blood usage (MPTk Quick Start, 2016).
   - It also uses stochastic processes to allow users to evaluate risk (MPTk Quick Start, 2016). The risk factors are related to the user's confidence in the results, in other words selecting a high risk result produces less conservative and lower outputs which have a higher risk of being incorrect (MPTk Quick Start, 2016).
   - EMRE has been used by the Air Force to generate planning factors and readiness requirements (Carson, 2015).
4. Estimating Supplies Program (ESP)
   - ESP uses CREstT estimates to generate time-phased estimates of consumable medical supplies. It outputs requirements in terms of cost, weight, and volume (MPTk Quick Start, 2016).

This suite of tools can be used to model MASCAL scenarios by designing a base scenario in PCOF with specified population sizes and then using CREstT to produce casualty streams from fixed-base missile strikes or HA/DR events. This produces stochastic patient streams which can be exported to and further analyzed within JMPT (MPT Course, 2017).

Joint Medical Planning Tool (JMPT)

JMPT is an object-based, discrete-event simulation tool developed by NHRC and Teledyne Brown Engineering, Inc. to model casualty outcomes. The tool allows the user to analyze the flow of patients from the time they are injured through a medical support system. Like MPTk, the data for the tool comes from empirical data from more than 400 patient conditions and their respective medical demands in terms of required tasks, equipment, and time to treat (AFTTP 4-02.7, 2016). The model allows for a variety of planning and logistic strategies to be implemented in an effort to improve operational missions. Users can examine the medical outcomes for patient streams entering various military treatment facilities and evacuation routes. Users are able to explore changes in treatment times, return to duty rates, and other metrics by customizing treatment facility parameters, such as caregiver access and available facility types (MPT Course, 2017). JMPT has been used by the United States Navy to estimate readiness requirements and simulate casualty movements (Carson, 2015) and by the RAND Corporation to measure mortality curves of patients injured on the African Continent (Mouton et al., 2016). A more detailed explanation of the features of JMPT, specifically those which are relevant to this research, is provided below in the section which covers the research's analytic design.

Theater Air Base Models

As part of its Project Air Force, the RAND Corporation has designed a number of modeling capabilities to analyze Combat Operations in Denied Environments (CODE). Two of these tools are:

1. Theater Air Base Vulnerability Assessment Model (TAB-VAM)
   - TAB-VAM is a Monte Carlo simulation model developed at the RAND Corporation to analyze trade-offs among base strategies and options to reduce the risk of threats. Aircraft beddowns, base recovery capabilities, infrastructure investments, forms of missile defense, and concepts of operations (CONOPS) can all be modeled by the user in TAB-VAM. To execute the model, a user specifies the air bases they wish to analyze, assigns resources to each base, and specific enemy attack strategy. The model uses this information to simulate attacks by an opposing force. The primary application of the model is to determine the ability of US bases to maintain various rates of sortie generation. TAB-VAM is important because it can be used to identify the operational benefits of different levels of investments in base capabilities (Thomas et al., 2015).
2. Theater Air Base Resiliency Optimization Model (TAB-ROM)
   - TAB-ROM is a multi-objective genetic algorithm that enables users to improve patient outcomes through and exploration of investments in mitigation technologies. With TAB-ROM, the user can assess the value of system enhancements, such as augmented treatment facilities, while constraining investments to specified budget levels. Furthermore, TAB-ROM allows the user to map the cost-optimal Pareto surface against various metrics, such as maximized return to duty rates and minimized incidence of patients who die of their wounds (Thomas et al., 2015).

While TAB-VAM does account for casualties incurred due to adversary action and the force reconstitution function of available medical resources, it does not capture the fine-grained detail that can be more explicitly modeled within JMPT. Likewise, TAB-ROM focuses on the preventative measures that can be made to make an operational base more resilient prior to a strike. For those reasons, neither of these tools were used in this research. However, it is important to note that they have been developed and are distinct from both MPTk and JMPT.

Existing Literature

Expeditionary Medical Support (EMEDS) and Air Force Theater Hospital (ATFH)

AFTTP 3-42, updated in August of 2014, is the primary source document for medical combat support capabilities, both the EMEDS system and the 58-bed AFTH. It outlines the basic structure for the EMEDS system and provides guidance on how the system should be used and implemented. The AFTTP focuses on the fact that the EMEDS system is a modular and scalable system which gives the Air Force the ability to quickly deploy a wide range of medical

capabilities. The document says that both the EMEDS and AFTHs have the primary mission of providing "forward stabilization, resuscitative care, primary care, dental services, and force health protection and prepare casualties for evacuation to the next level of care" (AFTTP 3-42.71.2.1).

The AFTTP also governs how field surgical care should be administered and the capabilities for addressing critical patients. For instance, an HRT is equipped with a Mobile Field Surgical Team (MFST) which can provide trauma surgery, life support, and emergency care for up to 10 casualties requiring surgery or 20 not requiring surgery (AFTTP 3-42.71.2.4.3.6). When the EMEDS system is fully expanded to a +25, the medical capability for patients requiring surgeries doubles to 20 (AFTTP 3-42.71.2.12.14). This represents a potential upper-limit on surgical medical capabilities from the EMEDS system which could result in severely unmet medical demands in the case of a mass-casualty event.

The AFTTP references mass-casualty protocols only twice. The first reference involves the handling of classified information and command and control (C2) (AFTTP 3-42.71.2.12.3). The second has to do with site location and the importance of setting aside areas for mass-casualty triage (AFTTP 3-42.71.3.4.1.2). The document lacks any clear guidance on how, in cases where it is necessary, the EMEDS system should be augmented to address particular patient streams, specifically those having to do with mass-casualty, trauma patients. However, the document does claim that, during HA/DR operations, the "EMEDS HRT can triage and treat 350 patients per day with a surge capacity of 500" (AFTTP 3-42.71.2.4.2). In later chapters, this research will analyze whether or not this level of patient throughput can be achieved by the EMEDS.

How Should Air Force Expeditionary Medical Capabilities Be Expressed?

A report by the RAND Corporation (Snyder, 2009) focused on two shortcomings of the EMEDS system. The first was that the EMEDS system is designed around patient movement but uses terminology which is consistent with a framework which focuses on definitive care. The report believes that this was an area that could be improved upon because using the definitive care unit of measurement of "beds" did not accurately present the capabilities of the EMEDS system. Rather than measuring the effectiveness of an EMEDS capability by just the number of beds, the report suggested using a calculated medical STEP rate which gets its name from its ability to stabilize, triage and treat, and evacuate patients. It proposed that these rates could be calculated using estimated UTCs prior to a deployment. The second shortcoming of the EMEDS system was that it was designed to treat combat injuries but was often used to treat patients from HA/DR missions. Of particular note in these scenarios is the difference in trauma patients. The report notes that injuries to combat patients are often predominantly trauma related, but that HA/DR patients require a wide range of services. HA/DR patients are a much more diverse group of patients than US military personnel (Snyder, 2009).

Timelines for Reaching Injured Personnel in Africa

In 2016, Mouton and his team addressed a gap in research on the effectiveness of potential changes to how rescues are attempted. This research investigated the relationship between time and the potential to rescue an injured patient in the US Africa Command area of responsibility (Mouton et al., 2016). Executing operations on the African continent is challenging because of its very wide area. Therefore, this research focuses on the impact of time between the injury and initial rescue. The research uses data compiled from both MPTk and JMPT in order to produce tailored patient rescuability curves which are comprised of JMPT mortality curves and MPTk mortality risk levels. The baseline results demonstrate 7 to 16 percent increase in survivability for a marginal increase in response speed, the time from injury to the first arrival of rescue forces, of two to four hours as compared to a standard six-hour response time. They also report a 3 to 7 percent increase in rescuability compared to a twelve-hour response time when response rates are improved by two to four hours. This research demonstrated the importance of having pre-positioned medical assets capable of providing medical care quickly after an injury (Mouton et al., 2016).

A Chance in Hell: Evaluating the Efficacy of US Military Health Systems in Foreign Disaster Relief

This document describes a framework for assessing how well the US military was able to respond to foreign disasters in terms of medical support (Lutz, 2013). Lutz provides a historic summary of times the EMEDS system has been employed. It references the Air Force's attempt at providing medical care following the Indian Ocean tsunami of 2004 during Operation Unified Assistance. The report mentions that, "confusion and inexperience among joint planners regarding the asset's capability, transportation, and support requirements delayed the deployment of the EMEDS until its presence was no longer relevant." Ultimately, the analysis concludes that the US military must improve how it provides health services following international disaster response efforts to more effectively safe lives.

This report did not properly address the challenges facing the deployment of an EMEDS system. Before an EMEDS can be deployed to respond to an HA/DR event, the US State Department must first take charge as the lead federal agency responding to an event. The Department of State working with the US Agency for International Development's (USAID) Office of Foreign Disaster Assistance (OFDA) must first turns to the host nation, the United Nations, non-governmental organization prior to requesting assistance from the Department of Defense. Only after pursuing those avenues, may OFDA submit a formal request for military assistance to the Department of State and Department of Defense (Perry and Travayiakas, 2008). Any delays in the deployment of an EMEDS cannot be attributed to the EMEDS system itself until after this process has occurred and the EMEDS has been officially told to deploy.

Conclusion

This chapter has provided a background into different AFMS medical capabilities and procedures and several pieces of literature on the subject of combat and disaster relief casualty research. However, this research has not looked at how the EMEDS would be employed in the case of missile strikes or different disaster scenarios. The following chapter provided additional background on the topic of missiles in an effort to illustrate the potential threat US bases are subjected to due to their proximity to potential adversaries. Chapter 2 along with the following chapter are meant to provide the audience with the necessary background to understand the importance of the EMEDS system and its ability to process patients during MASCAL events.

3. Threat Environment

US air bases around the globe are within striking distance of missiles operated by potential adversaries. In later chapters, this research shows approximately how many individuals would be injured and killed from possible missile strikes. After estimating the number of casualties produced from attacks, this research focuses on how to best treat those casualties. This chapter, however, sets the stage for that analysis by providing a brief summary of adversary missile arsenals to document and quantify the threat that exists to US air bases. Global trends show an increasing focus on strengthening national missile inventories. Such inventories could be used to target US air bases and generate hundreds or even thousands of casualties.

Missile Strike Attack Strategies and Requirements

To understand the dangers associated with adversary missile inventories it is important to understand how those missiles might be utilized in a targeted attack against the United States. "The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996-2017", explains in depth a possible targeting strategy for a US adversary, in this case, China. The research presents a targeting strategy China could use as part of a "counter-air strike campaign" in order to limit retaliatory combat sorties by the United States.

The research believes that the People's Liberation Army Air Force would use accurate ballistic and cruise missiles to target critical aspects of US air base operations. This would mean targeting assets such as runways, aircraft, fuel, and logistics facilities (Heginbotham et al., 2015). These assets would be targeted during the first stages of war in order to reduce the US's ability to respond offensively or secure defensive air superiority. In addition to this research, RAND has done further research to design a modeling framework which highlights the tradeoffs between different attack strategies against key US assets (Thomas et al. 2015). Likewise, additional research has been devoted to how the Air Force and military should prepare to operate within an environment where an adversary has targeted critical assets and have reduced US air superiority and mobility within a region (Hagen et al. 2016). Both research studies illustrate the seriousness of this threat and the need for the US to prepare for an operating environment where bases are targeted by adversary missile strikes.

Heginbotham's U.S.-China military scorecard provides specific estimates of what missiles would be needed to disable two US operating locations in the Pacific Theater. The report estimates that the Chinese military would require 108 missiles in order to close Kadena Air Base's ability to fly fighter sorties for up to 16 days and an inventory of 50 missiles to close

Andersen Air Force Base's runways from use by large aircraft for more than 8 days.[5] Due to its configuration, either of the two 10,000 feet runways at Andersen AFB becomes prohibitively disabled to large aircraft if an individual section is damaged. Kadena AB, on the other hand, has two larger runways which would each need to be damaged in two separate locations to prevent aircraft from being able to takeoff.

Heginbotham's research also included the distances from air bases in the Pacific Theatre to Chinese territory. The distances range from less than 400 kilometers, Kunsan and Osan Air Bases in South Korea, to almost 3,000 kilometers for Andersen AFB on the island of Guam. These are the distances missiles would have to travel to strike Air Force operating locations in the Pacific. The US has operating locations and potential adversaries spread around the globe. To understand the potential ramifications for casualty estimates and to assess the capabilities of the Air Force to posture medical care for combat situations, it is important to understand the credibility of the threat facing these operating locations.

Missile Class Nomenclature

It is important to distinguish between the types of missiles arrayed against US assets. Cruise and ballistic missiles differ in guidance and range. There are additional ways to classify missiles but, for the purposes of this analysis, guidance and range will be the two characteristics of interest.

Cruise missile can be designed with precise aerodynamic guidance technologies which adjust flight to ensure the missile hits the desired target (US-USSR, 1987). Ballistic missiles generally fly different flight paths, sometimes through space, and do not require as sophisticated controls. They are launched at predetermined angles and fly at specific altitudes so that gravity and air resistance will bring them to their designed target.

As for range, missiles vary drastically in the range they are capable of flying. Furthermore, a particular missile class can carry different payloads which impact how far an individual missile can fly. However, in general, ballistic missiles are categorized by the ranges which are presented in Table 3.1.

Table 3.1 Missile Range Classes

Class	Range (km)
Short-Range Ballistic Missiles (SRBMs)	500 to 1000 km
Medium-Range Ballistic Missiles (MRBMs)	1000 to 3000 km
Intermediate-Range Ballistic Missiles (IRBMs)	3000 to 5000 km
Intercontinental Ballistic Missiles (ICBMs)	5000 km and above

SOURCE: US-USSR Treaty (1987)

[5] The number of missiles required to disable an air base is calculated by measuring a missile's ability damage a runway severely enough to require at least eight hours to repair. Included in this calculation is a missile's malfunction rate, the probability that it is accurate, and the likelihood that it is shot down. These data are combined with the geometry of the individual base runways and the area required for aircraft to takeoff.

Current State of Affairs

Long-range ballistic missiles have regained a great deal of media attention since the beginning of 2017. This was in large part because of North Korea's test launches. Included in these tests was the launching of a missile which reportedly is able to strike US cities as far away as Los Angeles, Chicago, and Denver. The United States responded to this missile test by testing a missile of its own on August 2 (Sullivan, 2017).

Later in August of 2017, the North Korean government continued to threaten to strike the US island of Guam, home of Andersen Air Base, which is approximately 3000 km away from North Korea. In fact, North Korean leader Kim Jong Un was presented with detailed plans to fire four missiles aimed at the island. Meanwhile, United States President Donald Trump threatened North Korea with "fire and fury like the world has never seen" if they were to attack the United States. In the meantime, the US Air Force continued to fly operational, conventional B-1B bombers from Andersen Air Force Base towards the Korean Peninsula (Baker and Hun, 2017).

In addition to North Korean activity, Iran successfully launched a Simorgh missile which carried a satellite into space in July. This indicates a significant advance in Iranian missile capabilities (Erdbrink 2017).

In late 2016, the Russian government was identified as having moved the Iskander missile systems into the Kaliningrad region which neighbors Lithuania and Poland and provides Russia with closer, direct access to potential targets throughout Europe (Brumfiel 2017).

These events highlight the tensions which exist in the world and the potential for radical threat escalation. The US has a strategic interest in understanding the missile capabilities of key global players along with understanding the medical impact of potential strikes. The current state of international affairs is that there are credible threats of attack from numerous potential adversaries and that several of them continue to strengthen their missile arsenals.

Adversary Introduction

This research will focus on four potential adversaries who maintain intercontinental ballistic and cruise missile capabilities. Those nations include China, Russia, North Korea, and Iran.

China and North Korea pose a unique threat due to their strategic location in the Pacific. The US operates eight permanent military facilities in the Pacific theater and each is within potential striking distance from either Chinese or North Korean attack (Heginbotham et al., 2015).

The threat against operating locations from Russia is of different nature. Due to its proximity to the European continent, Russia has the capability of threatening US allies and bases in England, Germany and across the European continent. Furthermore, Russia may be able to target US bases in the Pacific and the Middle East.

The nation of Iran is strategically located in the Middle East and it maintains a mature ballistic missile program. Iran has the capability of striking Air Force bases in the United Arab Emirates, Qatar, Kuwait, and throughout the region. Furthermore, Iran may use its missile

inventory to strike the US-allied state of Israel. Iran launched strikes into the Syrian region during 2017 (Moshtaghian, 2017).

Country Profile: China

The People's Republic of China could pose a serious threat to the United States and its operating locations in the Pacific. Since 1996, China has drastically increased the size and capabilities of its military, including the expansion of its missile program in terms of the range of missiles and the number of missiles within its arsenal. Table 3.2 shows that China now spends more than three times as much money on defense than it did in 1985 and twice as much as it did in 1999. China has shrunk its military in terms of personnel. The US-China Scorecard's assessment is that the Chinese military has become a much more professional and capable armed forces since 1996 even though it reduced its numbers. Furthermore, a separate piece of research, "A Low-Visibility Force Multiplier: Assessing China's Cruise Missile Ambitions", asserts that since the 1990s the Chinese military has focused on reducing unnecessary personnel and has offset this with heavier investments in their missile capabilities (Gromley et al., 2014).

Table 3.2 Chinese Historic Defense Spending

China	Defense Expenditure (2014 US $ millions)			Number in Armed Forces (000)			Estimated Reservists (000)		Para-military (000)	
	1985	1999	2014	1985	1999	2017	1999	2017	1999	2017
	41,823	57,718	131,140	3,990	2,820	2,183	1,200	510	1,000	660

Source: The Military Balance (2000) and (2017)

The US-China Scorecard concluded that as recently as 2003, China did not have a sufficient number of conventional missiles to threaten Kadena AB or Andersen AFB, two strategically significant bases for the US within the Pacific. However, since 2003 the Chinese have drastically increased their capabilities. In 2016, the US Department of Defense estimated that China has at least 1200 SRBMs and MRBMs (OSD 2017). China can strike US Air Bases within a 1500 km range of China with short and medium-range missiles. Furthermore, their long-range capabilities include the DF-31A, which is a road-mobile, solid-fuel missile which can even strike the continental United States (Heginbotham et al., 2015).

The US-China military scorecard provided the following table, figure 3.1, which includes the types of missiles China possesses as well as their range and inventory size (Heginbotham et al., 2015).

Figure 3.1 Chinese Missile Estimates

Missile Type	Range (km)	Warhead (kg)	CEP (m)	Number in Inventory			
				1996	2003	2010	2017
SRBMs							
DF-11	280–350	500–800	500–600	Small number	175	700–750	~1,200
DF-11A	350	500	20–30				
DF-15	600	500	300	Small number	160	350–400	
DF-15A	600	600	30				
DF-15B	600–800	600	5				
MRBMs							
DF-21C	2,500	500	50	0	0	36–72	108–274
DF-16[a]	800–1,000	?	?	0	0	0	
IRBMs							
IRBM	5,000	500	30–300	0	0	0	Possible
Cruise missiles							
DH-10	1,500–2,000	400	5–20	0	0	200–500	450–1,250
ALCM	3,300	400	5–20	0	0	In inventory	

SOURCES: *Jane's Strategic Weapons Systems* data; IISS, *The Military Balance*, 1996, 2003, 2010 and 2015; and Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China*, Washington, D.C., 2010 and 2014.

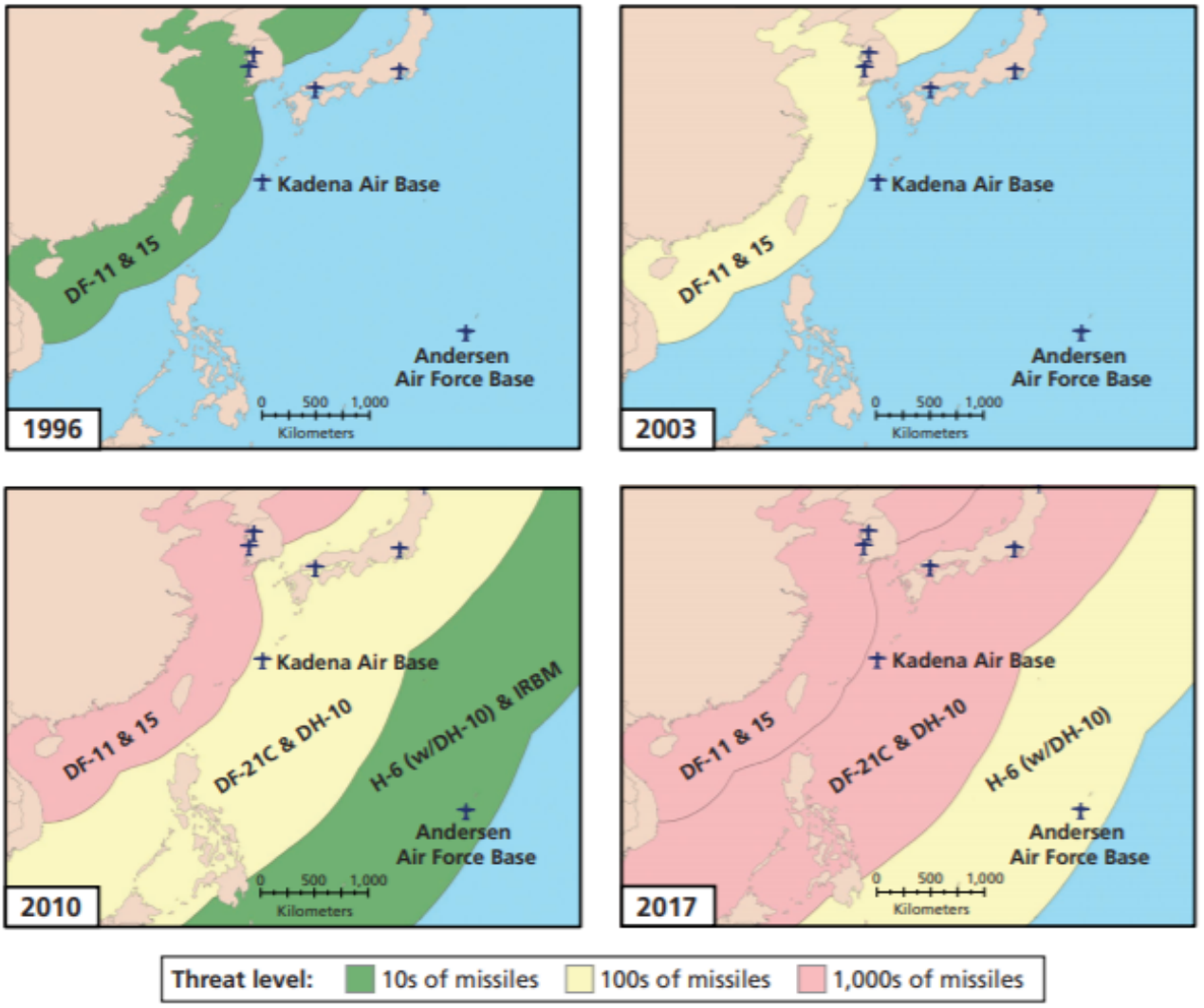
[a] Although the DF-16's range technically makes it an SRBM and it is classified as in some publications, the DF-16 straddles the boundary between SRBM and MRBM. We list it as an MRBM, both because of its ability to hit targets beyond Taiwan (e.g., Okinawa) and because of its two-stage construction. IISS, *The Military Balance*, 2015, lists the system as an MRBM.

Source: Heginbotham et al., (2015): pp. 48

Currently, it is estimated that Kadena AB is within the range of more than a thousand DH-10's and other cruise missiles. Andersen AFB, which is further away from mainland China, is under threat of air-launched cruise missiles (ALCMs) and Chinese IRBMs (Heginbotham et al., 2015).

The following figure, figure 3.2, illustrates this concept. The figure contains four snapshots of US air base vulnerability to Chinese missile strikes during 1996, 2003, 2010, and 2017. Not only is it clear that a growing number of bases have been subjected to the risk of a missile strike, but also that even the furthest base, Andersen Air Force Base, which is several thousand kilometers from the Chinese mainland, could now be targeted with hundreds of missiles. Meanwhile, two bases on the Korean peninsula, two on the Japanese mainland, and another on the Japanese island of Okinawa could be targeted with thousands of short and medium range missiles (Heginbotham et al., 2015).

Figure 3.2 US air base vulnerability to Chinese Missiles, 1996-2017



Source: Heginbotham et al., (2015): pp. 51

Country Profile: Russia

Russia represents another nation that could threaten the United States with its ballistic and cruise missile inventory. In the last two decades, Russia has significantly modernized its inventory and introduced heavier and more advanced precision guided missiles (Missiles of Russia).

Russia maintains a road-mobile short-range ballistic missile which is capable of carrying an explosive device or nuclear warhead. In 2011, the Russian Defense Minister announced that Russia was going to procure 120 missiles of a heavier and more advanced system over the course of ten years (Jane's Country Profile 2018).

Russia does not maintain any medium-range ballistic missiles. However, in 2015 they tested a missile which the United States believes is capable of traveling between 500 and 5500 km.

Furthermore, Russia maintains a number of ICBMs which can used to deliver nuclear weapons. In 2010, Russia deployed a new mobile ICBM which was followed by the development of a silo-based ICBM of the same name in 2014. It is also believed that Russia performed a rail-mobile test of a missile in 2016 even though it had previously announced that the development of that capability had been stopped (Jane's Country Profile 2018).

Table 3.3 Russian Missile Estimates

Missile	Class	Range	Status
Kinzhal	ALBM	1,500-2,000 km	Operational
Kh-101 / Kh-102	ALCM	2,500-2,800 km	Operational
SS-X-31 (RS-26 Rubezh)	ICBM/IRBM	2,000-5,800 km	In development
SS-20 "Saber"	IRBM	5,000 km	Obsolete
SS-X-30 "Satan II" (RS-28 Sarmat)	ICBM	10,000+ km	In Development
SS-N-6 (R-27) "Serb"	SLBM	2,400-3,200 km	Obsolete
SS-N-27 "Sizzler"	ASCM	220-300 km	Operational
SS-N-26 "Strobile"	ASCM	300 km	Operational
SS-26 "Iskander"	SRBM	500 km	Operational
SS-21 "Tochka"	SRBM	70-120 km	Operational
SS-1 "Scud"	SRBM	190-550 km	Obsolete
SS-N-30A "Kalibr"	LACM	1,500-2,500 km	Operational
SS-18 "Satan"	ICBM	10,200-16,000 km	Operational
SS-N-21 "Sampson" (RK-55)	Cruise Missile	2,400-3,000 km	Operational
Kh-55	ALCM	2,500 km	Operational
SS-N-23 "Skiff"	SLBM	11,000 km	Operational
SS-27 "Topol-M"	ICBM	11,000 km	Operational
SS-N-18 "Stingray"	SLBM	6,500 km	Operational
SS-25 "Topol"	ICBM	10,500-11,000 km	Operational
SS-19 "Stiletto"	ICBM	10,000 km	Operational
RS-24 Yars	ICBM	10,500 km	Operational
SS-N-32 "Bulava"	SLBM	8,300 km	Operational

SOURCE: Missiles of Russia (2018)

Russian defense spending, shown in table 3.4, has decreased significantly since the end of the Soviet Union. Its military as a whole has shrunk more than eighty percent since 1985. Although the military and its budget have decreased, the Russian missile inventory has been well maintained. As a means of projecting military power, developing an active missile arsenal can be less expensive than maintaining a comparable number of active duty forces.

Table 3.4 Russian Historic Defense Spending

Russia and the Soviet Union	Defense Expenditure (2014 US $ millions)			Number in Armed Forces (000)			Estimated Reservists (000)		Para-military (000)	
	1985	1999	2014	1985	1999	2017	1999	2017	1999	2017
	518,240	80,712	64,480	5,300	1,004	831	2,400	2,000	478	659

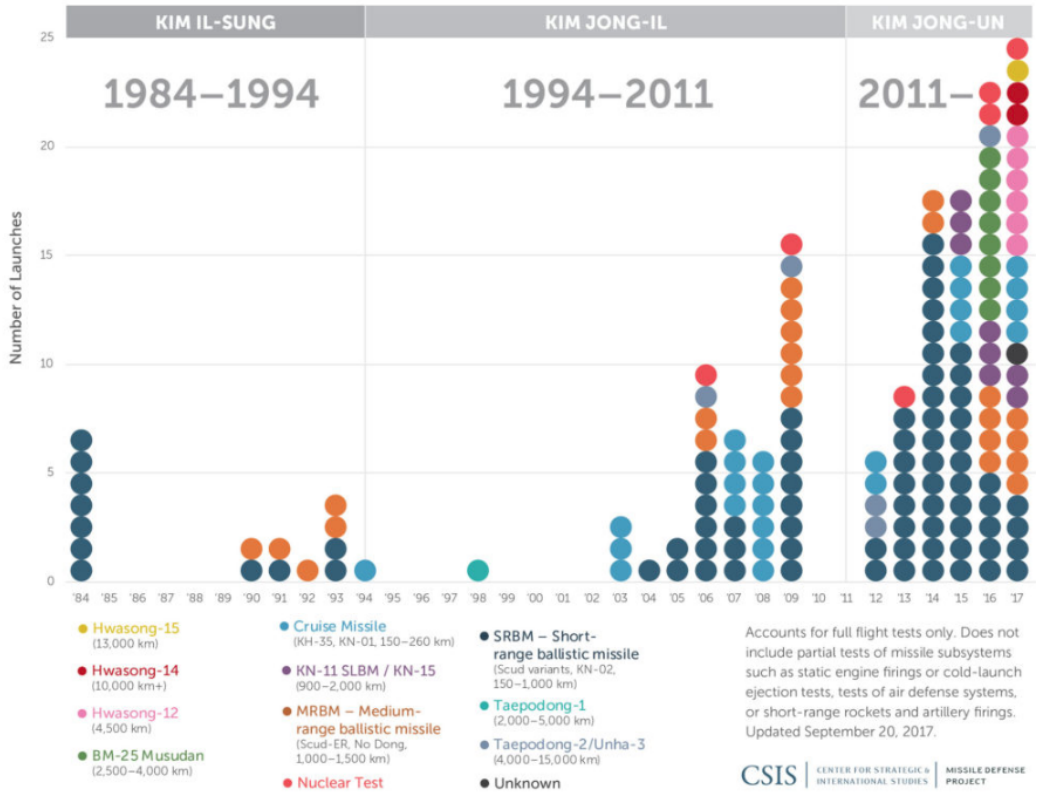
Source: The Military Balance (2000) and (2017)

Furthermore, although Russian spending on its military has shrunk as a whole, it has recently developed a new two-stage solid propellant missile, the RS-26 Rubezh, which is capable of traveling in excess of 5500 km. This and acquisitions of newer SRBMs and MRBMs illustrate that maintaining their missile inventory and threat capability are still two high priorities for the Russian government and military.

Country Profile: North Korea

The Democratic People's Republic of Korea (DPRK) poses potentially the largest threat to the United States. North Korea does not possess the largest or most capable inventory, but in recent years the Korean leader has shown his willingness to use missiles in strikes against the US. Since the 1980s, although the nation has been faced with political and economic hardship, the development and maintenance of its missile program has been a national priority. The following graphic, figure 3.3, produced by the Center for Strategic and International Studies, illustrates the development of North Korean missiles since the 1980s.

Figure 3.3 North Korean Missile Launches



Source: Missiles of North Korea (2018)

According to Jane's Strategic Weapon Systems Country Profile, North Korea is currently believed to possess as many as a thousand ballistic missiles of a variety of types. In addition to this inventory, it is estimated that North Korea has sold close to 400 to nations in the Middle East and Southeast Asia. Of the thousand North Korean missiles, roughly ten percent are medium- and long-range missiles whereas the other ninety percent are split evenly between Scud-class missiles and No-Dong missiles (Jane's Country Profile 2018). Scud-class missile have been in production since the 1980s but North Korea has improved on the early Scud models. On four separate dates in March of 2016, North Korea tested various numbers and types of these short-range ballistic missiles. They fired these missiles 200-800 km into the sea (Jane's Country

Profile 2018). More recently, they tested a new version of the missile system in May of 2017 which traveled 400 km towards the Sea of Japan. The No Dong missile system was first designed by North Korea as a medium-range ballistic missile in the 1980s. The missile system family has three variants which the US believes are capable of traveling between 1300 and 1700 km depending on the payload (Jane's Country Profile 2087). North Korea tested new improvements to this missile three times during 2016 (Missiles of North Korea 2017).

The following table, produced by Jane's Strategic Weapons Systems, provides an estimate for the roles, ranges, and payloads of different ballistic and cruise missiles within North Korea's arsenal.

Table 3.5 North Korean Missile Estimates

Type	Role	Range	Payload
Hyeonmu 1 (NHK 1)	Short-range ballistic missile	180 km	500 kg
Hyeonmu 2 (NHK 2)	Short-range ballistic missile	250 km	490 kg
Hyeonmu 2A (NHK 2A)	Short-range ballistic missile	300 km	500 kg
Hyeonmu 2B (NHK 2B)	Short-range ballistic missile	500 km	300 kg
Hyeonmu type	Short-range ballistic missile	800 km	500 kg
Haesong (SSM 700K)	Anti-ship cruise missile	150 km	220 kg
Cheon Ryong-1 (Hyeonmu 3A)	Land attack cruise missile	500 km	500 kg
Cheon Ryong-2 (Hyeonmu 3B)	Land attack cruise missile	1000 km	500 kg
Cheon Ryong-3 (Hyeonmu 3C)	Land attack cruise missile	1,500 km	500 kg

SOURCE Jane's Strategic Weapon Systems

A good estimate for North Korea defense expenditures was not available for 2014 through 2017. However, a significant drop in defense spending is shown in Table 3.5 between 1985 and 1999. The DPRK armed forces grew since 1985, but with a significant reduction in reserve troops since 1999.

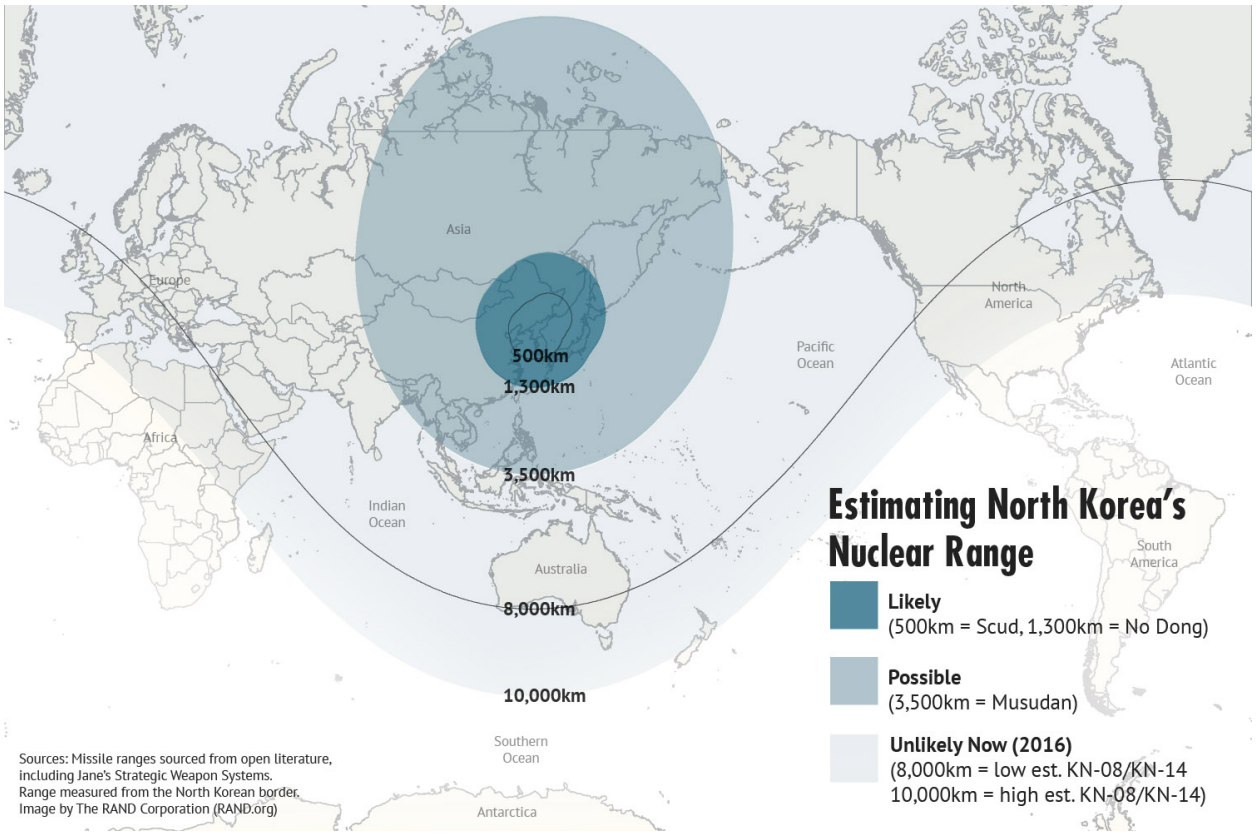
Table 3.6 North Korean Historic Defense Spending

North Korea	Defense Expenditure (2014 US $ millions)			Number in Armed Forces (000)			Estimated Reservists (000)		Para-military (000)	
	1985	1999	2014	1985	1999	2017	1999	2017	1999	2017
	8,756	2,986	n.k.	838	1055	1190	4700	600	189	187

Source: The Military Balance (2000) and (2017)

The most serious threat from North Korea is a nuclear attack against a US operating location in the Pacific or an attack against the US mainland. In July of 217, the North Korean government demonstrated the capabilities of an ICBM which could potentially threaten US cities such as Los Angeles, Denver, and Chicago. Figure 3.4, produced by the RAND Corporation, illustrates the range North Korean missiles could travel in 2016. With the most recent tests, the DPRK may now be able to threaten the entire shaded region of 10,000 km.

Figure 3.4 North Korean Missile Range



Source: RAND Corporation (2016)

Country Profile: Iran

Iran has more missiles than any other nation in the Middle East. These missiles can target European operating locations, European allied nations, and the nation of Israel. They have not yet demonstrated the capability of being able to strike a target within the United States. However, as shown in the following table, they maintain over 1700 missiles of various classes.

Table 3.7 Iranian Missile Capabilities

Missile	Class	Quantity
FROG 7	Tactical rocket system	250
Oghab	Tactical missile	200
Shahin-2	Tactical missile	250
Nazeat 130	Tactical missile	500
Fateh 110	Ballistic missile	n/a
Fateh A-110	Ballistic missile	n/a
Fateh-110-D1	Ballistic missile	n/a
Tondar 69	Ballistic missile	200
Shahab-1 (SS-1c 'Scud B')	Ballistic missile	250
Shahab-2 (SS-1d 'Scud C')	Ballistic missile	50
Shahab-3 (No-dong 2)[6]	Ballistic missile	25

[6] The Shahab-3 missile is a variant of the No-Dong missile developed by the North Korean government (Mizokami, 2017). The Center for Strategic and International Studies states that Iran purchased a No-Dong missile from North

BM-25	Ballistic missile	18
Qiam 1	Ballistic missile	n/a
Emad	Ballistic missile	n/a

Source: Jane's Strategy Weapon Systems

The following table documents how Iranian defense spending and military force structure has changed in the last three decades. Iran was allocating much more money in the 1980s, as much as 18 percent of its gross domestic product in 1985, on defense spending than it is today, roughly 3.9% in 2017. The size of its military has remained constant since 1999 with approximately nine hundred thousand combined active and reserve members in both estimates.

Table 3.8 Iranian Historic Defense Spending

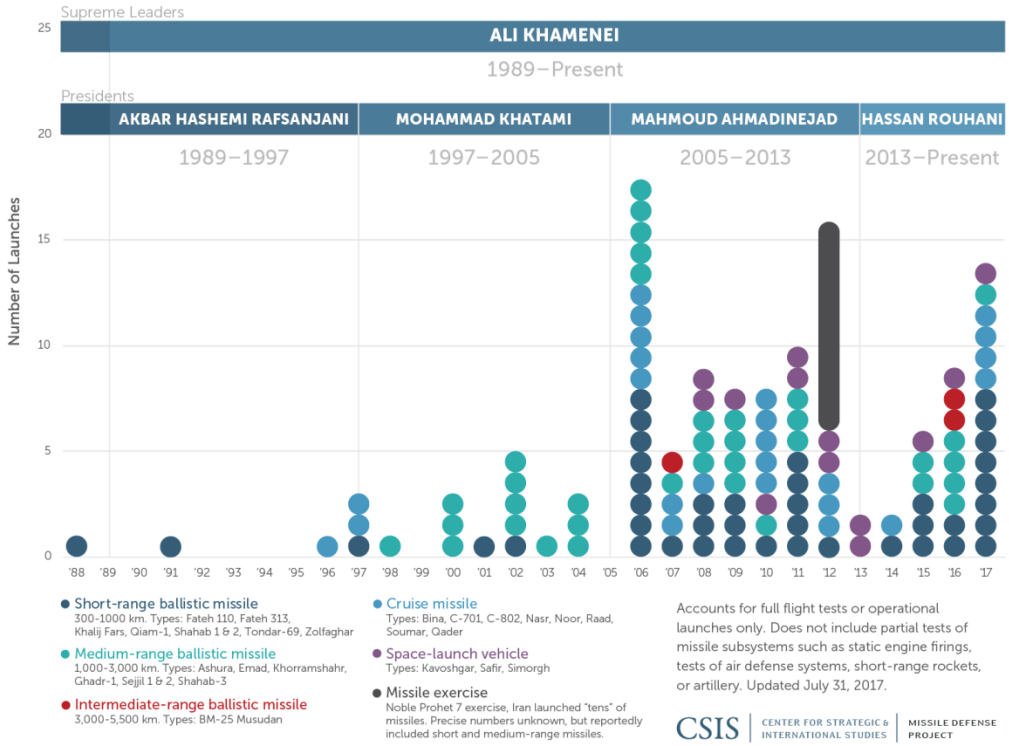
Iran	Defense Expenditure (2014 US $ millions)			Number in Armed Forces (000)			Estimated Reservists (000)		Para-military (000)	
	1985	1999	2014	1985	1999	2017	1999	2017	1999	2017
	14,953	8,120	15,801	610	546	523	350	350	240	40

Source: The Military Balance (2000) and (2017)

The Center for Strategic and International Studies published the following graphic which illustrates the number of full flight tests and operational launches of missiles by each Iranian President dating back to 1988.

Korea during the 1990s and then developed a domestic version of the missile in an effort to be able to strike targets throughout the Middle East – particularly within Saudi Arabia and Israel (Missile Defense Project 2016). This illustrates how missile technologies can be developed and proliferated across national borders.

Figure 3.5 Iranian Missile Launches



Source: Iranian Missile Launches (2018)

Figure 3.5 shows that since 2005, Iran has dramatically increased the rate at which it launches missiles.

A unique aspect of the Iranian missile program is its focus on short- and medium-range missiles rather than ICBMs. Iran's supreme leader and the leaders within Tehran view their missile inventory as integral to ensuring regional security. Iran's missile capabilities have been used offensively as recently as June of 2017. On June 19, Iran announced that it had fired missiles into Syria after the Islamic State had targeted Tehran on June 7 (Moshtaghian 2017). The attack consisted of multiple ballistic missile strikes which targeted Islamic State (IS) militants. It was Iran's first strike beyond its borders since the Iran-Iraq war of the 1980s. It was during the Iran-Iraq war that Iran first began its missile development in response to Iraq's superior striking capability (Jane's Country Profile 2018). Since then, Russia, North Korea, and China have each assisted in Iran accomplishing its goal of growing its missile inventory. Iran has also placed an emphasis on building its indigenous missile development capabilities and is considered to have made significant progress.

As for cruise missiles, in 2015 Iran announced a new ground-launched cruise missile designed to travel 3000 km. Iran has not publicly announced any tests of the missile, but some believe the missile was tested in early 2017 (Jane's Country Profile 2018). In the past, Iran has acquired air-launch missiles from Russia which it does not possess the aircraft required to launch

or the warheads the missiles are designed to carry. Analysts believe this is to reverse-engineer the missile itself.

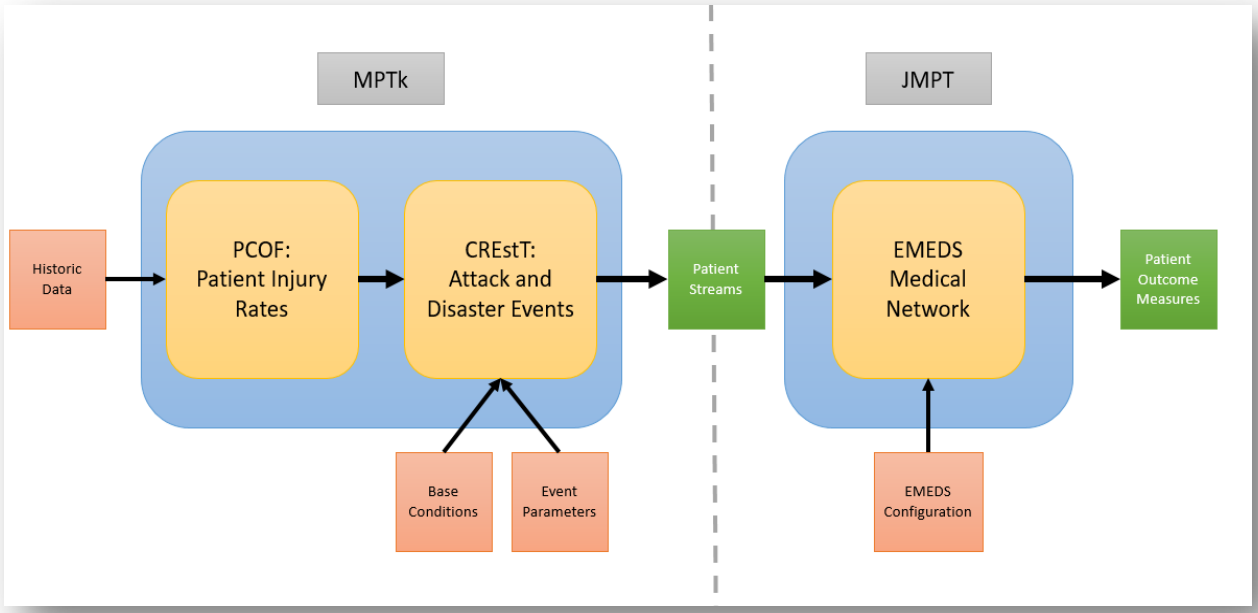
Conclusion

Across the globe, more nations are developing highly advanced missile arsenals. These arsenals are capable of projecting power great distances and causing significant damage to infrastructure, uniformed personnel, and non-combatants. This chapter highlights four such nations which have focused on the development and maintenance of their missile inventories as a central element of their national security. Given evolving strategic interests, especially in Europe, the Pacific, and the Middle East, some nations may be willing to use these highly advanced systems to target US operating locations in pursuit of political or military objectives. Such strikes could produce large numbers of casualties. The next two chapters present how such missile strikes (in addition to natural disaster events) can be modeled to produce casualty estimates.

4. Model Formulation

This chapter and the following chapter present the methodology this research followed to address each of the four research questions specified in chapter one. In describing how each research question will be answered, this chapter focuses on the application of two simulation models, the necessary data required for those models, and how those data were collected.

Figure 4.1 Two Stage Simulation Modeling Process



The above figure summarizes the modeling done in this research. On the left of the vertical dashed line, two tools within MPTk are used (using historic data, specific base conditions, and specified parameters) to produce stochastically estimated patient streams. JMPT, on the right of the dashed line, then receives those patient streams and processes them through different configurations of the EMEDS system to estimate patient outcomes. Within JMPT, a simulated medical network of MTFs treats the patient stream over the course of a user-defined scenario. This process, and how it can be used to answer this research's four questions is explained below.

Research Question 1

What casualty streams can be expected as a result of conventional missile strikes against Air Force operating locations and natural disasters in locations with developing and emerging economies?

The first step of this research was to demonstrate that US air bases could be targeted by adversary's missiles. As was explained in depth in Chapter 3, a literature review of existing research which analyzed the systematic growth and maintenance of adversary's missile inventories and their capabilities of striking US operating locations was done to demonstrate the reality of this threat.

Once that was accomplished, the next step was to estimate, as accurately as possible, the medical impact that would result from such attacks. Several fixed-base missile strike patient streams were generated to calculate the impact of such attacks. To capture the entirety of the EMEDS mission set, patient streams for different types of natural disasters were also generated. Both streams were generated using the stochastic simulation software introduced in Chapter 2. These patient streams will be used in further portions of the research. As explained previously, an existing Department of Defense (DoD) modeling tool, MPTk, which stochastically simulates the medical impacts of various attacks on operation locations using empirical data and user-defined parameters was used to create numerous patient streams. JMPT will be used to analyze the medical demands of these patient streams.

As has been explained previously, MPTk is comprised of the following tools; the patient condition occurrence frequency (PCOF) tool, the casualty rate estimation tool (CREstT), the expeditionary medicine requirements estimator (EMRE), and the estimating supplies program (ESP). As shown in figure 4.1, PCOFs were used to design patient streams within CREstT. These patient streams were later incorporated into the appropriate JMPT scenarios which were built to simulate the medical care available at an EMEDS facility. The data from the patient streams were used to calculate the baseline medical capabilities along with the impact of viable augmentation options.

Research Question 2

What are the patient outcomes for these steams based on the current EMEDS system?

Once the appropriate patient streams for different types of cruise missile attacks and natural disasters were created, JMPT was used to determine their corresponding baseline patient outcomes. In this analysis, the patient streams were processed through a simple network which was designed to focus exclusively on the medical capabilities of an EMEDS+25 facility. The output from those simulation runs provided the rest of the research with comparable, baseline results.

Research Question 3

What personnel, facilities, equipment or policies could be added to or changed within the existing EMEDS systems which may improve overall patient outcomes in MASCAL events?

After designing the appropriate patient streams, this research explored what adjustments could be made to the EMEDS system. The EMEDS system is heavily constrained in a number of dimensions. For instance, an EMEDS+25 facility is composed of a fixed number of personnel, operates within a specific number of tent structures, and is limited in its ability to add equipment. The EMEDS is designed to be a nimble, mobile facility which can be rapidly deployed and quickly become fully operationally capable. Therefore, not only are there physical constraints on the EMEDS system but there are also operational constraints. The AFMS does not want to strengthen the EMEDS by expanding its size or capabilities to the point where its current flexibility and functionality are compromised. Lastly, there are also modeling constraints. Because JMPT was used to represent EMEDS operations, this analysis was limited to analyzing only those adjustments to the EMEDS facility which are modeled in JMPT.

With these constraints in mind, this research analyzed the effect *small* changes would have within the EMEDS facility. For instance, this research analyzed the effect of adding one or two beds to the MTF and adjusting how patients are prioritized within the MTF.

Research Question 4

What are the benefits to patient outcomes associated with these potential adjustments?

After having created a set of possible EMEDS adjustments within JMPT, parallel patient streams were run through a JMPT-modeled medical network to identify the impact of each adjustment. Once that was accomplished the effect of individual changes on the EMEDS system's ability to process patient streams of different sizes were calculated.

There are numerous objectives when trying to improve patient treatment within MASCAL and disaster relief scenarios. For example, the priority could be maximizing RTD rates, minimizing DOW rates, or increasing overall evacuations and patient throughput. The effect of individual changes to the facility's performance can be calculated for each of these outcome variables. Calculating the effect for each outcome variable will allow Air Force decision makers to decide how to adjust the EMEDS facility in the face of different MASCAL events. The goal of this stage of the research is to prepare a set of graphics which illustrates the impact each change would have on each outcome variable.

Data Requirements

There are two primary types of data that need to be collected for this analysis. The first type is the input variables for MPTk used to generate the initial patient streams. The second is the data used to model the EMEDS and various EMEDS adjustments within the JMPT model.

MPTk Data Requirements

The primary tool used within the MPTk suite of tools was the Casualty Rate Estimation Tool, CREstT. CREstT is capable of creating very accurate patient streams when given the appropriate input variables. For the fixed base attacks, CREstT creates a patient stream from base demographic data, the event description (e.g., missile attack or natural disaster), and the associated historical injury distributions from the PCOF tool. The PCOF injury distributions were empirically derived from historic data by the Naval Health Research Center and were not edited. For example, the MPTk data requirements for the fixed base missile attacks consist of base demographic and attack strategy data. The natural disaster data requirements are less complex and simply require the user to specify the type and size of the disaster along with the population density of the location where the disaster takes place. For instance, a user can specify that a Category 3 hurricane strikes a developed nation with a low population density. These parameters will be explored further in the following sections.

In the case of the fixed base attacks, the base demographic data provides CREstT with the type of location targeted. Demographic data includes base geometry, in terms of overall square miles and the calculated area of different sectors, and the distribution of personnel across the base. able 4.1 presents a notional example of these data.

Table 4.1 Notional Sector Specific Geographic and Personnel Distribution Data

Sector Name	Personnel %	Area %	Weapon Hit %	Sheltered
Base Housing	40	5	5	N
Administrative Facilities	40	25	10	N
Airfield – Runway	10	10	50	N
Airfield – Facilities	10	10	30	Y
Undeveloped	0	50	5	N

In table 4.1, a notional base consists of five primary sectors. One of these sectors is the administrative facilities which are spread across the base. This sector cumulatively makes up 25% of the land area on the base and has 40% of the personnel. The table also includes a column for the percent of weapons which will hit the target. This allows the user to design an attack strategy which they believe the adversary would employ, in the case of administrative facilities in the above example this value is 10%. These numbers are linked to another portion of the input variables where the user must specify what types of attacks will take place. Here the user may select from different weapon types, including mortars, bombs, or cruise missiles, the size of the weapon, and the number which will hit the base.

Each weapon type has preset wounded and lethal radii which correspond to how much damage the individual hits will produce. The total number of hits corresponds to the sector distribution illustrated in table 4.1. In the above example, if the user specified that 20 small bombs would strike a base and that 10% of the weapons will hit administrative facilities, then 2 of the 20 small bombs will strike there. The bombs will hit somewhere in the sector and

depending on the personnel uniformly distributed across that sector and the wounded/lethal radii of the bomb, casualties may occur. If the sector is labeled as sheltered (in the case of administrative facilities it is not) then the wounded and lethal radii are reduced prior to calculating the probability distribution of causality injuries.[7] However, this research did not include any sheltered sectors.

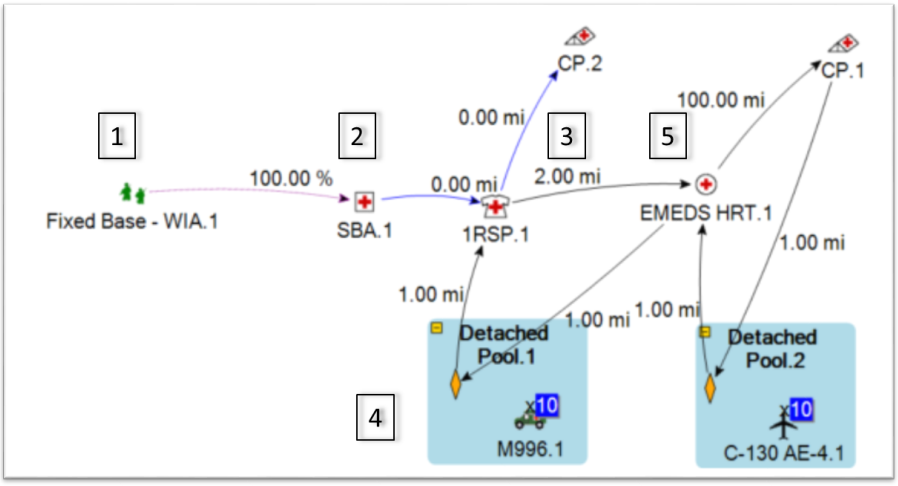
For this research, base specific personnel and geography were collected for several bases to incorporate into individual CREstT runs. What was produced within CREstT was a vector consisting of individual probability distributions for ICD-9 codes. In other words, the simulation determines the likelihood that a certain number of individual injuries will occur. This culminates in a probabilistic patient stream which can be imported into JMPT. When used in an individual simulation replication in JMPT, the probabilistic patient stream stochastically calculates the number of patients for each patient condition. JMPT then categorizes those patients by their patient condition and assigns them a mortality risk. Each patient is then assigned a probability of dying using the corresponding mortality risk distribution within JMPT.

JMPT Medical Network

As was previously introduced, JMPT is a discrete-event, agent-based stochastic simulation tool which models the delivery of care by medical care capabilities. JMPT accepts patient inputs, such as patient streams from MPTk, and flows them through user-designed medical networks. While MPTk allows a user to generate parameterized casualty probability distributions, JMPT allows a user to focus on all the nuances of treating those casualties through complex networks of care. Figure 4.2 illustrates an example of such a network. This visual network illustrates the flow of patients from a CREstT patient stream output through the network where they receive medical care at various levels of care. This network is more complex than the one used later in this research, but it is important in illustrating the capabilities and subtleties of JMPT.

[7] The term shelter refers to a structure which has been intentionally reinforced in order to protect itself and those within it from the impact of a missile. For sheltered sectors, MPTk reduces the wounded and lethal radii by a constant percentage. The default percentage within MPTk is 80%.

Figure 4.2 Example JMPT Medical Network



The above figure consists of several key components:

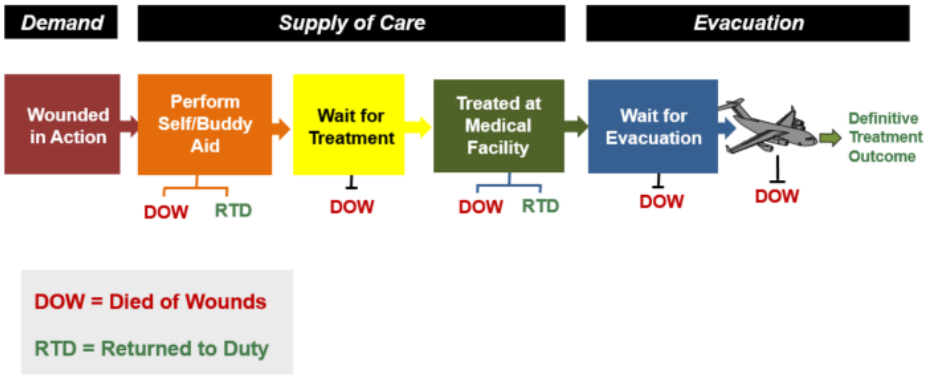
1. On the left-hand side of the figure, the fixed base patient stream enters the simulation and 100% of the patients enter the first object of the medical network. From there the patients flow to the right as they progress through the medical network.
2. The second stage of the medical network, labeled with a number 2, consists of the Self-buddy station (SBA.1). Self-buddy care is an example of a Role 1 medical capability.
3. From the Self-buddy station patients move to the first responder (1RSP.1) level of care.[8] From the first responder level of care the individual can exit the medical network to the first collection point (CP.2) or travel on a specified vehicle to an EMEDS HRT MTF (EMEDs HRT.1).
4. The fourth stage of the medical network consists of transportation between the first responder and the EMEDS. In this example, 10 M996.1 vehicles are available to transfer patients from the first responder to the EMEDS across a distance of two miles. The transportation assets in this example are kept in a detached pool. This is a pool of vehicles which could service more than one MTF but in this example it is only servicing the first responder. When they are not utilized and a patient requires transportation, they drive a mile to retrieve the patient(s), deliver the patients to the EMEDS, and then return a mile to their holding facility.
5. Once the patients arrive at the EMEDS HRT, they are treated within each of the functional areas within the EMEDS. From there they can again either leave the system or can be evacuated on an available C-130 to a collection point one hundred miles away.

This is a simplified depiction of a small network of expeditionary care that the AFMS might employ and is representative of how JMPT moves patients through a simulated medical network. The data requirements include the CREstT inputs, the designed medical network, the

[8] These patients are transferred across a 0.0 mile-long walk-route. JMPT requires there to be a distance between MTFs, but this distance can be set to zero. Furthermore, JMPT requires transportation assets such as vehicles or aircraft to be able to move patients unless a route in set as a walk-route.

transportation system, the theater evacuation policy for when individuals will be removed from the network, schedules for when various components of the network are available, the distance and routing options within the medical network, and a time component for how long the network has to treat the patients. Figure 4.3 illustrates how patients are modeled throughout this system. Within this research, the simulations will not include the *evacuation* portion of this process. This is intentional in order to capture the impacts of changes only within the *supply of care* portion of the treatment process.

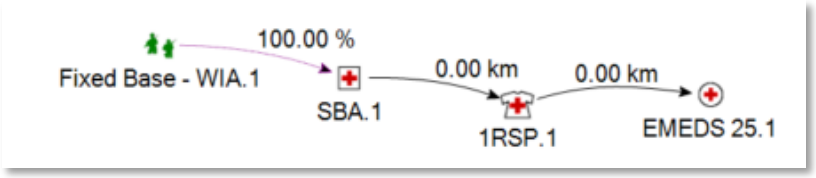
Figure 4.3 Modeling Casualty Flow from Point of Injury to Aeromedical Evacuation



Source: DeBlois et al., (2017) pp: 30

For this research, a JMPT network was designed to isolate the effect of an EMEDS facility while still modeling, as accurately as possible, the realistic flow of patients into an EMEDS facility. Figure 4.4 illustrates the medical network used in this analysis. It includes Role 1 facilities, in the form of self-buddy aid and first responder care, but intentionally does not model transportation in order to minimize the number of random processes effecting the treatment outcomes from the EMEDS facility.

Figure 4.4 Isolated EMEDS+25 JMPT Medical Network



Data Collection

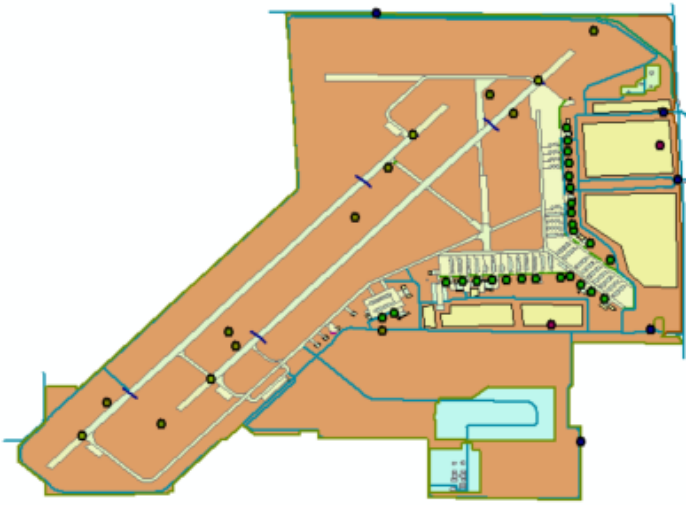
Attack Scenario Data Collection

Base Data

This research used data collected from various deployed Air Force operating locations. The data was used to calculate the distribution of area across different sectors on six Air Force bases.

The bases were used as representative examples of bases of various sizes.[9] Using the calculate-geometry tool within ArcGIS, the approximate area was calculated for eight unique sectors for the six Air Force operating location.

Figure 4.5 Representative Air Force Base ArcGIS Projection



Source: National Geospatial-Intelligence Agency

Figure 4.5 is an example of an ArcGIS representation of an Air Force base within the United States. The image portrays the area of the base and includes various sectors of interest. The sectors include building areas, storage areas, runways, taxiways, aircraft parking, aircraft hangars, hospital buildings, and undeveloped areas. This specific base is a domestic Air Force base and was not included in the study but can be used to illustrate the type of data which are available.

Personnel Data

A similar process was used to generate personnel distributions across the same sectors of Air Force operating locations. To produce accurate patient streams, it was necessary to know where people are located on a base when it is hit with a missile. This was done using aggregated personnel data available within RAND. The data provided the primary and duty Air Force Specialty Code (AFSC) and duty location for each individual in the Air Force as of July of 2017. These data were aggregated across the same six bases of interest to determine the approximate number of people assigned to each location.[10] The AFSCs of the individuals assigned to those

[9] These data were collected using ArcGIS software which allows a user to project polygons of different shapes and sizes over a satellite image of a geographic area. Datafiles which included these overlays already exist were available. Data provided by the National Geospatial-Intelligence Agency (NGA) which manages geospatial intelligence (GEOINT) for the Department of Defense and Intelligence Community.

[10] Within the records, the majority of individuals have both a primary AFSC (PAFSC) and a duty AFSC (DAFSC) but some individuals have only one. For any individual where a DAFSC was available, that was taken to be the

bases were compiled into a list. Once that list was compiled, each AFSC was assigned to a sector where the individual was most likely assigned. This assignment process was done based on assumptions of the responsibilities related to each job type. For instance, pilots and maintenance officers were assigned to be near the flight line whereas nurses and doctors were assigned to the medical clinic. This was done for each AFSC at each base of interest. The distributions of personnel across each sector were calculated for each base using this process.[11]

Missile Data

There are three key pieces of missile data which were required to generate accurate patient stream data. The first is the number of missiles which will strike a base, the second is the types of adversary missiles, and the third is the distribution of missile strikes across the different sectors of the base. Addressing each of these data needs was a particularly challenging piece of the anaysis for a variety of reasons. It is hard to know how many missiles a potential adversary has, how many they would use in an attack, what capability those missiles have, and what their targeting strategy would be.

To determine the size of the attack, unclassified data sources were used which estimate adversary military capabilities. As mentioned earlier in Chapter 2, there are a number of sources available which estimate the quiver size of various nations. Ultimately, the estimated quiver size of one particular nation was used as a representative case. Initially, this nation's missile inventory was divided by the number of days of anticipated missile strikes and finally by the number of bases the adversary is striking. In this research's war scenario, an adversary maintaining a uniform five-day campaign against six Air Force operating locations was analyzed.

Notional Adversary Missile Attack Size

As was presented earlier, there are a number of potential adversaries who maintain ballistic and cruise missile arsenals. Estimates for China, North Korea, Russia, and Iran were presented previously. The following threat is meant to be representative of the capabilities of a near-peer or peer competitor, as demonstrated earlier in Chapter 2. The following missile inventory estimates were used to generate attacks against US operating locations.

Table 4.2 Representative Adversary Missile Inventory

Missile Class	Maximum Range (km)	MPTk Payload Categories	Quantity
SRBMs	400	Medium	800
SRBMs	800	Large	500
MRBMs	1000	Medium	200
MRBMs	2500	Medium	100

position they are most likely currently filling. For individuals who did not have a DAFSC, their PAFSC was substituted to reflect the position they were most likely currently filling.

[11] Half of the base personnel were assigned to the sector for base housing. This was done to reflect the probability that at any given time, roughly half the base personnel would be off-duty and at the housing facilities.

ICBMs	5000	Medium	100
Cruise Missiles	2000	Small	1000

When designing the missile attacks this research assumed that the adversary will use their short- and medium-range missiles equally across any bases that are within striking range. The adversary will then use a portion of their remaining, longer-range missiles against targets which are further away. It was assumed that the adversary would then use remaining long-range missiles against either near or far targets in order to inflict the most equivalent damage across all bases. In other words, the adversary has a maximum total payload they are able to deliver to all targets in an attempt to use their missiles most efficiently. Based on missile capabilities and base distances it is possible to calculate the maximum payload that can be delivered to each base. In the previous chapter, figure 3.2, illustrated that while an adversary may be able to target multiple bases, their entire missile arsenal may not be able to reach each base.

For this research, an algorithm was used to minimize the sum of squared errors of payload delivered compared to the share of the payload which could be delivered to individual bases. This was done to design the most equitable, theater-wide adversary attack strategy.

There are several reasons why such a strategy might not be what an adversary would do in practice, but for the research design it is the most practical approach to take and can produce the most generalizable results. When considering specific adversaries and particular geography it may be possible to better design an attack strategy. However, an approach that utilizes a personalized attack strategy for a particular adversary would produce analysis at a higher level of classification than this research allowed. For instance, if a particular adversary feels threatened by a potential retaliation from the US Air Force, they may disproportionally target a base which is within a fighter aircraft's range of their mainland over a base from which a fighter would be required to refuel prior to reaching their mainland. However, these assumptions, although potentially practical, were not made within this analysis. The following tables illustrates the process of designing an attack which produces the most efficient allocation of missiles across six hypothetical bases with a notional distance from the launch point. In this example, the maximum available payload is calculated by multiplying the number of missiles which can reach the individual bases by a factor of 1, 2, or 3 to represent small, medium, or large missiles. The following equation highlights this calculation and the following table presents the results for our notional bases:

$$Maximum\ Available\ Payload_{Base\ x} = [1 \quad 2 \quad 3] \cdot \begin{bmatrix} Number\ of\ Small\ Missiles\ which\ can\ reach\ Base\ x \\ Number\ of\ Medium\ Missiles\ which\ can\ reach\ Base\ x \\ Number\ of\ Large\ Missiles\ which\ can\ reach\ Base\ x \end{bmatrix}$$

Table 4.3 Maximum Notional Adversary Payloads by Base and Distance

Base Name	Maximum Available Payload
Base Alpha (300 km)	4900

Base Bravo (300 km)	4900
Base Charlie (700 km)	3300
Base Delta (1000 km)	1800
Base Echo (2000 km)	1400
Base Foxtrot (2100 km)	400

The following table represents the most equitable distribution of the available missiles in this given example. The values were calculated using a *simplex* solver least-squares optimization method which required an integer solution.

Table 4.4 Notional Bases Missile Attack Allocation

Missile Class	Base Alpha (300 km)	Base Bravo (300 km)	Base Charlie (700 km)	Base Delta (1000 km)	Base Echo (2000 km)	Base Foxtrot (2100 km)
SRBMs	400	400	0	0	0	0
SRBMs	78	77	345	0	0	0
MRBMs	0	0	0	200	0	0
MRBMs	0	0	0	0	0	100
ICBMs	0	0	0	0	0	100
Cruise Missiles	0	0	0	300	700	0

This missile attack allocation illustrates the way an adversary could efficiently distribute their missiles of different ranges across different bases of different distances. This is a generalizable methodology which can be employed to model the allocation of missiles towards real bases from known adversary launch points.

Notional Adversary Missile Attack Strategies

Within CREstT, once a user has determined the scale of an attack, they must assign individual proportions of the attack to each individual sector. There is no way to know what attack strategy an adversary will use when striking Air Force bases. For that reason, three approaches were used. The three approaches consist of a best, worst, and mixed-case strategies from the perspective of casualty generation.

1. *Worst-Case:* In a worst-case attack strategy, red would use their entire attack to target base assets with high population density. These locations are most likely going to include base housing, administrative facilities, and other locations where large numbers of personnel gather.
2. *Best-Case:* In a best-case scenario, red would focus the entire payload on operationally significant targets rather than on population centers. For instance, there may be highly significant operational sectors, such as runways or fuel storage, which are not heavily trafficked by personnel.
3. *Mixed-Case:* A mix-case attack strategy tries to combine the operational and casualty focused attack strategies into one. This attack strategy focuses on producing the most disrupting attack which produces both heavy amounts of damage to operationally significant locations while still producing casualties. In an operational focused attack strategy, red may use more assets than necessary on a particular target. However, in this

case, they will seek to use as few missiles as possible to eliminate operationally significant targets and use their remaining missiles to produce casualties.

Although there are countless other potential strategies, these three strategies will offer meaningful insights into the types of patient streams which can be generated. The first two served to produce upper and lower-bounds in terms of casualty generation and the third highlights what might be a more likely outcome than either one of the two extremes. This method, using three types of attacks across six different bases, produced eighteen attack-generated patient streams.

Natural Disaster Data Collection

MPTk allows users to select from four types of disaster PCOFs. These PCOFs are built around the empirical patient records from historic disaster relief efforts. They include the 2010 Haitian Earthquake, the 2004 Sri Lankan Tsunami, Hurricane Katrina in 2005, and the flood that occurred in Pakistan in 2010. Beyond the disaster type there are five required parameters within the MPTk software to generate disaster relief effort patient streams. Three of these parameters reflect the impact of the event including the magnitude or category of the disaster, the state of the local economy, the population density of the location. The remaining two parameters deal with the medical response provided. The first is the number of days it takes for the medical response to arrive and the second is the number of patients that can be treated on average per day.

Table 5.2 presents twenty-four parameterized HA/DR events that were designed in CREstT. The parameters chosen were:

- Incident: Earthquake and Hurricane
- Severity: For Earthquake: 5.5, 7.5, or 9.5 magnitude. For Hurricane: category 3, 4, or 5
- Economy: Developing[12] and Emerging[13]
- Density: Moderate and High[14]

These twenty-four disaster scenarios capture a wide range of possibilities that the Air Force may be faced with and will allow the anticipated number of casualties to be estimated. The MPTk disaster designs where selected in order to identify the worst-case, edge-case scenario for two specific disaster types; earthquakes and hurricanes. Although the Air Force has been asked

[12] MPTk defines developing nations as "nations with generally lower living and educational standards, and an underdeveloped industrial base. Examples include, but are not limited to Haiti, Afghanistan, Belize, Ghana, Kenya and Malaysia" (User Guide 109).

[13] MPTk defines emerging nations as nations with "some traits of developed economies but are not yet developed economies. Examples include, but are not limited to Brazil, Russia, India, China, Mexico, Indonesia, and Turkey" (User Guide 109).

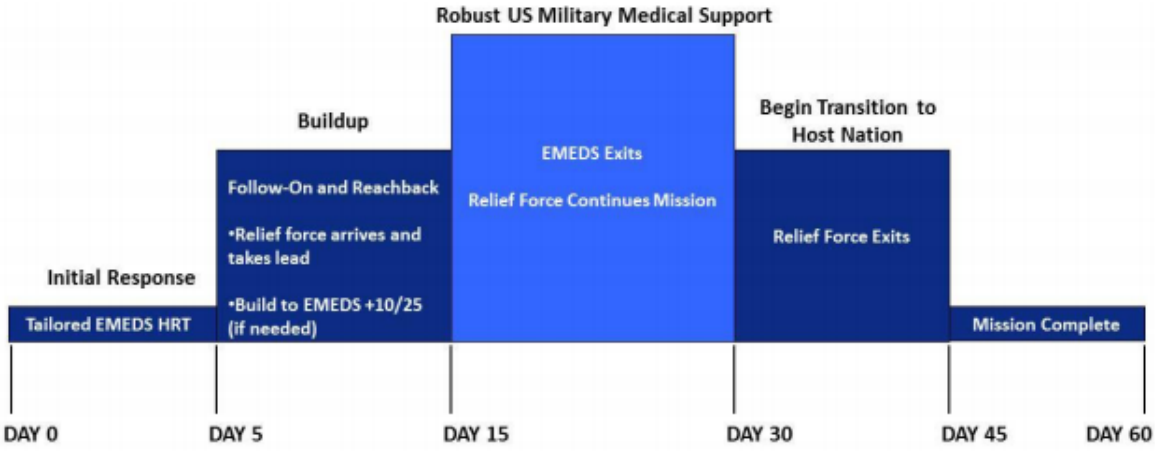
[14] MPtk defines population density as the number of individuals per square mile. The options include Very High (>5000), High (1000 to 5000), Moderate (366 to 999), and Low (0 to 365). [15] A functional EMEDS+25 is equipped with 97 personnel. JMPT does not list the 35 individuals within the EMEDS who do not perform medical duties.

to provide medical response to events not described by the parameters above, such as following Hurricane Katrina, the medical response to a specific event is not the primary concern of this research.

Three magnitudes and categories were chosen for each disaster type to produce least-, most-, and moderately-damaging scenarios. Each size of each disaster type was simulated in two different economy sizes and in two different population densities. CREstT allows users to select from the following economies: developing, emerging, developed (non-United States), and developed (United States). Due to the fact that this research is designed around the use of Air Force medical assets in remote locations, only developing and emerging economies were relevant. Finally, users can select between four population densities: low, moderate, high, and very high. CREstT warns users that the results for disasters where the population density is set to *very high* are less accurate than for smaller populations. Because a *low* population density refers to areas with less than 366 persons per square mile, the middle two options of *moderate* and h*igh* were selected.

Each disasters scenario must also be assigned medical response parameters. These represent the arrival day of medical care and the daily treatment capacity. The following graphic, figure 4.6, which is presented in the AFTTP document governing the use of the EMEDS system, illustrates the notional EMEDS response to a HA/DR scenario.

Figure 4.6 EMEDS deployment timeline



Source: Air Force TTP 3-42.71 (2014) pp: 48

By the fifth day, the Air Force believes it is capable of having built an initial EMEDS HRT up to a fully operational EMEDS +25. This is captured in CREstT by the arrival day parameter. The Air Force TTP also states that during HA/DR scenarios, an EMEDS HRT is capable of triaging and treating up to 350 patients per day with a surge capacity of 500 (TTP 3-42.17). For the sake of this research, the value 500 will be used, anticipating that the Air Force will build from an HRT to a larger, more capable +25.

Conclusion

This chapter highlighted the process through which the four research questions will be answered. Likewise, it clarified what data will be required to both produce casualty streams in MPTk and model those casualty streams in JMPT. Finally, it explained how the data required from MPTk were collected. Once all the required MPTk data was collected, numerous parameterized patient streams were generated. The next chapter will introduce how that process and explain more how those patient streams can be modeled in JMPT and the types of analysis that can be done with JMPT results.

5. Assessing Alternative EMEDS Configurations

This research consisted of a two-stage simulation design. The first stage was done using MPTk to generate patient streams. The second used JMPT to analyze MPTk generated patient streams across various medical networks. The results of the JMPT runs were compared to results for the baseline EMEDS+25 to determine some ways in which the EMEDS MTF could be improved. This chapter explains, in depth, the patient streams generated by the MPTk simulation runs and then the patient outcomes, as calculated by JMPT, for these patient streams and the various configurations of a medical network including the baseline EMEDS+25. Finally, this chapter ends with a statistical analysis of the various EMEDS option across the range of missile attack and disaster relief scenario to determine the most effective adjustments to the EMEDS system.

MPTk Patient Streams

As described in the previous chapter, patient casualty streams were created for a large number of variations for a missile attack scenario and a disaster relief scenario. A total of forty-two different patient streams were created that consist of eighteen designed attack scenarios and twenty-four designed HA/DR scenarios. The eighteen attack scenarios were generated using low, medium, and maximum missile allocation strategies against six operating locations. The twenty-four designed humanitarian relief scenarios came from twelve parameterized hurricane and earthquake designs using three different event magnitudes, two levels of economic development, and two levels of population density.

Table 5.1 presents the mean number of wounded-in-action and killed-in-action from each attack scenario.

Table 5.1 MPTk Casualty Results for Attack Scenarios

Scenario Number	Base Number	Attack Strategy	WIA	Initial Deaths
a1	1	Fewest	50	14
a2	1	Medium	417	121
a3	1	Most	223	154
a4	2	Fewest	1043	120
a5	2	Medium	4486	515
a6	2	Most	4767	548
a7	3	Fewest	316	37
a8	3	Medium	1199	140
a9	3	Most	1269	149
a10	4	Fewest	393	43

a11	4	Medium	1075	110
a12	4	Most	1763	192
a13	5	Fewest	668	76
a14	5	Medium	3203	419
a15	5	Most	3545	458
a16	6	Fewest	393	44
a17	6	Medium	1923	207
a18	6	Most	1949	206

This table presents the mean results from the eighteen unique attack designs. There are significant differences in the results for a variety of reasons. An observable driver of casualty numbers is the attack strategy. Strategies which were not designed to produce the fewest casualties possible, labeled as *fewest*, produced the base ceiling number of casualties. In other words, the remaining two strategies produced very similar numbers which identifies an approximate ceiling for each specific base where additional casualties are hard to produce. However, the ceiling of individual bases is dependent on base demographics. The six individual bases are different geographic sizes and have different population densities.

Furthermore, the individual sectors on the base have unique distributions of area and personnel. Each of these factors play a role in determining the number of casualties generated from each attack strategy.

For three of the six targeted bases, the *medium* attack strategy, the attack strategy which mixed operational and casualty-focused targets, produced between 94.1 and 98.7 percent of WIA total as the attack strategy which was intended to produce as many casualties as possible, labeled as *most*. This illustrates that if even a portion of an adversary's missile inventory is aimed at producing casualties, in terms of targeting billeting, administrative facilities, and other high-density sectors on a base, a significant number of causalities can be produced.

Table 5.2 illustrates the parameters and findings for the twenty-four HA/DR scenarios. The column in the table labeled "trauma" was exported in a form that could be fed into the JMPT simulation tool. This column represents the patients who are alive yet are injured from the disaster event and will require medical treatment. MPTk classifies patients who have physical injuries from HA/DR events as trauma patients as opposed to WIA patients generated from attack scenarios. This research did not analyze the care provided to patients suffering from diseases. When included, less than 1% of disease patients are assigned a mortality risk. It was assumed that, in a crisis scenario, non-life threatened disease patients would be triaged to a separate facility and the EMEDS would focus on treating patients with physical injuries.

Table 5.2 MPTk Casualty Results for HA/DR Scenarios

Scenario Number	Disaster Type	Disaster Magnitude	Economic	Density	Trauma	Disease	Initial Deaths
e1	Earthquake	5.5	Developing	Moderate	3412	1851	1139
e2	Earthquake	7.5	Developing	Moderate	5520	4558	2536

e3	Earthquake	9.5	Developing	Moderate	6166	8386	5643
e4	Earthquake	5.5	Developing	High	5785	5467	4376
e5	Earthquake	7.5	Developing	High	5200	4184	9739
e6	Earthquake	9.5	Developing	High	6081	7220	21675
e7	Earthquake	5.5	Emerging	Moderate	2262	1367	419
e8	Earthquake	7.5	Emerging	Moderate	4094	2412	933
e9	Earthquake	9.5	Emerging	Moderate	5388	4272	2076
e10	Earthquake	5.5	Emerging	High	4736	3150	1610
e11	Earthquake	7.5	Emerging	High	5419	4431	3583
e12	Earthquake	9.5	Emerging	High	5600	5071	7974
h1	Hurricane	3	Developing	Moderate	1483	1701	540
h2	Hurricane	4	Developing	Moderate	2588	3228	1033
h3	Hurricane	5	Developing	Moderate	3156	6140	1684
h4	Hurricane	3	Developing	High	2064	2333	810
h5	Hurricane	4	Developing	High	3048	5069	1549
h6	Hurricane	5	Developing	High	3500	10162	2526
h7	Hurricane	3	Emerging	Moderate	676	1161	384
h8	Hurricane	4	Emerging	Moderate	1686	1934	812
h9	Hurricane	5	Emerging	Moderate	2675	3460	1399
h10	Hurricane	3	Emerging	High	1051	1446	576
h11	Hurricane	4	Emerging	High	2331	2754	1218
h12	Hurricane	5	Emerging	High	3128	5777	2098

These data confirm that, in general, larger events in poorer, more densely populated areas generate more casualties. However, there are several results which stand out, including the decrease in disease patients between disaster #4 and disaster #5 even though the later consists of a more severe earthquake. However, the lack of disease patients may be accounted for in the fact that there were more than twice as many deaths in disaster #5 than in disaster #4. Disaster #6 also produced the worst-case scenario for the purpose of this analysis. A number of real-life earthquakes have claimed more casualties than this simulated number. Most recently, the Haitian Earthquake in 2010, which provides the historic data for the earthquake patient streams, claimed the lives of 230,000 people from both the initial event and a subsequent cholera outbreak, according to the Haitian Government (BBC, 2010).

Exporting the MPTk results to JMPT

The forty-two patient streams were exported from MPTk and imported into JMPT. When exporting patient streams from MPTk a variety of options are available. Most significant is the exported percentile. The patient streams were generated using 200 stochastic simulation runs. The user has the option of selecting the average number of patients, a low risk option which represents the 95th percentile, a medium risk option which represents the 85th percentile, or a high risk which represents the 75th percentile of results. The designers of the MPTk platform advise that users utilize the medium risk results. The low risk option produces the largest patient stream estimates which have, across the eighteen attack streams, on average 4.3% more patients than the medium risk option. The high risk option produces the fewest patients, on average 1.6% fewer than the medium risk output. Using the medium risk output aligns with the MPTk designer's recommendations and produces a conservative estimate for casualties between either extremes.

Simulated Medical Network

Each patient stream was initially treated using a baseline EMEDS+25 medical network. As was shown in Figure 4.4, the JMPT medical network consisted first of Self-Aid Buddy-Care, followed by medical care provided by a First Responder, and finally an EMEDS+25. This represents two Role 1 facilities followed by a Role 3 facility and mirrors what would happen in reality. In a real-life scenario, the Air Force would operate a complex network of MTFs. This could include multiple EMEDS of different sizes and different methods of patient movement. For instance, an EMEDS could be accompanied with a large En Route Patient Staging System (ERPSS) that can hold non-critical patients who are ready and eligible to be transported to a larger facility. However, due to the limited capabilities of JMPT and the aim of isolating the performance of an individual EMEDS+25 facility, an entire theater MTF network was not modeled. Rather, the simplified MTF network comprising of two stages of Role 1 care and a single EMEDS+25 was chosen.

JMPT also has the capability of modeling transportation. The simulation tool allows the user to select individual vehicles, aircraft, and ships on which patients can be moved from one facility to another. The user can specify distances, loading capacities, and a variety of other factors which influence transportation. However, for the purpose of this analysis transportation was not considered. To circumvent the need for transportation the patient streams and medical networks were collocated. Within JMPT, routes between medical capabilities can be specified as walking routes. These routes do not require a transportation asset such as a vehicle. For this analysis, all routes were set to walking routes of 0.0 kilometers. Non-ambulatory patients are still able to proceed over such routes.

Once the patients arrived within the EMEDS+25 medical capability they were treated at a variety of *functional areas* (FAs). FAs refer to components within the EMEDS+25 where patients receive specific types of treatments. Within the EMEDS+25 there are six FAs: triage, flight medicine, the Critical Care Ward, the emergency room, the operating room, and the intensive care unit ward. Patients enter the MTF at the triage ward before being treated at either the flight medicine or emergency room FAs. All surviving patients enter the ER. From there, if necessary they go to the OR, before entering either the Critical Care Ward or the ICU ward. Patients who exit the MTF either are evacuated to a higher level of care or return-to-duty.

Within JMPT, the EMEDS+25 consists of 62 baseline personnel who perform specific medical tasks. These 62 personnel have a wide range of skill levels.[15] Table 5.3 presents the 62 personnel assigned to an EMEDS+25 within JMPT. The table lists the personnel type, the number of that type assigned to the EMEDS, the skill level of that personnel type (a lower

[15] A functional EMEDS+25 is equipped with 97 personnel. JMPT does not list the 35 individuals within the EMEDS who do not perform medical duties.

number indicates a more highly skill personnel type), and lastly whether or not that individual is assigned to a particular FA.

Table 5.3 EMEDS+25 Baseline Personnel: Quantity, Skill Level, and Assigned FA

Personnel Type	Quantity	Skill Level	Assigned FA
45BX - Orthopedic Surgeon	1	110	OR
45SX - Surgeon	2	150	OR
45AX - Anesthesiologist	1	200	OR
46YXM - Nurse Anesthetist	1	205	OR
44EX - Emergency Services Physician	1	300	
44MX - Internist	1	305	
44FX - Family Physician	3	350	
48AX - Aerospace Medicine Specialist	1	350	FLT MED
48RX - Residency Trained Flight Surgeon	1	350	FLT MED
47GX - Dentist	2	355	
46SX - Operating Room Nurse	2	400	OR
46NXE - Clinical Nurse Critical Care	3	410	
46NXJ - Emergency Nurse	1	420	
46NX - Clinical Nurse	7	420	
4N071C - Independent Med Tech	1	475	FLT MED
4H000 - Cardiopulmonary Laboratory	1	500	
4N171 - Surgical Technician Craftsman	3	500	OR
4N000 - Aerospace Medical Service	22	500	
4T0X1 - Medical Laboratory	2	525	
4R0X0 - Radiology Diagnostic Imaging Cfmn	2	525	
4Y0X1 - Dental Assistant	2	550	
43TX - Biomedical Laboratory	1	800	
43PX - Pharmacist	1	800	

Source: Joint Medical Planners Tool

Nine positions are assigned to a specific functional area, the majority to the operating room. It is important to note that the four most highly skilled positions are all individuals who are assigned to the operating room. A potential solution to strengthening the EMEDS might be to reallocate more highly skilled personnel to the EMEDS. However, if patient backlogs are identified in other functional areas, additional surgeons will not be able to directly assist those function areas and reduce patients waiting. However, additional surgeons may in fact increase the throughput rate of the operating room and further backlog a functional area such as the ward. The most highly skilled, unconstrained individuals within the EMEDS+25 system are emergency services physicians, internists, and family physicians. If additional emergency services

physicians were added, for instance, they would be able to provide care in any of the functional areas. However, they would only be able to provide for which their skill level allows them.

Each functional area within the EMEDS+25 system has a number of specific constraints. JMPT allows the user to view and customize many of these settings. The first is the maximum number of casualties that can be treated within each individual functional area. The following table presents these baseline values.

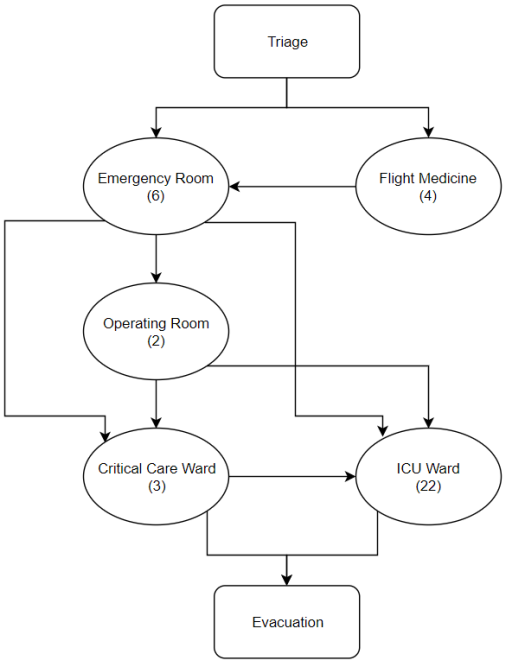
Table 5.4 EMEDS+25 Baseline FA Holding and Treatment Capacity

Functional Area	Max Casualties in FA
Flight Medicine	4
Critical Care Ward	3
Emergency Room	6
Operating Room	2
ICU Ward	22

Source: Joint Medical Planners Tool

The following graphic illustrates the previously explained network flow of patients through the EMEDS MTF. Illustrating the flow of patients through this will aid in identifying bottlenecks. For instance, following the triage FA, patients most flow to one of two FAs which have a combined capacity of 10 patients. However, all patients must eventually pass through the emergency room. The capacity of the ER represents the narrowest cut point, in terms of number of beds, within the system.

Figure 5.1 EMEDS+25 Patient Flow and Maximum Casualty Load



Within JMPT, the baseline EMEDS+25 also has a global capacity constraint over its entire system. This value is the maximum number of casualties that may be waiting outside the EMEDS. This value is initially set to 50 within JMPT. However, for the purpose of this analysis this value will always been adjusted to 9,999. The purpose of this adjustment is to prevent patients from balking from the MTF and not receiving care.[16] This leads to inaccurate and unrealistic results.

Patients are given one of four mortality risk states based on their injuries. The mortality risk is defined as either life-threatening or non-life threatening. Patients who have life-threatening injuries are further categorized as either having a low, medium, or high risk of dying. These patients are unable to return-to-duty and must evacuate to higher levels of care if they exit the MTF. Non-life threatened patients are able to return-to-duty but may also evacuate.[17] How JMPT categorizes potential patient outcomes are further explained below.

Each functional area also maintains a supply of critical equipment. The use of this equipment can be tracked under certain conditions within JMPT. Examples of critical equipment are ventilators, resuscitators, defibrillators, and devices to monitor patient vital signs.

Functional areas are also assigned *treatment priority data*, *task and usage data*, and *task sequence* data. These data are editable, but for baseline tests were not adjusted. *Treatment priority* corresponds to which patients are treated first. This is based on the patient's condition, the treatment priority which corresponds to that condition (a value from 1 to 999), and the appropriate stabilization time. The stabilization time reflects the amount of time a patient will have to remain within the functional area after receiving treatment. A treatment priority of 1 corresponds to the patient code for traumatic pneumothorax, hemothorax, injury to heart and lung, and injury to blood vessels of the thorax. The value of 218 on the other hand corresponds to an unspecified fever. The value of 999 can correspond to symptoms such as dehydration and motion sickness. Within JMPT, when a functional area is able to provide treatment to an additional patient, it scans the list of patients waiting to receive care and selects the individual with the highest priority value.

The *task list* specifies the order in which tasks occur within the functional area. The tasks are discrete steps and can range from setting up drainage containers to checking vital signs prior to sedating a patient or performing surgery. The tasks are assigned to default personnel. Within a JMPT simulation, when a task is required the program first attempts to utilize the default personnel to perform a task. If the default individual is not available, the simulation software will

[16] During a simulation in which the maximum queue length is not adjusted, patients will be "evacuated" prior to entering the MTF. During a number a test runs it was clear that even patients who were given a high mortality risk would evacuate without being treated if more than 50 patients were in the queue.

[17] In a sample simulation run, several patient conditions with no mortality risk result both in patients who return-to-duty and some who evacuate. These conditions included types of concussions, first and second-degree burns, sprains and strains to the knee or leg, and open wounds of various body parts. Conditions which consisted of no mortality risk but resulted in evacuations for all patients included several types of closed fractures.

look for the least qualified individual capable of performing the job based on their skills. Some tasks are also identified as continuous. Continuous tasks require that the patient receives ongoing care or monitoring from a piece of equipment. That equipment becomes unavailable for use by other patients while the individual remains within the functional area receiving care.

Beyond the EMEDS facility, there are two other scenario-level parameters which are critical. These include the theater evacuation policy and the time length of the simulation scenario. The baseline JMPT theater evacuation policy is seven days. This means that if a patient's total recovery time is more than a week, the patient is evacuated as soon as they are stable enough to be transported and transportation is available. In this research, the theater evacuation policy was shortened to three days. As has been mentioned, this research used thirty-day simulation runs to estimate how well the EMEDS facility could process patients within one month's time. This value was chosen because the AFTTP specifies that the EMEDS generally operates for thirty or fewer days.

Patient Outcomes

There are four patient outcomes which can occur in JMPT. These patient outcomes are referred to as the "final patient disposition." The JMPT user manual (Teledyne Brown Engineering, 2017) provides the following definitions for the final dispositions:

- Return-to-duty: Casualties who were either wounded in action, disease, non-battle injuries that were able to return to their unit.
- Final Evacuation: The number of casualties that completed treatment at the last medical treatment facility in the scenario.
- Died-of-Wounds: Casualties who die after being seen by a physician
- Killed-in-Action: Casualties who are assigned a patient code but die before they enter a medical treatment facility with a physician present.

At the end of a simulation, a patient is assigned a final disposition. However, during the process their disposition is "in system" unless they exit before the end of the simulation by passing away (either DOW or KIA), returning-to-duty, or evacuating. At the end of the simulation run, patients who are still in the system are assigned a fifth final disposition, "in system," to reflect that they never received care during the simulation.

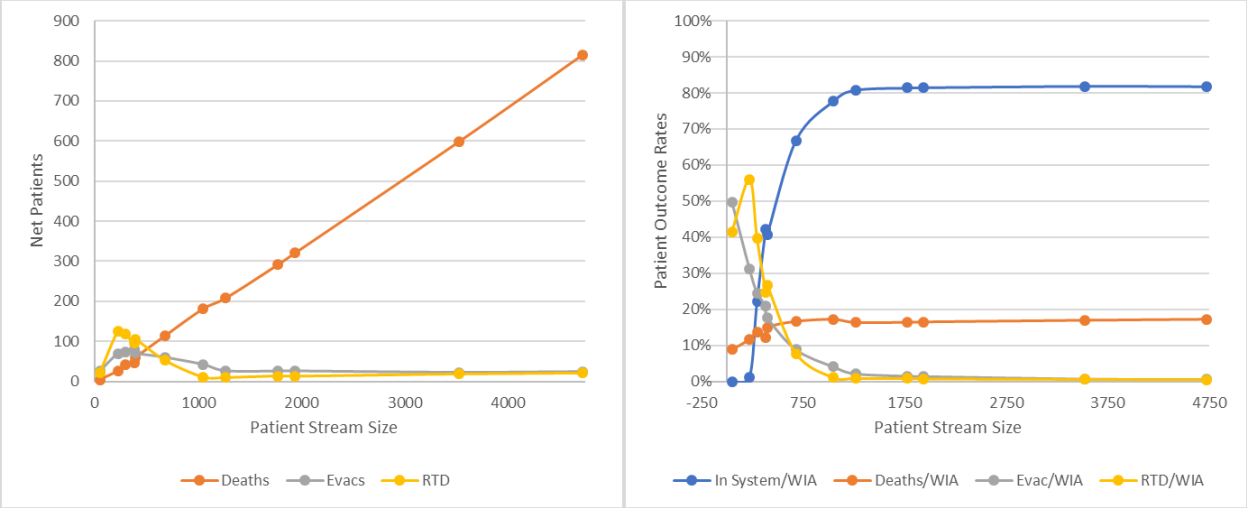
The definitions for KIA and DOW can be counterintuitive. Although KIA may sound as though it means patients who die immediately following or shortly after an injury, a patient may actually KIA several days into a scenario. In fact, in this analysis, the majority of overall mortality consists of KIA rather than DOW. Furthermore, the definitions for KIA and DOW do not appear to capture the entirety of a patient's progression through an MTF. If a patient dies while receiving care they are counted as DOW. The DOW definition, therefore should be interpreted as meaning "casualties who die after having *begun* treatment with a physician." The word "after" which appears in the original definition can be misinterpreted as meaning that only

after the care is finished can they be categorized as DOW. This confusion becomes apparent when a patient dies. JMPT categorizes each patient's activity at the time of death. The options are "waiting for care," "receiving care," and "awaiting transportation." In our scenarios, the majority of patients die waiting for care. These patients are always categorized as KIA. In some instances, patients die after beginning care or while waiting to be evacuated, these patients are labeled as DOW. For that reason, this research summed DOW and KIA as the total mortality measure.

Baseline EMEDS+25 Patient Outcomes

The following figure illustrates the rates of four patient outcomes across twelve of the eighteen attack scenarios. Only twelve scenarios are used here to illustrate the full range of patient stream sizes and the baseline patient outcomes. These scenarios were run using the designed medical network with self-buddy aid, first responders, and an EMEDS+25 facility.

Figures 5.2 and 5.3 Mean Baseline Patient Outcomes Across Patient Streams



As the number of patients who are wounded in action, presented on the horizontal axis, increases, the rate in which patients remain in the system approaches 82%. Each patient stream with more than 1000 average patients has between 78-82% of the patients who remain in the system after a 30-day simulation. This illustrates a break point where the MTF is no longer able to admit new patients. Later, this research analyzes the type of patients remaining in the system.

As the patient population increases, there is a corresponding decrease in the overall RTD and evacuation rates. Overall mortality increases linearly from approximately 10% to 17%. For patient streams larger than 1000 patients, the same break point noted in terms of overall throughput, there is no corresponding increase in mortality. Across all the scenarios, the average mortality is 15% of the patient population. The fact that mortality does not increase is a reflection of the percentage of the patient population which have a mortality risk. For patient

streams of more than a 1000 patients, virtually every patient with a mortality risk dies when the only medical facility they have access to is an EMEDS+25.

The above figure illustrates that there may be room for improvement within the EMEDS. Although it is not designed to handle a surge of life-threatened trauma patients, after thirty days the Role 3 facility would ideally be capable of processing more than 20% of the overall patient load, yet for scenarios where there are more than 1000 patients this is currently not the case.

Initial Comparisons

In order to verify that the EMEDS system can be improved, a series of tests for three different MTF configurations were run to analyze the baseline capabilities of the system. These comparisons were made across several attack patient streams which were introduced earlier in this chapter. The first MTF was the baseline EMEDS+25. The second was the 58-bed AFTH. This MTF was designed to reflect a functional upper-bound on the EMEDS+25 medical network structure. It is unlikely that any changes to the EMEDS structure could produce a medical facility capable of exceeding the AFTH. As its own medical entity, the AFTH represents the next level of care beyond an EMEDS while still being a Role 3 facility within the Air Force Medical Service.

The third MTF was an adjusted version of the EMEDS+25. The baseline results showed that some equipment, functional areas, or personnel with in the EMEDS+25 were either fully utilized over multiple consecutive days or had an overall high utilization rate. These results suggest that specific resources within these three resource types may well be causing bottlenecks it the care that can be provided to casualties. Increases in these three resource types were made to produce a more capable MTF.

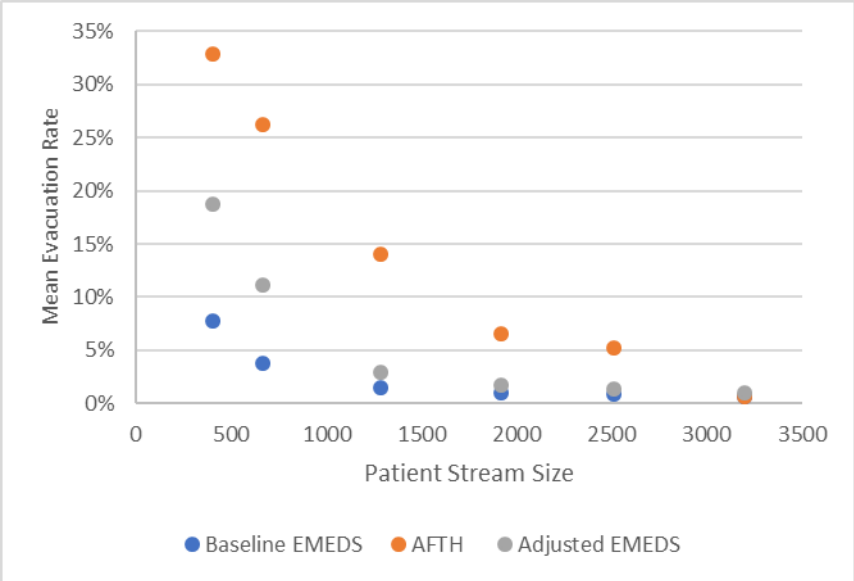
First, within JMPT the amount of critical equipment available in each functional area was doubled. This was done as a result of several test simulations which showed that periodically certain pieces of critical equipment, most often a patient monitor, had utilization rates of 100% for several consecutive days. Secondly, the maximum casualty load of two functional areas were increased. The baseline OR has only 2 beds and the baseline Critical Care Ward has only 3 beds. These values were both expanded to 4 beds. Lastly, a total of six personnel were added to the MTF. The six personnel consisted of an additional Orthopedic Surgeon, Anesthesiologist, Nurse Anesthetist, Emergency Services Physician, Internist, and Clinical Nurse Critical Care.[18] These individuals were chosen due to their high skill level within the MTF as well as their utilization rates during test simulations. The Orthopedic Surgeon is the most highly skilled individual within the MTF and as such a second surgeon was added. Since an additional surgeon was added

[18] In this research's final design process it was decided that recommendations which considered adding additional personnel to the EMEDS should be avoided. This was done in order to preserve the status quo end strength of the fully developed EMEDS+25. However, in initial research this avenue was explored as a potential way to strengthen the EMEDS system's ability to provide care.

as well as an additional OR bed, an anesthesiologist and nurse anesthetist were added. The Emergency Services Physician was added because s/he is most highly skilled individual within the MTF that is not assigned to a particular functional area. Lastly, an additional Internist and Clinical Care nurse were added because test simulations showed that these two positions, along with Orthopedic Surgeon, are the most highly utilized, an average of over 20% utilization across a thirty-day scenario.

A series of simulations were run using the MTFs just described and six different attack scenario patient streams. These patient streams were chosen from the eighteen designed attack scenarios in order to represent a wide range of patient stream sizes. The following figures present the findings. On the vertical axis, the simulated mean evacuation rate is plotted against the mean number of casualties for a given patient stream. The point in top left corner, for instance, illustrates that after thirty days an AFTH, when faced with an average of 405 patients generated from an attack scenario, is able to evacuate an average of 32.8% of the patients.

Figure 5.4 Mean Evacuate Rate Across Patient Streams

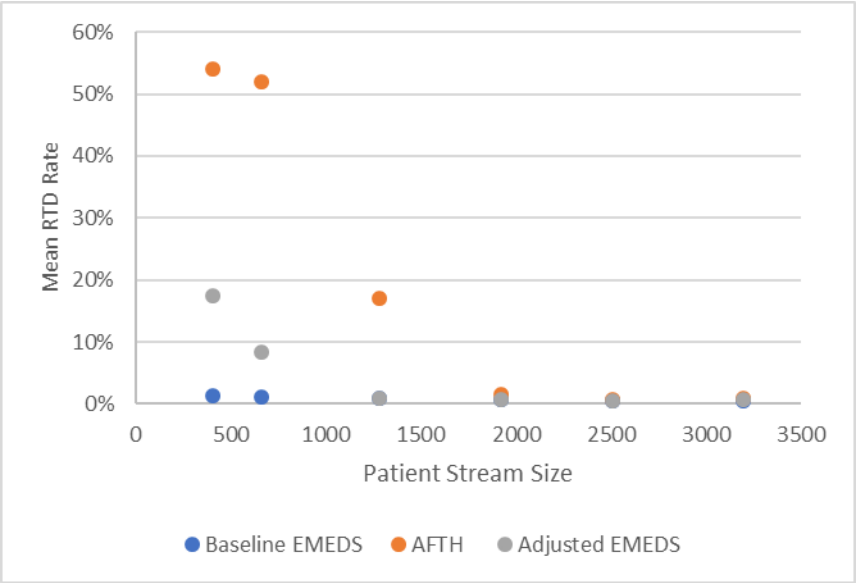


The figure above illustrates that across several patient streams, the AFTH is able to achieve a much higher mean evacuation rate of patients than either the baseline EMEDS or the adjusted EMEDS. For the smallest patient stream with a mean patient population of 405 patients, the baseline EMEDS evacuates an average of 7.8% of patients and the adjusted EMEDS evacuates 18.8% of patients. In other words, the AFTH evacuates 2.4 times as many patients as the baseline EMEDS.

As expected, this confirms the notion that the larger AFTH is a superior medical capability, in terms of its ability to treat and process patients, than the smaller EMEDS. However, it is also important to note that the advantage the AFTH has over the EMEDS decreases as the number of patients increases. There is a point at which both systems are so overrun with patients that neither can effectively evacuate a significant number. Lastly, the above figure illustrates that

there is room for improvement in the baseline EMEDS in terms of its ability to evacuate patients, particularly for patient streams of fewer than 1000 patients.

Figure 5.5 Mean RTD Rate Across Patient Streams



The above graph, figure 5.5, a plot of return-to-duty rates by patient stream size across the same three MTFs, tells a very similar story to figure 5.3. The AFTH is able to outperform both the EMEDS facilities. Likewise, the adjusted EMEDS outperforms the baseline EMEDS for patient streams of fewer than 1000 patients. For the smallest patient stream, the baseline EMEDS can only RTD an average of 5.2 out of 404.8 patients. Meanwhile, the AFTH's RTD mean is 218.9 patients, more than 42 times as many as the baseline EMEDS. However, in this figure we see that the convergence of the AFTH and the EMEDS percentages happens more rapidly in the case of RTD rates.

Comparison of Alterative EMED Systems

In this research, samples of simulation results are compared to one another to isolate whether or not individual changes to a medical network have an effect on three primary output variables. As explained, these variables are evacuations (*Evacs*), returns-to-duty (*RTDs*), and mortality (*Mort*). The previous section simply plotted and compared the mean percentages for each of these variables. Moving forward, this research will statistically analyze simulation outcomes to determine if the mean of samples using various adjusted EMEDS is statistically different than the mean of outcome samples using the baseline EMEDS for patient streams of different sizes. This research adhered to a standard statistical methodology to correctly do hypothesis testing to compare sample means (Larsen and Marx, 2012).

Confidence Intervals

For each adjusted and baseline EMEDS facility, thirty independent and identically distributed replications were done using each individual patient stream.[19] During these runs, synchronized common random numbers were used as a variance reduction technique between consecutive runs where the only variable changed was the adjusted EMEDS facility. Doing so encourages corresponding replications of sequential runs to have a positive correlation with one another (Teledyne Brown Engineering, 2017). This allows the independent variable, the type of EMEDS facilities, to be more accurately comparable.

In the following notation, MTF_X refers to the individual EMEDS adjustments and $MTF_{Baseline}$ refers to an EMEDS+25 facility without any adjustments. Furthermore, i refers to an individual replication number where the patient stream, PS_N , and the MTF_X have not changed. In the following equation, $\mu_{D,\,PS,\,MTF}$, refers to the sample of mean patient outcome rates after thirty replications using an individual patient stream and MTF combination.

To calculate the difference, μ_D, between the simulated patient outcomes for an adjusted MTF and the patient outcomes for a baseline EMEDS one must simply subtract each replication's individual outcome variables from the corresponding baseline replication's outcome variable for each individual patient stream. That produces a sample of difference values which can be summed and averaged over the number of replications to produce the mean sample difference, $\bar{d}$, for each outcome variable. The following equalities illustrate this process:

$$\mu_{D,\,PS_N,MTF_X} = \begin{bmatrix} \bar{d}_{Evac,\,PS_N,MTF_X} \\ \bar{d}_{RTD,\,PS_N,MTF_X} \\ \bar{d}_{Mort,\,PS_N,MTF_X} \end{bmatrix} = \frac{1}{30}\begin{bmatrix} \sum_{i=1}^{30}(Evacs_{\,PS_N,MTF_X,i} - Evacs_{\,PS_N,MTF_{Baseline},i}) \\ \sum_{i=1}^{30}(RTDs_{\,PS_N,MTF_X,i} - RTDs_{\,PS_N,MTF_{Baseline},i}) \\ \sum_{i=1}^{30}(Mort_{\,PS_N,MTF_X,i} - Mort_{\,PS_N,MTF_{Baseline},i}) \end{bmatrix}$$

Where:

$$Mort_{\,PS_N,MTF_X} = DOW_{\,PS_N,MTF_X} + KIA_{\,PS_N,MTF_X}$$

By calculating the mean difference in the patient outcome rates for an individual MTF_X as compared to $MTF_{Baseline}$ we can test if $\mu_D = 0$ for each adjusted MTF and patient stream combination. This is done by first calculating the standard deviation for each sample of differences:

[19] To retrieve the output variables for individual replications within JMPT, a user-defined query must be run to access the data. The SQL code for such a query is presented as an appendix.

$$S^2_{D,\,PS_N,MTF_X,K} = \frac{\sum(d_{K,\,PS_N,MTF_X})^2 - \frac{\left(\sum d_{K,\,PS_N,MTF_X}\right)^2}{30}}{30-1}$$

where the variable K represents the patient outcome variables: *Evacs, RTDs,* and *Mort.* Once that is calculated, a confidence interval with $b-1$ degrees of freedom can be calculated:

$$\left(\bar{d}_K - t_{\alpha/2,b-1} * \frac{s_{D,\,PS_N,MTF_X,K}}{\sqrt{n}},\quad \bar{d}_K + t_{\alpha/2,b-1} * \frac{s_{D,\,PS_N,MTF_X,K}}{\sqrt{n}}\right)$$

such that:

$$\left(\bar{d}_K - 2.05 * \frac{s_{D,\,PS_N,MTF_X,K}}{\sqrt{30}},\quad \bar{d}_K + 2.05 * \frac{s_{D,\,PS_N,MTF_X,K}}{\sqrt{30}}\right)$$

at the $\alpha = 5\%$ confidence level with $n = 30$ simulation replications. If such a confidence interval does not include 0, a null hypothesis that $\mu_{D,\,PS_N,MTF_X,K} = 0$ can be rejected.

Paired T-Test

Paired t-tests provided another form of hypothesis testing which could be done using the same data. Using a similar procedure as above, a paired t-test can be done to test the hypothesis that two samples have an identical mean. In this research, this was done to compare the mean number of evacuations, RTDs, or deaths from a baseline EMEDS configuration to a configuration with some type of adjustment. The samples' mean difference and standard deviation could be calculated as shown above. With those values, a t-score and corresponding p-value could be calculated using the following equation:

$$t = \frac{\bar{X}_D - \mu_0}{S_D \Big/ \sqrt{N}}$$

Once the t-score was calculated the appropriate p-value could be determined. The p-value could then be used to determine whether to reject or fail to reject the null hypothesis that $\mu_{D,\,PS_N,MTF_X,K} = 0$.

Conclusion

This chapter has presented the casualty streams that were produced using MPTk and the process through which they can be analyzed in JMPT. Finally, this chapter included an introduction in how different EMEDS configurations can be designed and how their outputs can be statistically analyzed. The section on initial comparisons set the stage for improving the EMEDS system. The next chapter, however, will take a deep dive into how the baseline and adjusted EMEDS configurations perform when asked to treat casualties generated from fixed-base missile strikes.

6. EMEDS Improvements for Fixed Base Attacks

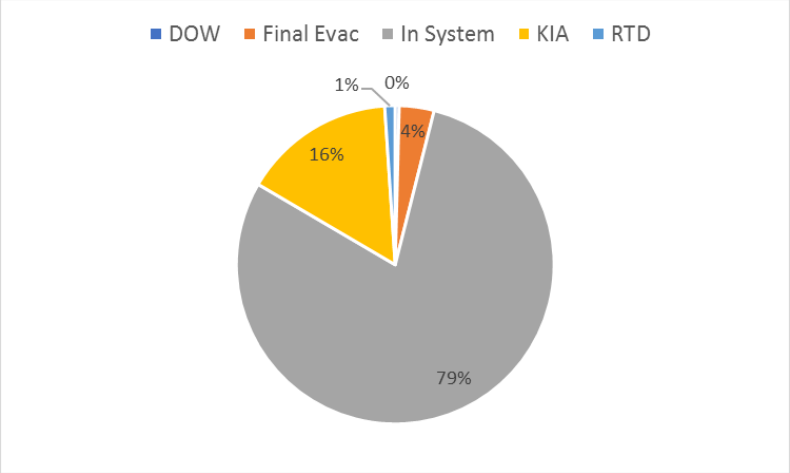
The primary mission of the EMEDS is to provide rapid medical care to patients from combat. Although the EMEDS has been employed in a number of non-combat events, the primary mission set remains combat casualty care. Therefore, a priority of this research is to identify ways in which the EMEDS system's ability to provide combat casualty care can be improved. This chapter presents alternatives for strengthening the EMEDS ability to better serve combat casualties.

A Closer Look at an Individual Patient Stream

In Chapter 5, we saw that the EMEDS+25 loses a significant percent of its capability once it is challenged to treat more than 1000 patients produced during an individual combat scenario. This section takes a closer look at what occurs when the EMEDS receives more than this critical level of patients.

Across thirty replications, one patient stream produced a mean of 1042 trauma patients, of 178 of which had life-threatening injuries. When the 1042 patients were treated by a medical network consisting of self-aid buddy care, first responders, and an EMEDS+25, a mean value of 165 of 178 patients with life-threatening injuries passed away. This represents only a 7.3% survival rate for patients with a non-zero mortality risk. Figure 6.1 below, illustrates that the vast majority of patients who attempt to receive care at the EMEDS remain in the EMEDS system after thirty days.

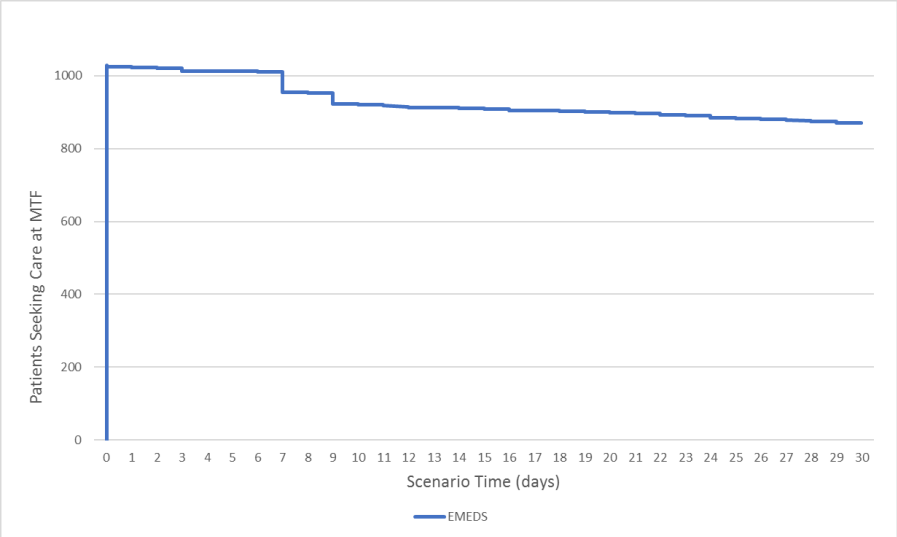
Figure 6.1 Patient Outcome Rates for 1042 Trauma Patients Treated in an EMEDS+25



The EMEDS+25 fails to provide effective medical care to the majority of this patient stream. However, it is important to note that the MTF was not designed to serve this type of large patient

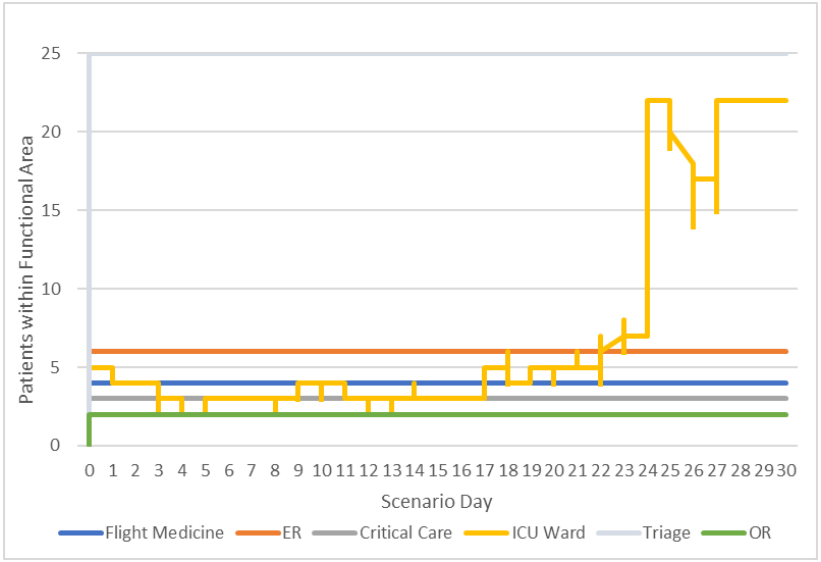
surge due to a mass-casualty event. As shown in Figure 6.2, patients rush into the MTF following a fixed-based attack and a few slowly trickle out from the MTF over the course of the thirty-day scenario. In the figure, the total number of patients within the EMEDS system (both inside the EMEDS and in line for care) is shown on the vertical axis. As time, shown on the horizontal axis, progresses only approximately two hundred patients are able to leave the system, including those who pass away.

Figure 6.2 Patients Seeking Care in an EMEDS+25 Over Time



Patients who have a low mortality risk make up 53% of the deaths in this baseline scenario. Furthermore, 96.7% of patients who die in the thirty replications of this scenario die in the triage FA. In this scenario, patient mortality is driven by the fact that the MTF is operating at its capacity. Without being able to process more patients, patients with even a low risk of mortality are not being treated and a significant number die.

Figure 6.3 Patients within Functional Areas Over Time



During the length of the scenario, four of the five core functional areas are operating at capacity. This is shown in figure 6.3, where time is again shown on the horizontal axis. The vertical axis now represents the number of patients within an individual functional area. In this example, more than 800 patients who are waiting for care outside the MTF are not shown.

The ICU ward is the only FA which does not rapidly reach capacity, but it does become full later in the scenario.[20] Capacity refers to the number of beds within an individual FA. The following table illustrates the capacity of individual FAs within the different EMEDS levels as well as the AFTH.

Table 6.1 Baseline Functional Area Casualty Limits Across MTFs

Functional Area	EMEDS HRT	EMEDS+10	EMEDS+25	AFTH
Flight Medicine	4	4	4	4
Critical Care Ward	3	3	3	12
Emergency Room	5	5	6	10
Operating Room	1	1	2	6
ICU Ward	4	7	22	46
Bed total	17	20	37	78

An observation can be made from table 6.1 and figure 6.3. In the table, it is clear that in terms of beds the only difference between the EMEDS+25 and EMEDS HRT is the addition of bed(s) in three FAs: the ER, OR and ICU ward. The ER and the OR are both given one additional bed. In contrast, the ICU ward has grown from 4 beds to 22 beds. However, from figure 6.3, it was noted that across thirty replications the ICU ward did not utilize more than 7 beds until day 24. This suggests that a recomposition of beds within the EMEDS may enable it to better treat MASCAL patients during at least the first three weeks of treatment.

Comparing the EMEDS's Capacity to the AFTH's Capacity

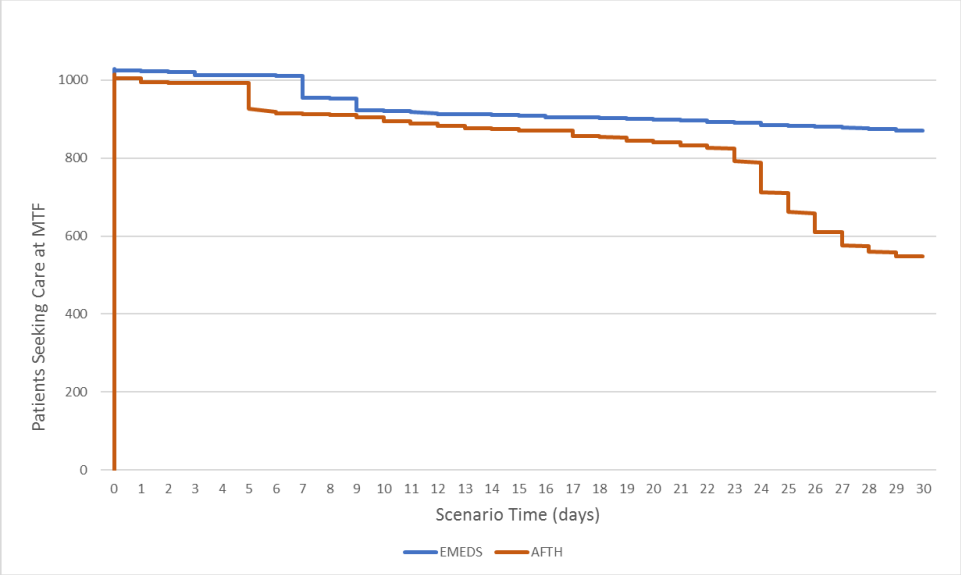
There are two lessons to be learned from comparing the EMEDS system to the AFTH system. As mentioned in the previous chapter, the capacity of the 58-bed AFTH presents an upper-bound on the EMEDS system. Since the Air Force intentionally maintains the AFTH system as a larger medical capability than the EMEDS+25 MTF, it will not expands the EMEDS to that size. The second takeaway from this comparison is that although the AFTH system has twice as many beds and personnel as the EMEDS+25 system, it can also be overrun with

[20] It is not clear what produces the influx of patients into the ICU ward on day 24 during this simulation run. Smaller patient streams see an influx of patients earlier in the thirty day simulation runs and some larger streams never observe such an event. This is likely due to survival rates of patients with mortality risks and the number of patients the MTF is trying to treat. However, this behavior presents an opportunity for future research to better understand how patients flow between FAs within the MTF.

patients. For both MTFs, when the system becomes overrun with patients it loses the ability to evacuate or return large numbers of patients to duty. This section illustrates both of these points.

The AFTH is slightly better at processing patients than the EMEDS+25. This is in part due to its increased capacity. The following figure, figure 6.4, presents the patient throughput when a patient stream, identical to the one used to generate figure 6.2, is treated using an AFTH. Fewer patients remain in the system when an AFTH is used. In this scenario, an AFTH is able to treat an average of 465 patients as compared to the EMED system's mean value of 205.

Figure 6.4 Patient Seeking Care in an EMEDS+25 and AFTH Over Time During Thirty Day Scenario



Expanding the FA capacity of the EMEDS to the point of the AFTH is not a viable solution for a variety of reasons. First, the Air Force already has a medical capability the size of an AFTH and likely does not require an additional capability of that nature. Secondly, the EMEDS is a three-stage system. Expanding the third variant of the system would require either the first and second stages to expand proportionately or would require a larger jump between the second and third stage. Both of these would come with their own logistical and manpower challenges. Therefore, this research attempted to capture improvement to the EMEDS+25 performance that exploited small overall adjustments.

The throughput graphic illustrates another finding as well. Until day 24, the gap between the AFTH and the EMEDS is not overwhelming. On day 10, the AFTH has only processed an average of 18 more patients than the EMEDS. This is due to the fact that the AFTH and EMEDS are both overwhelmed and attempting to treat the most severely injured patients. These patients require the most treatment and occupy hospital beds for long periods of time.[21] For the first three

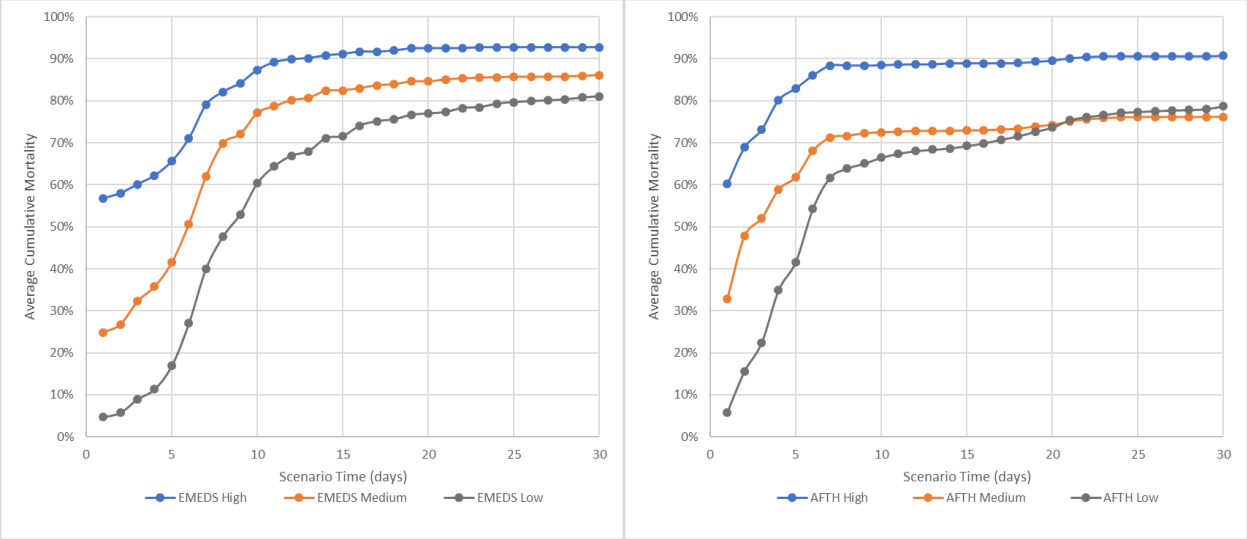
[21] Patient treatment times, as modeled within JMPT, differ between the two MTFs. Due to its increased capacity, the AFTH has additional time set aside for more patient rehabilitation for individual patient injury codes.

weeks neither facility is able to treat a high volume of patients while their focus is on higher risk patients. Only once the AFTH is able to move on to lower risk patients and patients with reduced or no mortality risks is it able to demonstrate its advantage over the EMEDS. Due to its size, the AFTH is vastly more challenging to deploy than the EMEDS system. A conclusion from this observation is that the Air Force has potentially more than two weeks following a large-scale patient event to mobilize larger medical capabilities before seeing a large drop-off in medical throughput if it is able to quickly supply a smaller medical capability such as the EMEDS.

Comparison of an AFTH vs. EMEDS on Mortality

When either the EMEDS+25 or the AFTH attempt to treat a patient load of just over a thousand patients the majority of patients with a mortality risk ultimately die. Previously it was shown that this is a result of congestion within the MTF that prevents individuals from receiving care prior to succumbing to their injuries. The following figure presents the mean cumulative mortality curve for the three mortality risk categories for both the EMEDS+25 and the AFTH.

Figures 6.5 and 6.6 EMEDS+25 and AFTH Average Cumulative Mortality Distributions in Combat Casualty Scenarios



The above figure plots six different mortality risk mortality curves. The horizontal axis represents time of the scenario. The vertical axis presents average cumulative mortality. Each data point presents the mean value from thirty replications. Each data point is the mean cumulative mortality for individual mortality risks at the end of each day of the scenario. For example, the left most point set of points for baseline EMEDS shows that on average 4.7, 25, and 57% of low, medium, and high-risk patients die during the first day. Likewise, at the end of the scenario 81, 86, and 93% of patients have died within each respective mortality risk group.

When a 58-bed AFTH is used to treat the same patient load, the mortality curves shift. Interestingly, mortality initially occurs more quickly for each mortality risk group. For both high and medium risk patients, the mortality curve begins to level off after day 7. This illustrates that

patients with severe injuries, if not quickly treated, have a high probability of dying. Between the EMEDS and the AFTH both high and low risk patient mortality are within one percent of each other. However, on average when an AFTH is used 10.8% fewer medium mortality risk patients die. As compared to a baseline EMEDS, even an overwhelmed AFTH does not have the time or resources to impact the survival of high risk patients. Eventually because of the size of the patient stream and constraints of the facilities, over 90% of high risk patients will die in either scenario. However, because the AFTH has more resources and space available they do eventually begin to focus on the surviving medium risk patients. This accounts for the significantly improved survival rates for this patient population. In both scenarios, the surplus of high and medium risk patients prevents the MTF from ever focusing on low risk patients. This explains why both MTFs have effectively the same mortality for low risk patients.

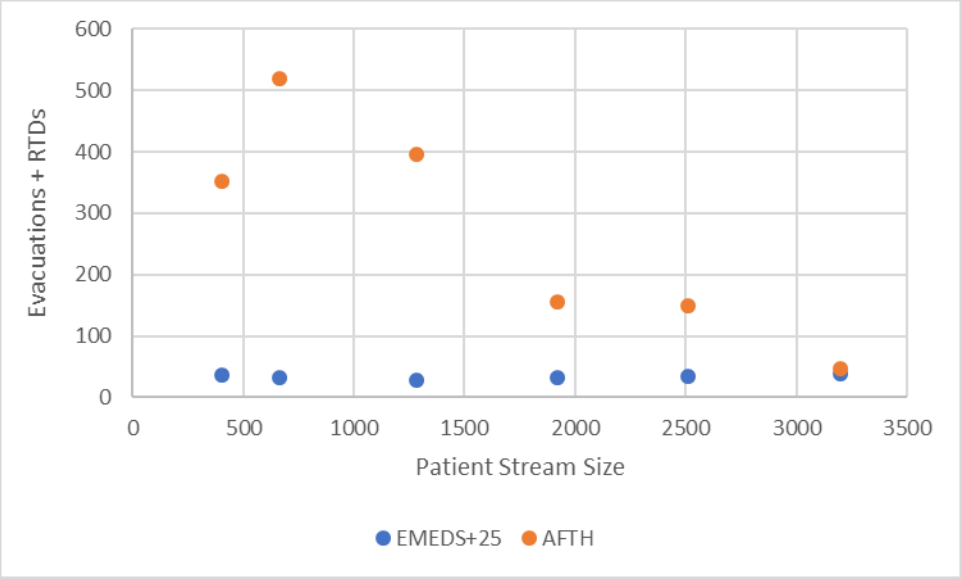
Comparison of an AFTH vs. EMEDS on Evacuations and RTDs

As explained, the AFTH has a larger capacity than the EMEDS. As such, after thirty days an AFTH is able to evacuate and return more patients to duty than an EMEDS. However, neither facility is able to treat the entirely of the patient stream.

The EMEDS+25 AFTTP does not reference estimated patient throughput for combat operations. However, for HA/DR missions it states that, “EMEDS HRT can triage and treat 350 patients per day with a surge capacity of 500” (AFTTP 3-42.71.2.4.2). However, the document does not specify what types of patients those 350 or 500 would be or how that number was calculated. Furthermore, that number is specified for the smaller EMEDS HRT and is not scaled to either the EMEDS+25 or the AFTH. When both of these MTFs are used to treat six different patient streams and the average number of evacuations are added to the average number of RTDs neither facility is able to achieve either of these estimates.

The following figure shows that regardless of patient steam size, the EMEDS+25 can discharge (evacuate or RTD) an average of 33.7 patients with a 95% confidence interval between 30.9 – 36.5. This accounts for roughly a single patient per day during a thirty day scenario. Meanwhile for patient streams of less than 1500 patients the AFTH can process an average of 422.4 (14.1 per day). For larger patient streams, the AFTH can only process an average of 117.2 (3.91 per day).

Figure 6.7 Patient Evacuations and RTDs from an EMEDS+25 and AFTH in Combat Casualty Scenarios



This figure illustrates that neither the EMEDS nor the AFTH is capable of processing nearly 350 patients per day when the patients are generated from missile strikes and when a significant portion suffer from severe, life-threatening injuries. In fact, both MTFs struggle to process 350 patients even after 30 days for the three largest patient streams. Furthermore, the figure illustrates another finding. The larger AFTH's performance presents a functional upper-bound on any adjustments made to the EMEDS system. Nonetheless, the following sections will present several ways to marginally improve the EMEDS system so that its performance more closely aligns with that of the AFTH's.

The value of the First Additional Bed in Combat Casualty Scenarios

The previous section illustrated the capacity challenges facing the EMEDS+25. In summary, the EMEDS must remain small and agile even though it may be tasked to process large numbers of patients. Small incremental changes to the EMEDS's capacity were explored in order to capture ways of strengthening the facility's treatment capabilities without forfeiting its rapid mobility and small footprint. If the EMEDS were to expand to include one additional bed, where is the most beneficial place, in terms of improving evacuations and returns-to-duty without increasing mortality, to add the bed?

Answering this question was accomplished by doing several thousand simulation runs of different attack patient streams. As explained, the EMEDS has six functional areas: triage, flight medicine, emergency room, operating room, Critical Care Ward, and the intensive care ward. The triage ward was not considered a viable location to place an additional bed. Several test simulation runs showed that adding additional capacity to the triage ward has no effect on patient outcomes. Furthermore, several simulation runs showed that the ICU ward's 22-patient capacity

is rarely fully utilized even for large attack patient streams. For instance, for one patient stream with 1917.1 mean patients over thirty replications, the peak number of patients present within the 22-bed ward was 6 even during a thirty-day scenario. With this in mind the ICU ward was not considered a potential recipient of an additional bed. This left four functional areas which could receive an additional bed: Flight Medicine, the ER, the OR, and the Critical Care Ward.

Design

The following patient streams were tested against the baseline EMEDS system and an EMEDS which had one additional bed:

Table 6.2 Mean Number of Patients After 30 replications

Patient Stream	Mean WIA
a2	418.1
a13	672.5
a4	1058.3
a9	1284.9
a12	1756.4
a17	1917.1

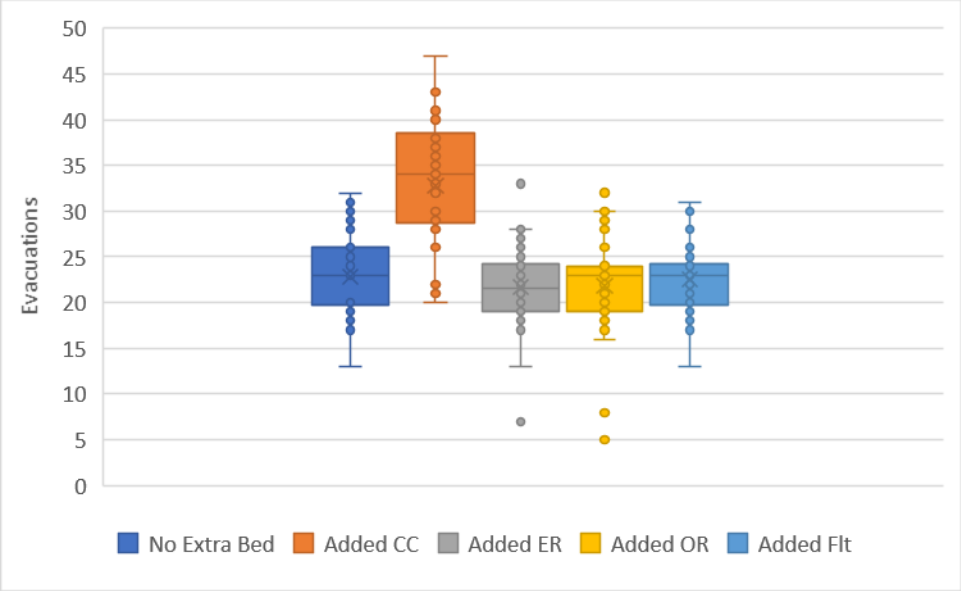
These patient streams were derived from combat scenarios and chosen due to their increasing number of average WIA patients. The following sections will show that, adding a bed to the EMEDS system can produce statistically significant results in each outcome variable. For three of the four core functional areas, an additional bed never led to an increase in mortality. Larger patient streams of more than 2000 average patients were not shown to be impacted by the addition of a single additional bed.

The six patient streams were first tested against five MTFs. The first of the five MTFs was the baseline EMEDS. The second consisted of identical patient streams with the baseline EMEDS plus an additional critical care bed. The same was done for the third, fourth, and fifth test using an additional bed in the ER, OR, and Flight Medicine FAs respectively. For each test, thirty replications were done and the methodology presented in chapter 5 was followed to determine the effect of the additional bed.

Value of an Additional Bed on Evacuations

When an additional bed is added to an EMEDS+25 which is asked to treat patient stream a4, which had a mean of 418.1 patients, the following results, shown in figure 6.8, are seen in terms of patient evacuations. Each box in the following boxplots consists of a sample of thirty replications.

Figure 6.8 Patient Stream a4 Evacuations from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios



The above figure shows the distribution of evacuation across the 30 replications. The five boxes represent different EMEDS designs. The first one, shown in dark blue, presents evacuations from an unadjusted EMEDS. The baseline EMEDS evacuates an average of 22.8 patients out of a4's total 1058.3 mean WIA.[22] Each of the other boxes represents a different EMEDS design in which an additional bed is added to the indicated FA. The first one from the left, shown in orange, presents the results of thirty replications of the same patient stream when treated with an EMEDS that has one additional critical care bed. Here, the mean has improved to 32.8. The next three boxes present the same information for EMEDS with additional ER, OR, and Flight Medicine beds. The means for those three simulations are 21.6, 21.9, and 22.5 respectively. Only adding a bed to the Critical Care Ward positively increases the mean number of patients evacuated. This is shown in more detail in the following table.

Table 6.3 Patient Stream a4 Mean Difference in Patient Evacuations with One Additional Bed

Additional Bed Location	Evacuations Mean Difference	95% CI
Critical Care Ward	+10.0	7.4 - 12.6
Emergency Room	-1.1	-2.9 - 0.6*
Operating Room	-0.9	-3.0 - 1.2*
Flight Medicine	-0.3	-1.2 - 0.7*

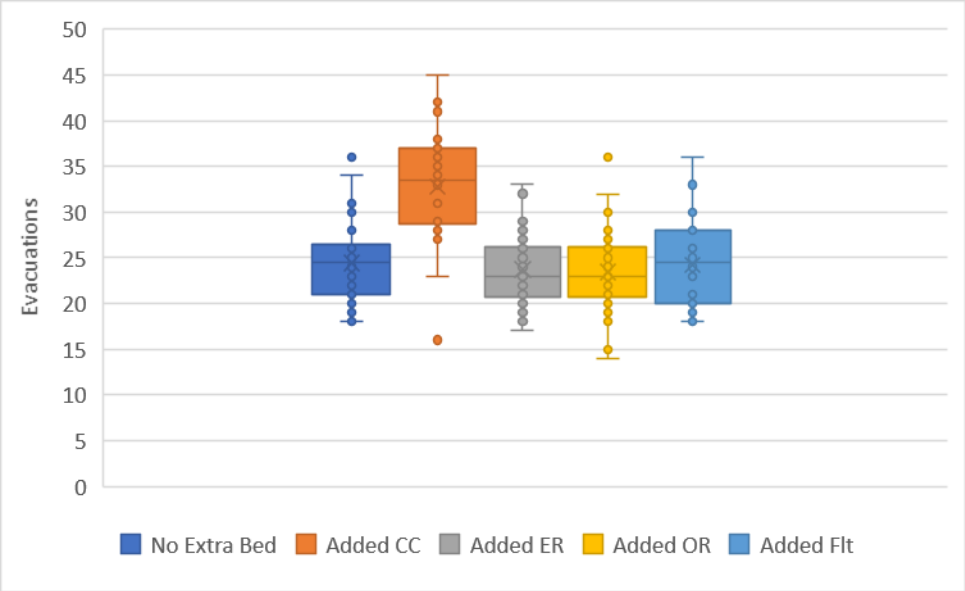
[22] A box and whisker plot presents several pieces of information. The graph illustrates data from a given sample of numbers. In this case, the sample of numbers for each box is comprised of the number of evacuations resulting from thirty replications with a given MTF. Within each box is an "X", representing the mean value of the sample. The body of the box, the portion which is filled in with a solid color, represents the range of the 2nd and 3rd quartile of the data. The lower and upper whiskers represent the 1st and 4th quartile of data respectively. The dots represent points which lie three standard deviations from the mean and can be considered outliers.

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level

Across thirty simulations with identical patient streams the EMEDS with an additional Critical Care Ward bed increases the number of evacuations in twenty-eight of the thirty replications. As shown by the confidence intervals in the above table, only the Critical Care Ward adjustment offers a non-zero, statistically significant increase in the overall mean evacuation rate.

These findings are reaffirmed when looking at results from other patient streams. The following figures presents the same information for simulations when tested again patient stream a9 with a mean WIA population of 1284.9 and patient stream a12 with a mean WIA population of 1756.4.

Figure 6.9 Patient Stream a9 Evacuations from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios



For patient stream a9, the baseline EMEDS evacuates an average of 24.5 patients. When beds are added to the critical ward, average evacuations increases to 32.8.[23] Again, we note that only the Critical Care Ward adjustment improves the EMEDS performance in terms of evacuations. A 95% confidence interval (5.9-

10.8) of the difference in mean evacuations shows that only the mean evacuations from the Critical Care Ward adjustment is statistically larger than baseline EMEDS system's evacuations.

The following table presents the mean differences in evacuations between the baseline EMEDS and the one where an additional critical care bed is added across the six patient streams we analyzed.

[23] An additional bed in the ER, OR or Flight Medicine FAs changes the average number of evacuations to 23.7, 23.4, and 24.2 respectively.

Table 6.4 Comparison of Adding a Critical Care Bed vs. the Baseline EMEDS on Evacuations from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	Baseline Mean WIA	Baseline Mean Evacs	+1 Critical Care Bed Mean Evacs	Baseline Mean Evac/WIA Rate	+1 Critical Care Bed Mean Evac/WIA Rate
a2	418.1	34.8	58.9	8.3%	14.1%
a13	672.5	29.8	47.8	4.4%	7.1%
a4	1058.3	22.8	32.8	2.2%	3.1%
a9	1284.9	24.5	32.8	1.9%	2.6%
a12	1756.4	21.8	29.4	1.2%	1.7%
a17	1917.1	20.6	28.7	1.1%	1.5%
Weighted Average		23.6	33.8	2.17%	3.26%

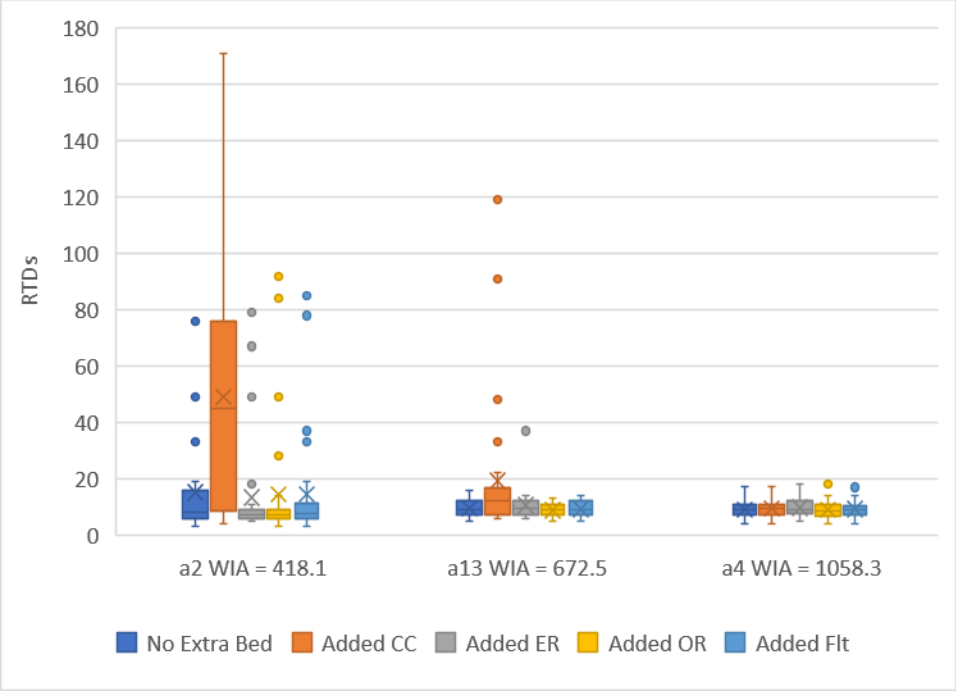
Across the six patient streams, the baseline EMEDS evacuates a weighted average of 2.2% of WIA patients. After adding one bed to the Critical Care Ward this number increases to 3.3%. This represents a 50.2% increase in the average evacuation rate for patients from MASCAL combat events. Increasing the size of the ward allows more patients to receive care and ultimately process through the system leading to more evacuations.

Value of an Additional Bed on Returns-to-Duty

A similar observation is made for the effect of an additional bed on return-to-duty rates. However, for RTD the marginal effect of an additional bed more quickly diminishes as the number of WIA patients increases. The following figure presents the range of RTD across thirty simulation replications for patient streams a2, a13, and a4. These patient streams consist of mean patient populations of 418.1, 672.5, and 1058.3 respectively. Within each group, the figure presents the five different EMEDS systems, the baseline EMEDS in blue and each of the four expanded functional areas.

For patient streams a4 (and larger patient streams a9, a12, and a17), which consists of slightly more than a thousand patients we see that a one-bed expansion has virtually no effect on RTDs. For this patient stream, the baseline EMEDS returns an average of 9.13 patients to duty. Adding an extra bed to the ER statistically improves the mean number of RTDs (95% CI +0.3 – 0.6) but by less than a single individual.

Figure 6.10 Patient Streams a2, a13, and a9 RTDs from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios



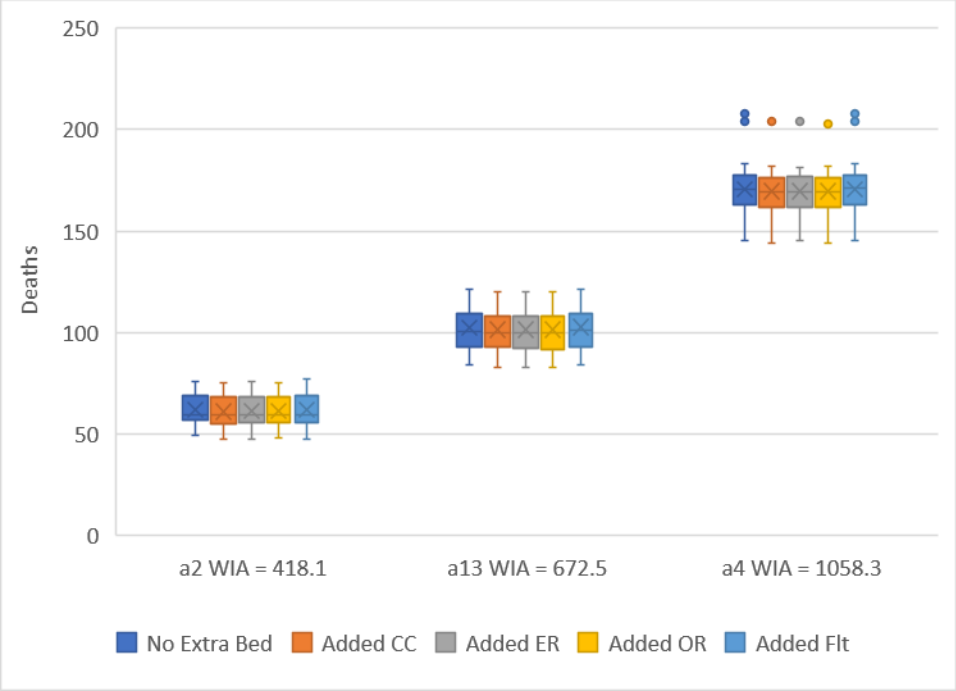
For the smaller patient stream of a13, adding a bed to the Critical Care Ward more than doubles the mean RTDs from 9.4 to 19.3. Again, an additional bed in the ER would improve the mean number of RTDs but not by a statistically significant amount (95% CI -0.5 – 2.9).

In the case of patient stream a2, the only statistically significant way to increase the mean evacuation rate by adding a bed is to expand to the Critical Care Ward. Doing so improves the mean RTD rate from 15.1 to 49.1, an increase of 225%. A 95% confidence interval for the difference in RTDs between the baseline EMEDS and an EMEDS with an expanded Critical Care Ward is between 20.3 and 47.9 with a mean difference of 34.1. The previous section showed that increasing with severe injuries are evacuated space is made available for patients with less severe injuries who can potentially RTD. This is why the number of RTDs from patient streams a2 and a13 can significantly increase but larger patient streams, such as a4, are not affected. For larger patient streams increasing the Critical Care Ward helps strengthen the facility but the number of patients prevent the MTF from ever treating those who would be able to RTD.

Value of an Additional Bed on Mortality

Increasing return-to-duty rates for small patient streams by as much as 225% or improving overall evacuations by 57% may not be worthwhile if there is a corresponding statistically significant increase in overall mortality. However, such a change in mortality is not seen in the data. The similarity in mortality between the baseline and adjusted MTFs is shown in Figure 6.11. In the figure, no difference in mortality is observable across three patient streams.

Figure 6.11 Patient Streams a2, a13, and a9 Deaths from an EMEDS+25 with One Additional Bed in Combat Casualty Scenarios



Across six patient streams which were tested using four MTFs which had been given an additional bed only four out of twenty-four times did the average mortality increase when compared to the baseline EMEDS. All four of these cases came for patient streams that were being tested against an MTF which had been given an additional bed for the flight medicine FA. Of these twenty-four comparisons, the mean mortality was bound between 98.5% and 100.2% of the baseline mortality. When only looking at the six comparisons done for MTFs which were given an additional critical care bed, the range is between 98.5% and 99.8%. None of these comparisons between the expanded Critical Care Ward and the baseline EMEDS were shown to be statistically significant in reducing mean mortality. Each of these six mean comparisons consists of thirty individual replications. Of the 180 replications which were done using differing patient streams to compare the baseline EMEDS and the one with an additional Critical Care Ward, only two had a larger number of KIA. In both cases, one additional individual died. In other words, adding an additional bed to the Critical Care Ward can dramatically improve evacuations and RTD rates without statistically increasing or decreasing mortality within the EMEDS+25.

The value of the Second Additional Bed in Combat Casualty Scenarios

The previous section demonstrated that if the Air Force allocated one additional bed to the EMEDS system the bed should be added to the Critical Care Ward in order to improve patient outcomes. The Critical Care Ward is one of three functional areas where mortality is reduced by adding an extra bed, albeit by a small amount, and is the only FA in which an added bed

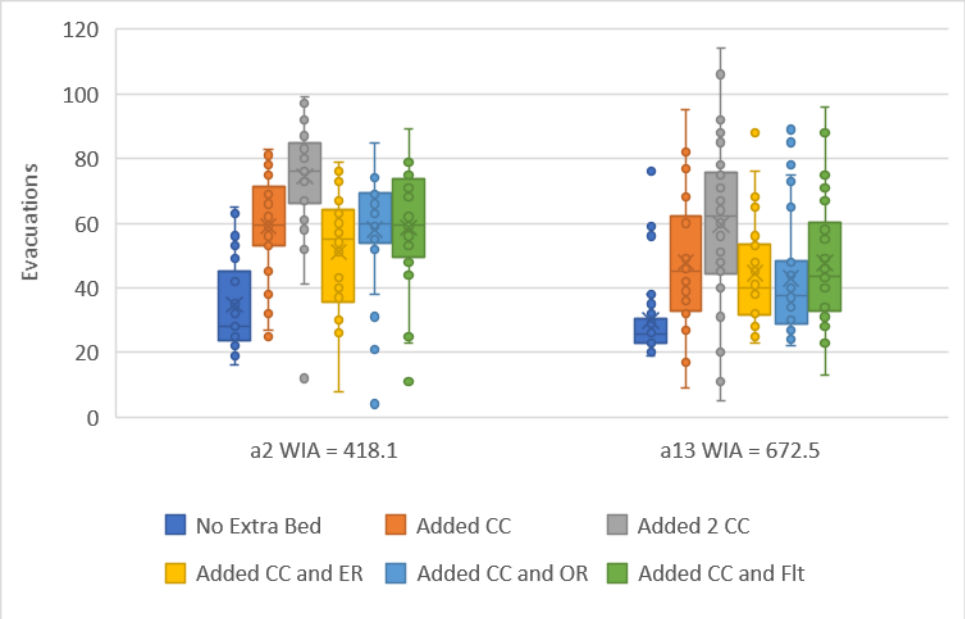
translates to statistically higher evacuations and returns-to-duty. In this section, a similar question is asked: how can patient outcomes be most improved by adding a second additional bed to the EMEDS?

There are sixteen different combinations of ways the Air Force could distribute two additional beds across four functional areas. However, we have already demonstrated that the first bed should be allocated to the Critical Care Ward. Therefore, this section will look at four new simulation scenarios in which a second additional bed is allocated to each of the core functional areas conditional on the first additional bed being placed in the Critical Care Ward.[24] These scenarios in addition to two scenarios analyzed previously – one using the baseline EMEDS and the other in which the Critical Care Ward was given an additional bed, comprise the six scenarios which will be analyzed here.

Value of Second Additional Bed on Evacuations

The following figure presents the results of these simulation runs for two patient streams a2 and a13 in terms of evacuations.

Figure 6.12 Patient Streams a2 and a13 Evacuations from an EMEDS+25 with up to Two Additional Bed in Combat Casualty Scenarios

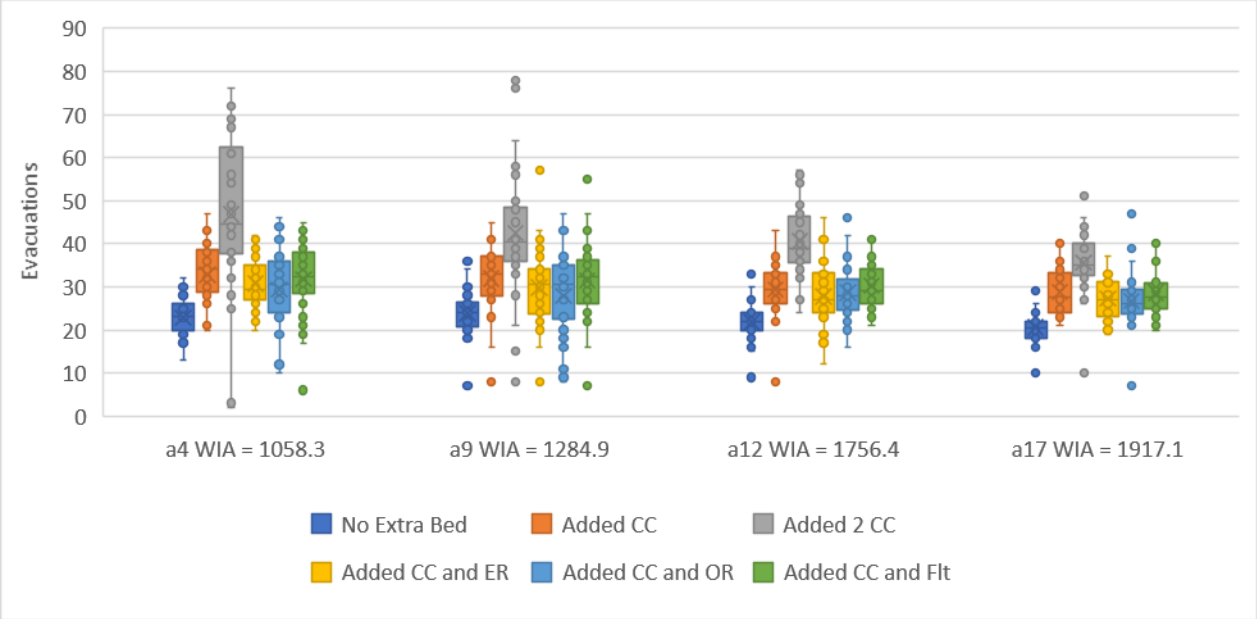


In the above figure, we see the results for the smallest two tested patient streams, labeled as a2 and a13. These patient streams have mean patients of 418.1 and 672.5 respectively. In the figure, we see the range of evacuations across thirty replications which occur in MTFs which

[24] A series of simulation runs using other combinations of bed placement was done that confirmed that there were no unanticipated interaction effects from untested combinations that would lead to more significant results. These runs confirmed that when two beds are added to the EMEDS, the first bed should be added to the Critical Care Ward in order to improve patient outcomes.

have an additional bed in the Critical Care Ward and a second bed in each of the four core FAs. For both patient streams, the same ranges are presents when the patients are flown through a baseline EMEDS and an MTF with an additional bed in the Critical Care Ward. Again, we note that adding a single bed to the Critical Care Ward improves the mean number of evacuations. Furthermore, we note that a second additional bed in the Critical Care Ward improves the mean number of evacuations. For patient stream a2 the mean number of evacuations jumps from 34.8 with no adjustments to 58.9 with the first additional bed in the Critical Care Ward and from there to 74.4 when a second bed is given to the same ward. Interestingly, the mean number of evacuations does not jump for the last three MTFs and in fact drops to 51.1, 57.9, and 58.6 respectively. For patient stream a13 we see similar results with the mean going from 15.1 to 49.1 and peaking at 107.3 when consecutive beds are added to the Critical Care Ward. Meanwhile, the mean drops to 43.0, 49.5, and 48.3 when the second bed is allocated to a separate FA. The same pattern is seen for the remaining four patient streams: the second additional bed, when added to the Critical Care Ward, increases evacuations.

Figure 6.13 Patient Streams a4, a9, a12, and a17 Evacuations from an EMEDS+25 with up to Two Additional Bed in Combat Casualty Scenarios



As explained previously, six patient streams were tested against four different MTFs which had been given a total of two additional beds. This produced twenty-four different samples of thirty replications. The mean number of evacuations for each of these twenty-four samples was found to be statistically larger than the mean number of evacuations when no additional beds were added. This was to be expected, however, because adding only one bed to the Critical Care Ward was found to be statistically different on its own. Therefore, a more appropriate comparison is not between the performance of these MTFs and the baseline EMEDS,

but between them and the MTF which had only been given one additional Critical Care Ward. In this way, we can address whether the second bed provides added value to the EMEDS.

Confidence intervals comparing the twenty-four samples and the samples where only one bed was added to the Critical Care Ward showed that the second bed is not statistically significant at the 95% significance level, in terms of the mean change in evacuations, in all cases. When the second bed was added to the Flight Medicine FA it was not statistically shown to improve the number of evacuations in any of the six patient streams. Furthermore, the change in the mean number of evacuations was only statistically different for three patient streams when placed in the ER and two patient streams when placed in the OR. However, for all six patient streams the mean number of evacuations was shown to statistically improve when the second bed was added to the Critical Care Ward compared to when only one bed was allocated to the Critical Care Ward. The change in the number of evacuations when the Critical Care Ward is expanded, relative to a baseline EMEDS, is shown in table 6.5 below.

Table 6.5 Comparison of Adding 1 vs. 2 Critical Care Beds on Evacuations from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	Baseline Mean WIA	Baseline Mean Evacs	+1 Critical Care Bed Mean Evacs	+2 Critical Care Beds Mean Evacs	Baseline Mean Evac/WIA Rate	+1 Critical Care Bed Mean Evac/WIA Rate	+2 Critical Care Beds Mean Evac/WIA Rate
a2	418.1	34.8	58.9	74.4	8.3%	14.1%	17.8%
a13	672.5	29.8	47.8	59.6	4.4%	7.1%	8.9%
a4	1058.3	22.8	32.8	46.8	2.2%	3.1%	4.4%
a9	1284.9	24.5	32.8	43.6	1.9%	2.6%	3.4%
a12	1756.4	21.8	29.4	40.5	1.2%	1.7%	2.3%
a17	1917.1	20.6	28.7	35.6	1.1%	1.5%	1.9%
Weighted Average		23.6	33.8	44.5	2.2%	3.3%	4.2%

Adding one critical care bed increases the weighted average evacuation rate from 2.2% to 3.3%. The table above shows that a second critical care bed increases the evacuation further to an average of 4.2% across patient streams of different sizes. The first bed increased the evacuation rate by 50.2% and the second bed increase it further by 30.1%. In total, two additional critical care beds increase the EMED's weighted average evacuation rate by 95.4% from 2.2% to 4.2%. Again, this increase in evacuations can be attributed to the Critical Care Ward being able to treat and process through more patients. The baseline Critical Care Ward has 3 beds and when it is increased to 5 beds it can evacuate almost twice as many patients.

Value of Second Additional Bed on Returns-to-duty

Previously we demonstrated that adding a single bed to the Critical Care Ward dramatically increases RTD rates for small patient streams. Patient streams a2 and a13 (418.1 and 672.5 mean WIA patients) had mean improvements of 226.1 and 105.3% respectively. However, the

remaining four patient streams with larger patient populations saw less than a 4.9% increase in mean RTDs. However, placing the first additional bed in a separate FA produces even lower results. Does adding a second bed anywhere in the EMEDS improve these rates or expand the improvements to larger patient streams?

The most frequently statistically significant (in terms of RTDs) place to put a second bed, having already put the first bed in the Critical Care Ward, is the ER. However, for five patient streams the difference in the means is negative. In other words, adding a second bed to the ER produces a net loss in overall RTDs. Therefore, the second bed should not be placed in the ER. This is shown in the following table.

Table 6.6 Comparison of Adding 1 Critical Care Bed and Adding 1 Critical Care Bed + 1 Emergency Room Bed on RTDs from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	Baseline Mean WIA	+1 Critical Care Bed Mean RTDs	+1 Critical Care Bed and +1 ER Bed Mean RTDs
a2	418.1	49.1	43.0
a13	672.5	19.3	17.5~
a4	1058.3	9.4	9.2
a9	1284.9	10.7	10.6
a12	1756.4	12.5	12.8~
a17	1917.1	12.9	12.5

A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which had already been given an additional critical care bed at the 95% confidence level

In only three of six cases was adding a bed to the OR statistically significant compared to the baseline EMEDS. Furthermore, in two of those three cases the mean improvement is less than one additional return-to-duty when compared to the MTF with one additional critical care bed. When a second bed is added to the Flight Medicine FA the same pattern is seen. In other words, adding a second bed to either the ER, OR, or Flight Medicine FAs can be statistically significant compared to the baseline but any improvements can be attributed to the additional Critical Care Ward bed and not the second bed, regardless of where the second bed is placed. This is shown by 95% confidence intervals of the mean difference between samples. In zero tests, was both the mean RTD rate improved by adding a second bed in the ER, OR, or Flight Medicine and the improvement statistically significant.

When the second bed is added to the Critical Care Ward, the results are also minimal. For only four patient streams was the mean number of RTDs statistically significant compared to the MTF with only one additional critical care bed. Furthermore, of these four patient streams the mean number of RTDs was increased by a value of more than one patient in only two cases. Again, the two patient streams which are the most dramatically improved are the smallest two. Adding a second bed to the Critical Care Ward expands the mean number of RTDs for patient stream a2 from 49.1 to 107.3. This value represents a 612% increase in RTDs as compared to the

baseline mean of 15.1 Meanwhile, expanding the Critical Care Ward to have two additional beds leads to a mean of 33.0 RTDs for patient stream a13. This value is 251% higher than the baseline value of 9.4 and 71% higher than the value of 19.3 when only one critical care bed is added.

Table 6.7 Comparison of Adding 1 vs. 2 Critical Care Beds on RTDs from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	Baseline Mean WIA	Baseline Mean RTD	+1 Critical Care Bed Mean RTDs	+2 Critical Care Beds Mean RTDs	Baseline Mean RTD/WIA Rate	+1 Critical Care Bed Mean RTD/WIA Rate	+2 Critical Care Beds Mean RTD/WIA Rate
a2	418.1	15.1	49.1	107.3	3.60%	11.75%	25.66%
a13	672.5	9.4	19.3	33.0	1.40%	2.87%	4.91%
a4	1058.3	9.1	9.4	9.4~	0.86%	0.89%	0.89%
a9	1284.9	10.6	10.7*	10.9~	0.82%	0.84%	0.85%
a12	1756.4	12.3	12.5*	13.6	0.70%	0.71%	0.77%
a17	1917.1	12.3	12.9	13.2	0.64%	0.67%	0.69%
Weighted Average		11.4	14.6	19.7	0.97%	1.60%	2.64%

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level
A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which had already been given an additional critical care bed at the 95% confidence level

If a second bed is added to the EMEDS, the best place to add it is the Critical Care Ward. However, the improvements to overall RTD rates are only experienced for patient streams which contain a mean of less than a thousand patients.

Value of Second Additional Bed on Mortality

Adding a second bed to the EMEDS does not increase overall mortality. Six patient streams were tested against MTFs where the second bed was added to each FA. Of the twenty-four outcomes, not a single result had a mean mortality value which exceeded the baseline mortality value. When the second be is added to the Critical Care Ward, the range of mortality drops by a minimum of 0.6% to a maximum of 3.3% as compared to the baseline EMEDS.

When the second bed is added to the Flight Medicine FA, four of six patient streams result in mean mortality which is greater than the mortality when only one bed was added to the Critical Care Ward. In these scenarios, the second bed makes the MTF worse from the perspective of mortality. It has already been demonstrated though that the second bed should not be added to the ER, OR, or Flight Medicine FAs from the perspective of evacuations and RTDs.

When the second bed is added to the Critical Care Ward, mortality drops by a statistically significant amount for five of six patient streams. However, as compared to the MTF which was only given one additional Critical Care Ward, the mortality drop is between 0.3% and 1.8% for these statistically significant patient streams.

Table 6.8 Comparison of Adding 1 vs. 2 Critical Care Beds on Mortality from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	Baseline Mean WIA	Baseline Mean Deaths	+1 Critical Care Bed Mean Deaths	+2 Critical Care Beds Mean Deaths	Baseline Mean Mortality	+1 Critical Care Bed Mean Mortality	+2 Critical Care Beds Mean Mortality
a2	418.1	62.0	61.1	60.0	14.8%	14.6%	14.3%
a13	672.5	102.3	101.5	100.6	15.2%	15.1%	15.0%
a4	1058.3	170.5	169.6	168.6	16.1%	16.0%	15.9%
a9	1284.9	208.2	207.1	206.1	16.2%	16.1%	16.0%
a12	1756.4	292.7	291.7	290.9	16.7%	16.6%	16.6%
a17	1917.1	321.2	320.4	319.1	16.8%	16.7%	16.6%
Weighted Average		235.3	234.4	233.4	16.3%	16.2%	16.1%

The above table shows how adding additional beds to the Critical Care Ward adjusted weighted average mortality for the six patient streams. The change for patient stream a9 was not found to be statistically significant. After adding one bed to the Critical Care Ward the mean mortality drops from 16.3 to 16.2%. When a second bed is given to the Critical Care Ward this drop another 0.1% to 16.1%. The final weighted average mortality is 16.1%.

Conclusions

If one bed is to be added to the EMEDS, it should be placed in the Critical Care Ward. If a second bed is also added to the EMEDS, it should also be placed in the Critical Care Ward.

Table 6.9 Change in Patient Outcome Rates from an EMEDS+25 in Combat Casualty Scenarios when Beds are added to the Critical Care Ward

Patient Outcome	Adding One Critical Care Bed	Adding Two Critical Care Beds
Change in weighted average evacuation rate	50.2%	95.4%
Change in weighted average return-to-duty rate for patient streams < 1000	180%	473%
Change in weighted average return-to-duty rate for patient streams > 1000	3.01%	6.41%
Change in weighted average mortality	-.65%	-1.18%

The above table presents the percent change in the mean patient outcome rates for the six patient streams we tested when one or two beds are added to the Critical Care Ward as compared to the baseline EMEDS+25. Although there is a minimal drop in the RTD rate for large patient streams and almost no drop in mortality, there are potentially very significant improvements in terms of evacuations. Furthermore, if there are fewer than 1000 WIA patients then expanding the Critical Care Ward by either one or two beds can capture large-scale improvements in the overall RTD rate.

Increasing Capacity and Equipment

JMPT models critical equipment within MTFs. Within an EMEDS+25 specifically, JMPT models and tracks the utilization of seven pieces of critical equipment. Table 6.10 presents baseline utilization rates for five pieces of critical equipment used in the treatment of casualties from fixed-base missile strikes.[25]

Table 6.10 JMPT Critical Equipment Utilization in an EMEDS+25 in Combat Casualty Scenarios

Critical Equipment	Mean Baseline Utilization Rate	Peak Baseline Utilization Rate	Minimum Baseline Utilization Rate
Patient Vital Signs Monitor	67.3%	99.0%	11.1%
Anesthesia Vaporizer	37.4%	73.1%	.04%
Portable Anesthesia Monitor	37.4%	73.1%	.04%
Anesthesia Field Apparatus	37.4%	73.1%	.04%
Defibrillator	0.1%	.23%	.01%

Table 6.10 includes three columns for utilization rates. Across simulation runs using all eighteen attack patient streams, the mean, peak, and minimum utilization rates were calculated using a baseline EMEDS. The value of 99.0% within the column for the peak utilization rate means of the eighteen patient streams, for one patient streams a patient monitor was utilized an average of 99.0% of the time across different replications of a thirty day scenario. Likewise, for a separate patient stream an individual monitor was only utilized an average of 11.1% of the time. The value of 67.3% under the column for the mean utilization rate means that across all Patient Vital Sign Monitors across all eighteen attack scenarios are utilized an average of approximately two thirds of the time during replications of a thirty-day scenario. This table shows that the Defibrillator is almost never used and that when the anesthesia devices are used they are used as a set. Finally, this brief analysis of equipment utilization illustrates that the Patient Vital Signs Monitor is the most frequently used piece of critical equipment. A baseline EMEDS+25 has eight total Patient Vital Signs Monitors. These monitors are used in the ER, OR, and Critical Care Ward whereas the anesthesia devices are only used in the OR.

This chapter has already shown that in MASCAL scenarios EMEDS+25 patient outcomes, particularly evacuations, could be improved if the Critical Care Ward were expanding to include one or two additional beds. Here, we show that adding additional critical equipment to the EMEDS could expand these benefits. Simulation runs showed that adding pieces of critical equipment which were not highly utilized had little to no effect on patient outcomes. Statistically significant improvements to patient outcomes were only seen when multiple Patient Vital Sign Monitors were added in conjunction with an expanded Critical Care Ward. Across multiple

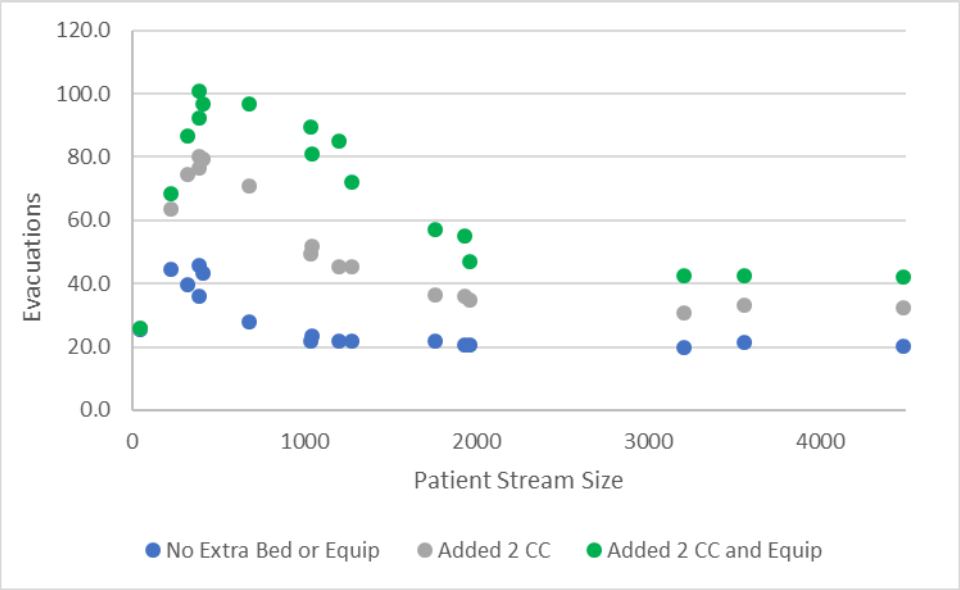
[25] JMPT also includes additional pieces of critical equipment such as a Resuscitator and a Ventilator that were not utilized in fixed-base scenarios due to the types of injuries produced most frequently during blast events.

patient streams, patient outcomes could be improved by adding up to three additional Vital Sign Monitors. After the third patient monitor was added, no additional benefit was shown unless the Critical Care Ward was expanded to a size that was not deemed viable. The following three MTFs were compared:

- Baseline: A baseline EMEDS+25 with no adjustments
- 2 CC: An EMEDS+25 which was given two additional critical care bed
- 2 CC + Equipment: An EMEDS+25 which was given two additional critical care bed and three additional patient vital signs monitors

The following figure, figure 6.14, presents the mean patient evacuation rates for eighteen attack scenarios using all three comparison MTFs. The figure illustrates that adding three Vital Signs Monitors, in addition to expanding the Critical Care Ward, can significantly increase overall evacuations relative to the case with two additional Critical Care Ward beds and relative to the baseline EMEDS. The mean number of evacuations for the largest patient stream for an EMEDS with critical equipment and an expanded Critical Care Ward, 38.6, is almost twice that of the baseline EMEDS+25, 20.5. For all but one patient stream tested the addition of critical equipment produces a mean evacuation rate which is statistically larger than the evacuation rate where only beds were added to the Critical Care Ward. The one patient stream which was not positively influenced by the addition of critical equipment was the smallest patient stream, a1, which already evacuates over 50% of its patient population.

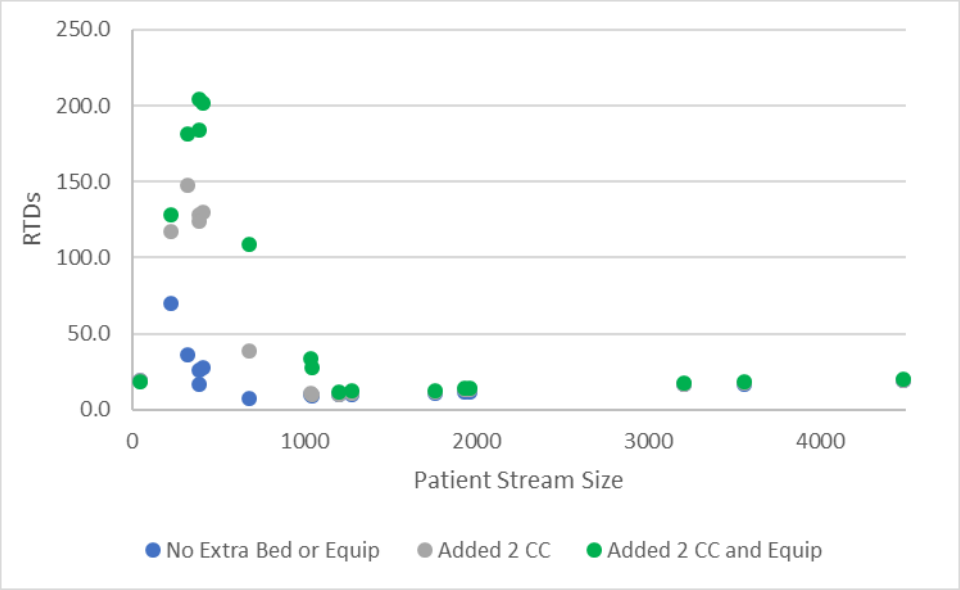
Figure 6.14 Evacuations from an EMEDS+25 with Two Additional Critical Care Beds with and without Additional Equipment in Combat Casualty Scenarios



The following figure, figure 6.15, presents the mean number of RTDs for the same three MTFs. Here we see that when the expanded Critical Care Ward MTF is given additional Patient Monitors, smaller patient streams are able to return more patients to duty. Again, however, there

are diminishing benefits as the patient stream sizes increase. However, the benefit of this adjustment extends to even the largest patient streams.

Figure 6.15 RTDs from an EMEDS+25 with Two Additional Critical Care Beds with and without Additional Equipment in Combat Casualty Scenarios



Patient streams a4 and a11 both have an average patient stream size of approximately a thousand patients, 1037.6 and 1046.9 respectively. When these patient streams are tested using an MTF with two additional critical care beds the effect on RTDs is not statistically significant. For patient stream a4 a 95% confidence of the interval around the mean difference in RTDs is between -0.5 and 2.4. For patient stream a11 the confidence interval is between -0.4 and 0.5. In both cases, the confidence interval includes zero and the effect of adding two additional beds to the Critical Care Ward cannot be said to increase RTDs.

When the same simulations are run with the addition of three Patient Monitors, the results change drastically. For patient stream a4 the new mean difference is 23.8 with a 95% confidence interval between 9.8 and 38.3 and for patient stream a11 the mean difference is 18.5 with an interval between 1.2 and 35.8. These patient streams represent the largest patient streams where this combination of adjustments has a large effect. The nine larger patient streams are each statistically significantly impacted by the adjustment in terms of the mean difference in RTDs, but the mean increase is less than 2.5 individuals for each patient stream.

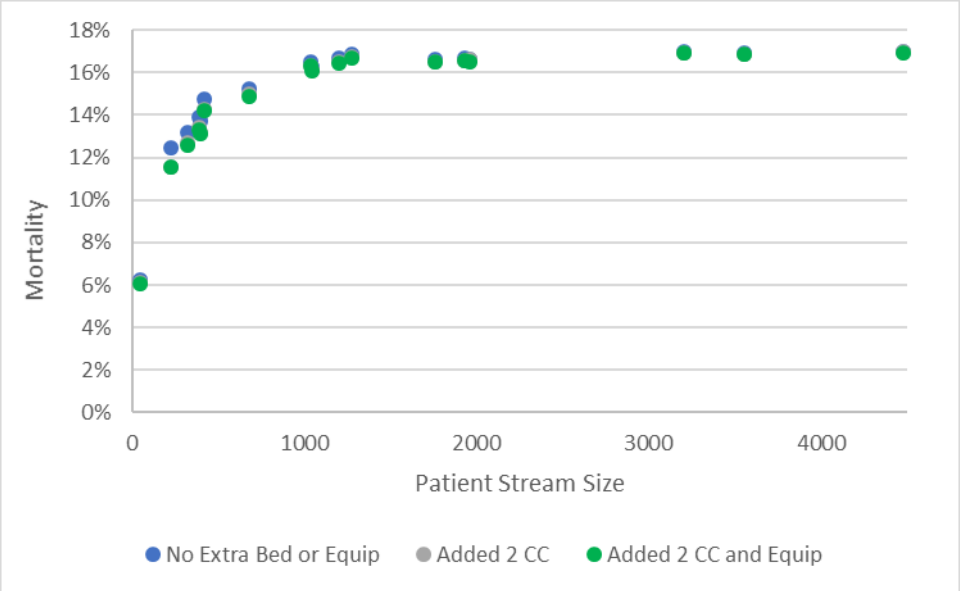
Table 6.11 95% Confidence Intervals for the Mean Difference in Patient RTDs in Combat Casualty Scenarios between a Baseline EMEDS+25 and an EMEDS with 2 Additional Critical Care Beds and 3 Additional Patient Vital Signs Monitors

Patient Stream Number	Mean WIA	Mean RTD Difference	95% CI
1	47.7	-0.4	-0.75 - 0.02*
3	222.7	58.7	42.3 - 75.1
7	319.7	145	120.6 - 169.4
16	386.9	166.9	141.5 - 192.4
10	392.3	177.6	158.8 - 196.3
2	414.4	174.2	151.3 - 197.1
13	677.0	101.4	80.2 - 122.6
4	1037.6	23.8	9.3 - 38.3
11	1046.9	18.5	1.2 - 35.8
8	1199.9	1.6	0.4 - 2.9
9	1278.2	2.2	0.7 - 3.7
12	1761.2	2	1.4 - 2.6
17	1931.1	2.4	1.7 - 3.2
18	1960.7	1.8	1.2 - 2.4
14	3204.1	1.1	0.5 - 1.7
15	3554.8	1	0.4 - 1.6
5	4480.7	0.7	0.4 - 1
6	4780.1	0.8	0.5 - 1.1

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level

The diminishing nature of the effects is show in the above table, table 6.11, and seen in the wide range of the confidence intervals. Nonetheless, for both patient streams the effect of adding two additional critical care beds along with three additional patient monitors can be said to be statistically significant in terms of increasing mean RTDs relative to a baseline EMEDS+25.

Figure 6.16 Mortality from an EMEDS+25 with Two Additional Critical Care Beds with and without Additional Equipment in Combat Casualty Scenarios



In the figure above we see that adding Patient Monitors on top of expanding the Critical Care Ward does not increase mean overall mortality. In fact, in the seventeen largest scenarios the mean mortality drops by a statistically significant amount. This is more clearly illustrated in the table below.

Table 6.12 95% Confidence Intervals for the Mean Difference in Patient Mortality in Combat Casualty Scenarios between a Baseline EMEDS+25 and an EMEDS with 2 Additional Critical Care Beds and 3 Additional Patient Vital Signs Monitors

Patient Stream Number	Mean WIA	Mean Mortality Difference	95% CI
1	47.7	-0.1	-0.16 - 0.03*
3	222.7	-2.0	-2.4 - -1.6
7	319.7	-2.0	-2.3 - -1.7
16	386.9	-2.4	-2.8 - -2.0
10	392.3	-2.3	-2.5 - -2.1
2	414.4	-2.3	-2.5 - -2.0
13	677.0	-2.3	-2.6 - -2.0
4	1037.6	-2.1	-2.5 - -1.7
11	1046.9	-2.1	-2.5 - -1.7
8	1199.9	-2.3	-2.7 - -1.9
9	1278.2	-1.9	-2.3 - -1.5
12	1761.2	-1.9	-2.3 - -1.6
17	1931.1	-2.5	-2.9 - -2.1
18	1960.7	-2.3	-2.8 - -1.9
14	3204.1	-2.0	-2.3 - -1.6

15	3554.8	-2.3	-2.7 - -1.9
5	4480.7	-2.5	-2.8 - -2.3
6	4780.1	-2.4	-2.6 - -2.2

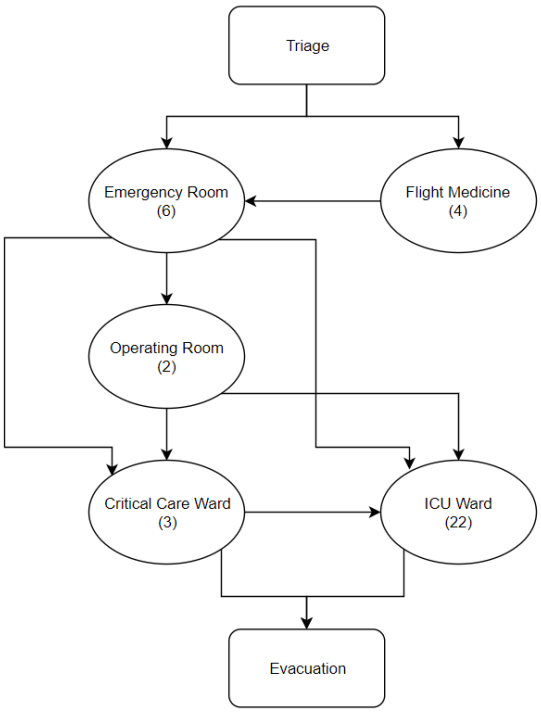
An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level

In the table above, we see that the EMEDS+25 is already able to address the demands of the smallest patient stream. When the facility is given additional equipment and capacity, it is not able to statistically improve mortality for such a small patient load. However, mortality drops by roughly 2 patients for each of the larger patient streams. Effectively, the two additional Critical Care beds, when combined with additional equipment, are saving one life per bed over the length of the scenario. This example illustrates the critical importance of equipment availability. JMPT assumes that once a patient exits the facility that the Patient Vital Sign Monitor they were using is available again. However, in reality the Air Force may assign that piece of equipment to the patient and have them utilize it throughout their transportation. In other words, facilities must have enough monitors to be able to address the medical demands of a large-scale scenario or have an ability to receive more during such an event.

Triage Protocol

Within JMPT each functional area has a treatment priority queue. When space becomes available in a functional area the patients who are highest in the queue are treated first. The treatment priority is predetermined based on the type of injury. The treatment priority relates to the triage protocol the MTF uses to determine how to allocate resources and who to treat. Adjusting this treatment priority significantly alters the course of a simulation scenario. The treatment priority does not directly adhere to the DIME or START triage protocols. Rather, the priority is built on a most injured to least injured priority scheme.

Figure 6.17 EMEDS+25 Patient Flow and Maximum Casualty Load



In understanding the treatment priority, it is important to recall that there is a specific route which every patient follows within the MTF. A figure illustrating this route is presented above. From the triage FA they enter the Emergency Room, but may be treated at Flight Medicine first. From the Emergency Room they can transfer to the Operating Room or go directly to either the Critical Care Ward or ICU Ward. From the Critical Care Ward they can either evacuate or process to the Ward before evacuating if necessary. Within the system patients can also RTD after receiving care at different functional areas or die while receiving or waiting for care.

Any adjustments to the triage protocol upstream of a certain FA will impact the patients who arrive downstream. In other words, if, for instance, the Air Force wanted to have the operating room prioritize medium mortality risk patients first, such as those who might be classified as *Immediate* in either the Dime or START triage protocols, in order to do this the adjusted priority scheme would also have to be introduced in the ER, flight medicine, and triage FAs.

Not only are there five functional areas but the fixed-base combat streams consisted of patients who had one of over 150 different injury types which could be ordered in any manner. There are virtually endless ways to adjust the patient priority queues based on individual patient conditions. This illustrates why such a complex process is simplified into the four categories of the DIME triage protocol or the sequential flowchart of the START process.[26]

[26] There are *150!* ways of ordering the 150 patient conditions within each functional area and even more when different patient streams are allowed to share an individual priority, as JMPT does. JMPT lists patient conditions on the priority list which proceeds from 1 to 999. Although there are only 150 patient conditions, their priorities are spread across the 999 values.

Within JMPT, the baseline EMEDS structures its priority queue from most injured to least injured. The patients with the most severe injuries receive care first. The following patient code, code *860_861_901*, which is a combination of three injuries, is considered the highest priority within the Operating Room. It translates to "traumatic pneumothorax and hemothorax & Injury to heart and lung & Injury to blood vessels of thorax." Several patient codes are ranked as the lowest priority such as "motion sickness" and "ingrowing nail."

A scenario was run in which five patients were generated who were suffering from PC *860_861_901*, the highest priority injury within JMPT. These patients entered the medical network and were treated by self-buddy aid and first responders. Across 100 replications, on average 2.49 patients arrived at the EMEDS. The other 2.51 patients died prior to entering the MTF. On average, 1.72 patients would exit the MTF through evacuation. The average patient would receive 22.85 hours' worth of tasks and spend 162.3 hours waiting between tasks. The majority of that time is spent in the ICU. Patients who survived the entire process spend as much as 5 days during the simulation occupying a bed in the ICU Ward recovering from their injuries. This simulation illustrates that even when they are the only patients to treat and the entire MTF can focus on them, the potential for a backlog exists if beds become occupied. The treatment priority, as it currently operates, inhibits the flow of low risk and non-life threatened patients through the hospital because hospital beds are occupied for several days at a time by higher risk patients. A patient will not be operated on if they will not be able to be transferred to a ward due to the fact that no beds are available. Therefore, low risk patients, who are at risk of dying, can become subject to long wait times (in some cases multiple days) prior to entering the MTF. Prioritizing one set of at-risk patients over another inherently exposes the other set of patients to longer wait times and therefore a higher probability of dying.

The OR ranks patient code *822.1*, open fracture of unspecified part of femur, is 48 on its list of treatment priority. In test simulations using a patient stream which has a mean patient stream size of approximately 2000 patients, fifty-five patients of this type arrive at the EMEDS to receive care. The majority, 91.1%, of these patients are given a low mortality risk. Across multiple replications in a baseline EMEDS, each of these patients passed away because none ever received care. This illustrates that patients with serious, yet survivable conditions are not surviving fixed-based attacks due to the inability of the MTF to reach them in the queue. There is a surplus of high risk patients who are treated first and quickly occupy critical space within the system.

Design

Within each functional area individual patient conditions have designated stabilization times. These times represents how long patients of individual types are required to remain in an FA after receiving care. Within the ward this time ranges from zero to twenty-four hours. However, in the Critical Care Ward (where there are far fewer beds) the time can be as high as 120 hours for some patient conditions. This time is not directly correlated with patient priority queue, as

some patients as low as 544 out of 999 on the treatment priority list are required to remain for 120 hours while some as high as 18 are only required to remain in the FA for a day.

Across thirty replications using a baseline EMEDS and a fixed-base attack patient stream with an average of about one thousand patients, 11 patient conditions account for 51.1% of the deaths. 59.2% of these patients have a low mortality risk. It is clear that low-risk patients make up the majority of deaths and that certain injuries, if treated, could account for a large quantitative increase in overall survival. The treatment priority protocol can be adjusted to better allow patients who would be able to survive their injuries without occupying a ward bed to quickly move through the system. Several alternative treatment priority systems were designed across the five functional areas. The following system proved to be the most effective at improving patient outcomes:

- Triage, ER and Flight Medicine FAs: Adjust treatment priority to ensure priority equity among those with low risk, predominately fracture-type injuries who require 0 hours stabilization in order to allow them to process further into the MTF.
- Operating Room FA: Leave unchanged as no patients require stabilization time within the OR and patients should be operated on in a first-in first-out (FIFO) manner.
- Critical Care Ward FA: Adjust treatment priority to ensure priority equity among all those who require 0 hours stabilization in order to quickly facilitate patient evacuation and return-to-duty prior to long-term stabilization of patients with longer stabilization times.
- Ward FA: Leave unchanged due to its large overall capacity.

The above adjusted treatment priority strategy allows low risk patients with a high likelihood of survival along with non-life threatened patients with a high likelihood of returning-to-duty to enter the system quickly in order to be efficiently processed before a backlog develops. This strategy allows low risk patients to be treated and exit the system many of whom would have otherwise died outside of the triage FA waiting for care.

An additional priority that was tested was to treat patients who had a medium mortality risk first. This was done to mimic the DIME and START triage processes which focuses on patients who are not expected to die but have series life-threatening injuries. This was accomplished by analyzing the patient conditions where individuals were most frequently classified as having a medium mortality risk.[27] These patient conditions were then elevated in the priority queue. However, when this priority strategy was used the EMEDS+25 system did not produce better patient outcomes in terms of evacuations, RTDs, and mortality across several patient streams.

A large majority of the patients face non-life threatened injuries. Within the DIME and START triage processes these would be labeled as minimal or minor. The most frequent two

[27] There is no way within JMPT to isolate only individuals of a certain mortality risk. For instance, a scenario may consist of 20 individuals who share a patient condition where 2 have a high mortality risk, 14 have a medium mortality risk, and 4 have a low mortality risk. If this patient condition was ranked first in the priority queue all 20 individuals would be elevated. The only exception is when an individual patient condition never results in patients of more than one mortality risk. This occurs for patient conditions where no patient ever has a mortality risk.

patient conditions are two types of concussions. “Concussion, unspecified” and “Concussion, with loss of consciousness of unspecified duration” collectively accounted for 46.0% of the overall patient pool for a representative attack patient stream.

A third treatment priority system was developed which elevated patients with concussions above all others in the priority queue. This prioritization was designed not because patients with concussions are more important, but because if an MTF could quickly process 46.0% of its patient population it could dramatically reduce the overall burden and prevent future backlogs within the system. This treatment priority, however, did not perform as well as the aforementioned treatment priority strategy. The primary reason this treatment priority strategy failed to improve the EMEDS was because of the stabilization time required for patients with a concussion. Regardless of whether or not a patient who has a concussion loses consciousness, there is a minimum stabilization time of 24 hours within the Critical Care Ward. Furthermore, patients who lose consciousness are required to spend another 12 hours in the ICU ward. This produces a backlog as patients enter the wards but are unable to exit for up to a day. During this wait time, patients who are at risk of dying are exposed to a higher, prolonged risk of death. In reality, the Air Force could establish a separate concussion triage protocol that enabled individuals who do not have life-threatening intercranial injuries to exit an MTF and receive treatment elsewhere. JMPT is not currently able to accurately model how this process would occur in a real-life combat scenario.

Thirteen of the eighteen attack scenarios were tested using the adjusted treatment priority strategy to determine the impact the adjustment has on patient outcomes. Five patient streams were not tested due to the fact that they were so similar to other patient streams in both volume and patient condition distributions. These tests consisted of consecutively running an attack scenario through two medical networks. As with previous tests, the first medical network consisted of the self-buddy aid, a first responder, and a baseline EMEDS+25. The second test consisted of the same medical network but with an adjusted EMEDS. The adjustments came in the form of the treatment priority scheme introduced above where patients with different patient codes are given a higher priority over other patients in several functional areas. Several replications of these simulations were done for each of the thirteen attack scenarios to be able to compare a sample of results from the baseline EMEDS to the adjusted EMEDS to determine if there was a statistical difference between the two.

Patient Outcomes from Adjusted Priority Strategy

Across thirteen attack scenarios, adjusting the patient priority strategy significantly increases patient throughput in terms of evacuations and returns-to-duty. However, using the adjusted strategy leads to a modest increase in overall mortality.

Impact of Adjusted Priority Strategy on Evacuations in Combat Casualty Scenarios

Across thirteen attack scenarios, the baseline EMEDS is able to evacuate a mean of 9.6% patients. However, that number is skewed by several of the patient streams which have fewer than seven-hundred patients. These patient streams each evacuate more than 10% of the overall patient population while larger patient streams, such as patient stream a4 which has 1045.8 mean patients, are only able to evacuate 2.5% of its population. In fact, the weighted average number of evacuations from a baseline EMEDS is only 2.3% of patients. This is presented in the following table.

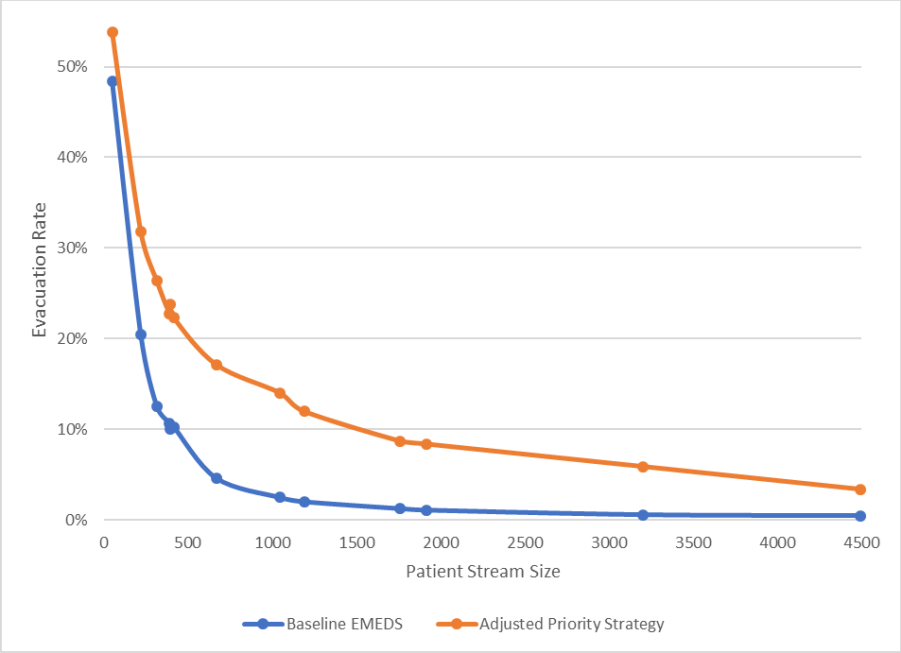
Table 6.13 Comparison of Patient Priority Strategy on Evacuations from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	Mean WIA Patients	Baseline Mean Evacs	Adjusted Priority Strategy Mean Evacs	Baseline Mean Evac/WIA Rate	Adjusted Priority Mean Evac/WIA Rate
a1	51.0	24.7	27.4	48.4%	53.8%
a3	220.9	45.1	70.2	20.4%	31.8%
a7	315.9	39.5	83.3	12.5%	26.4%
a10	392.2	41.8	89.3	10.7%	22.8%
a16	394.6	39.6	93.9	10.0%	23.8%
a2	416.8	42.6	92.8	10.2%	22.3%
a13	668.2	30.7	114.3	4.6%	17.1%
a4	1045.8	25.8	146.3	2.5%	14.0%
a8	1191.7	23.7	142.4	2.0%	11.9%
a12	1759.2	21.7	152.8	1.2%	8.7%
a17	1917.7	20.6	160.1	1.1%	8.3%
a14	3200.7	18	188	0.6%	5.9%
a5	4490.7	20.9	151.3	0.5%	3.4%
Weighted Average		23.5	150.4	2.33%	9.28%

The table above and the figure below illustrate that although the adjusted priority strategy improves evacuations for all patient streams, the magnitude of the improvement is dependent on the size of the patient population. Confidence intervals of the mean difference in evacuations showed that for all thirteen attack scenarios tested, the sample of simulation runs using the adjusted priority strategy was statistically significant when compared to the baseline EMEDS.

The figure below demonstrates that the largest improvement in the mean evacuation rate comes for patient streams with fewer than 1000 patients. Beyond that there are still meaningful improvements, but they diminish as patient population increases.

Figure 6.18 Evacuation Rate from a Baseline EMEDS+25 and an EMEDS using an Adjusted Priority Strategy in Combat Casualty Scenarios



Impact of Adjusted Priority Strategy on Returns-to-duty in Combat Casualty Scenarios

The adjusted priority strategy improves the overall RTD rate. This is a result of the fact that patients who were otherwise unable to be processed through the EMEDS's different functional areas under the original treatment priority queue are now able to advance to available beds. The newly prioritized patients who otherwise would not be treated are able to be processed quickly and do not have a required stabilization time.

When the adjusted priority strategy is employed RTD rates can jump from less than one percent to almost 40% of the overall patient population. This is shown in the table below.

Table 6.14 Comparison of Patient Priority Strategy on RTDs in Combat Casualty Scenarios

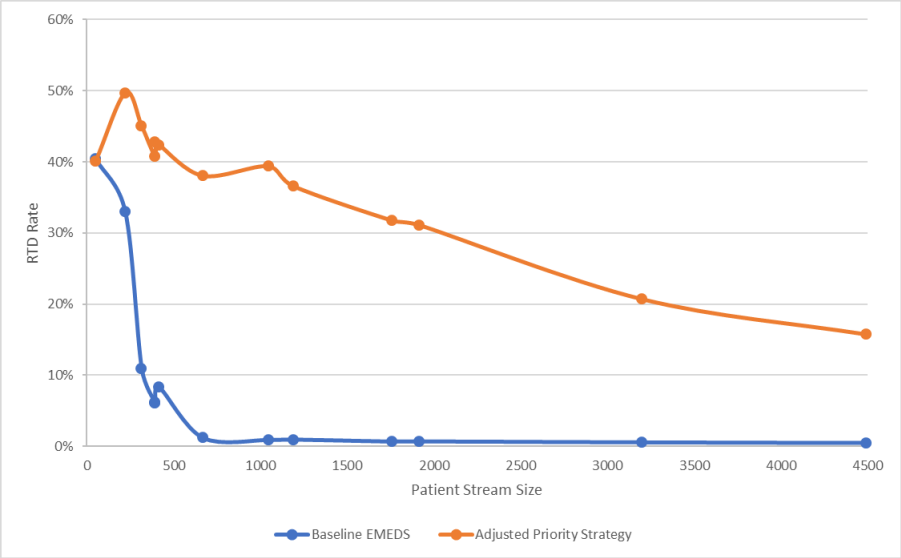
Patient Stream	Mean WIA Patients	Baseline Mean RTDs	Adjusted Priority Strategy Mean RTDs	Baseline Mean RTD/WIA Rate	Adjusted Priority Mean RTD/WIA Rate
a1	51.0	20.6	20.4*	40.4%	40.1%
a3	220.9	72.8	109.7	32.9%	49.7%
a7	315.9	34.3	142.0	10.9%	45.0%
a10	392.2	24.3	159.8	6.2%	40.8%
a16	394.6	24.1	168.7	6.1%	42.8%
a2	416.8	34.4	176.4	8.3%	42.3%
a13	668.2	7.8	254.0	1.2%	38.0%
a4	1045.8	9.2	411.6	0.9%	39.4%
a8	1191.7	11.0	435.4	0.9%	36.5%
a12	1759.2	11.4	558.2	0.6%	31.7%

a17	1917.7	12.8	595.8	0.7%	31.1%
a14	3200.7	17.0	662.3	0.5%	20.7%
a5	4490.7	20.3	707.8	0.5%	15.8%
Weighted Average		17.4	550.4	1.75%	27.4%

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level

Unlike with evacuations, the adjusted priority queue improves the RTD rate for even large patient stream sizes. As shown in the figure below, although the degree of the improvement does diminish, a jump from virtually zero RTDs to more than 20% and 15% for the largest two patient streams respectively is still observed.

Figure 6.19 RTD Rate from a Baseline EMEDS+25 and an EMEDS using an Adjusted Priority Strategy in Combat Casualty Scenarios



Confidence intervals of the mean difference in RTDs show that twelve of the thirteen samples which include the adjusted priority strategy are statistically larger than identical samples which are treated using the baseline EMEDS. The only exception is the smallest patient stream which already has an RTD rate of over 40%. For that sample which represents the results from simulations run against a patient stream of only 51 patients, using the adjusted priority strategy did not demonstrate a statistically significant improvement.

Impact of Adjusted Priority Strategy on Mortality in Combat Casualty Scenarios

The adjusted priority strategy results in slightly increased overall mortality. For thirteen attack scenarios, analysis shows that twelve of the thirteen patient streams have statistically higher rates of mortality when treated using the adjusted priority strategy than when treated with

a baseline EMEDS. Again, the exception is the smallest patient stream which already has less than half the mortality of any of the other patient streams.

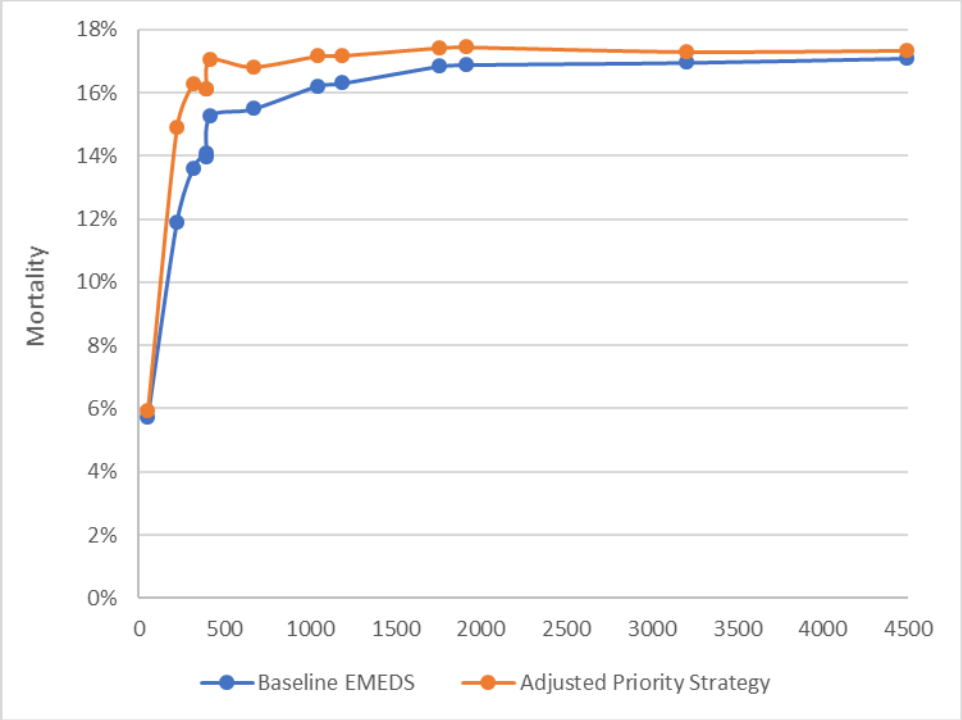
Table 6.15 Comparison of Patient Priority Strategy on Mortality in Combat Casualty Scenarios

Patient Stream	Mean WIA Patients	Baseline Mean Deaths	Adjusted Priority Strategy Mean Deaths	Baseline Mean Mortality	Adjusted Priority Mean Mortality
a1	51.0	2.9	3.0*	5.8%	6.0%
a3	220.9	26.3	32.9	11.9%	14.9%
a7	315.9	43.0	51.4	13.6%	16.3%
a10	392.2	55.3	63.2	14.1%	16.1%
a16	394.6	55.1	63.6	14.0%	16.1%
a2	416.8	63.6	71.0	15.3%	17.0%
a13	668.2	103.5	112.4	15.5%	16.8%
a4	1045.8	169.6	179.5	16.2%	17.2%
a8	1191.7	194.3	204.7	16.3%	17.2%
a12	1759.2	296.3	306.5	16.8%	17.4%
a17	1917.7	323.9	334.6	16.9%	17.4%
a14	3200.7	542.7	553.8	17.0%	17.3%
a5	4490.7	767.5	778.6	17.1%	17.3%
Weighted Average		430.5	440.8	16.5%	17.2%

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level

The table above and the figure below illustrate that both the baseline EMEDS and an EMEDS with an adjusted priority strategy have an effective mortality steady state for large patient streams. In other words, once a patient population exceeds a thousand patients the baseline EMEDS has a weighted average mortality of 16.9% and the adjusted EMEDS has a mean mortality of 17.3%. For all but one patient stream presented in the table below, the increase in mortality was found to be statistically significant. The one exception was patient stream a1 which is the smallest patient stream.

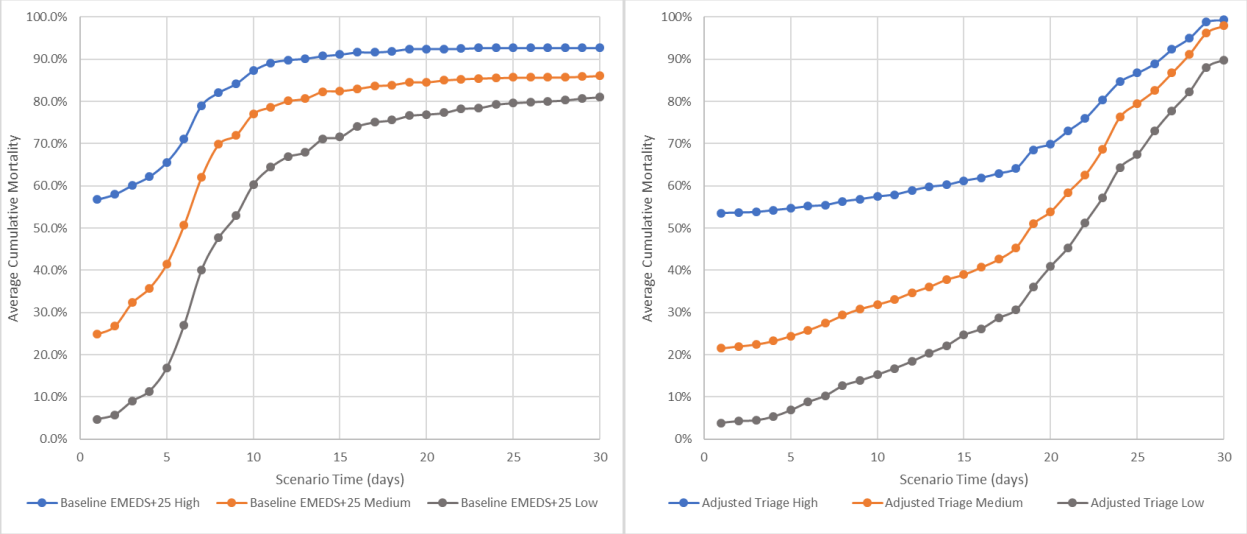
Figure 6.20 Mortality from a Baseline EMEDS+25 and an EMEDS using an Adjusted Priority Strategy in Combat Casualty Scenarios



Change in Mortality Curve Shape

In table 6.13 it was shown that the baseline EMEDS has a weighted average mortality of 16.5% when asked to treat patient stream a4. When the EMEDS employs the adjusted priority scheme the mortality changes to 17.2%. This difference was found to be statistically significant and, out of the 1046 patients, account for an average of 9.8 patients. This pattern was seen for numerous patient streams. However, when the rate of mortality across different mortality risks is viewed graphically, it is clear that the adjusted triage system reduces mortality for a portion of the thirty day scenario. This is shown in figures 6.20 and 6.21 below.

Figures 6.21 and 6.22 EMEDS+25 and Adjusted Triage EMEDS+25 Average Cumulative Mortality Distributions in Combat Casualty Scenarios



The above figures plot the same baseline EMEDS mortality curves for patient stream a4 that were presented in figures 6.5 and 6.6. In addition to those plots, three mortality curves are plotted presenting the cumulative mortality of patients when an the adjusted priority scheme is used.

The figure illustrates that the majority of mortality occurs, when the baseline EMEDS is used, before day 10. Furthermore, regardless of the MTF, more than 50% of high risk patients die by the end of the first day. By the end of the scenario, the adjusted protocol has higher cumulative mortality rates for each mortality risk. This confirms what was shown in table 6.15. However, what is not shown in the table is that it is not until day 28 that the adjusted protocol individual cumulative mortality curves slightly exceed the baseline EMEDS cumulative mortality curves.

This indicates that a potential triage strategy could employ the alternative patient priority scheme during the first wave of a medical response to an attack scenario before defaulting to the baseline priority scheme after predetermined number of days. On day 18, each of the three adjusted priority strategy trends accelerates in slope while the corresponding baseline trends have each leveled off. On the start of the 13th day the difference between the baseline cumulative mortality curves and the adjusted priority scheme cumulative mortality curves is the largest. At this point the net differences between the cumulative mortality curves are 49, 45, and 31% for low, medium and high-risk patients and the baseline EMEDS has a mean of 2.1 times as many overall deaths as the adjusted priority EMEDS does. Changing the priority scheme a day or two before either of these inflection points may allow the patient population to transition to the baseline mortality curve and result in reduced mortality. A more thorough analysis would be

required to analyze the patient outcomes if multiple patient priority schemes were to be used within a single MTF across different days.[28]

Combing Adjusted Priority Strategy and Expanded Critical Care Ward Capacity

We have shown that the most effective functional area to place an additional bed in is the Critical Care Ward. We showed that an additional critical care bed can increase the mean evacuation rate by 57% from 3.2% to 5.0%. Furthermore, we showed that for smaller patient streams expanding the Critical Care Ward could significantly increase RTDs. Meanwhile, this adjustment resulted in a net decrease in overall mortality. Secondly, we showed that adding a second Critical Care Ward bed expanded these improvements by increasing evacuations and RTDs while further reducing mortality. After that, we saw that additional equipment could further improve the benefits captured by expanding the Critical Care Ward. In the previous section, we analyzed the impact of a fourth adjustment strategy. This adjustment strategy focused on the treatment priority scheme within each functional area. We showed that making a small adjustment to prioritize patients with no additional stabilization time could dramatically improve evacuations and RTDs. However, we also identified that such an improvement might increase overall mortality by an overall average of 1.3%. In this section, we analyze the combined effect of two of these changes: expanding the Critical Care Ward with one or two additional beds and adjusting the triage system.[29]

Design

In this section, we analyzed the combined effects of two previously explained methods by doing two additional simulation run sets. In the previous section we explained how we analyzed the effect of adjusting the treatment priority queue by running consecutive simulations where the baseline EMEDS was used for a patient stream before the same patient stream was tested using a medical network which included an EMEDS system with an adjusted priority queue. In this section, we do the same process but with two additional simulation sets: one where the adjusted priority queue EMEDS is given an additional Critical Care Ward bed and a second where it is

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[28] JMPT allows multiple MTFs to be modeled within a single network. These MTFs can be scheduled to open or closed for each day of a scenario. This capability could be used to model a second MTF arrive to an event several days after an initial MTF arrived. However, if one MTF were to be "switched off" so that patients would then seek treatment at a second MTF which had a different prioritization protocol the transition would not be seamless. For instance, patients who were in the act of receiving care at the first MTF would have to exit the MTF and enter the new MTF back at the triage FA.

[29] When these simulation runs were accomplished, no replications were in which where the EMEDS facility was given additional critical equipment. Further research could analyze whether or not addition equipment would improve patient outcomes when an adjusted priority strategy is employed with or without additional critical care capacity.

given two additional beds. In total, we accomplished this set of four simulation sets using the baseline EMEDS, the adjusted priority EMEDS, the adjusted priority EMEDS with one additional Critical Care Ward bed, and the adjusted priority EMEDS with two additional Critical Care Ward beds. These simulation sets were done for the same thirteen attack scenarios as the previous section. The results of those simulations are presented below.

Combined Effect of Different EMEDS Adjustments on Evacuations in Combat Casualty Scenarios

Statistical tests showed that the mean evacuations for an EMEDS which uses the adjusted priority strategy and has an additional critical care bed is statistically significantly higher than the mean number of evacuations for an EMEDS which only uses the adjusted priority strategy for ten of our thirteen scenarios. The three exceptions where patient streams a1, a13 and a12 shown in the table below to have 51.0, 668.2 and 1759.2 average patients respectively.

Table 6.16 Combined Effect of Different EMEDS Adjustments on Evacuations in Combat Casualty Scenarios

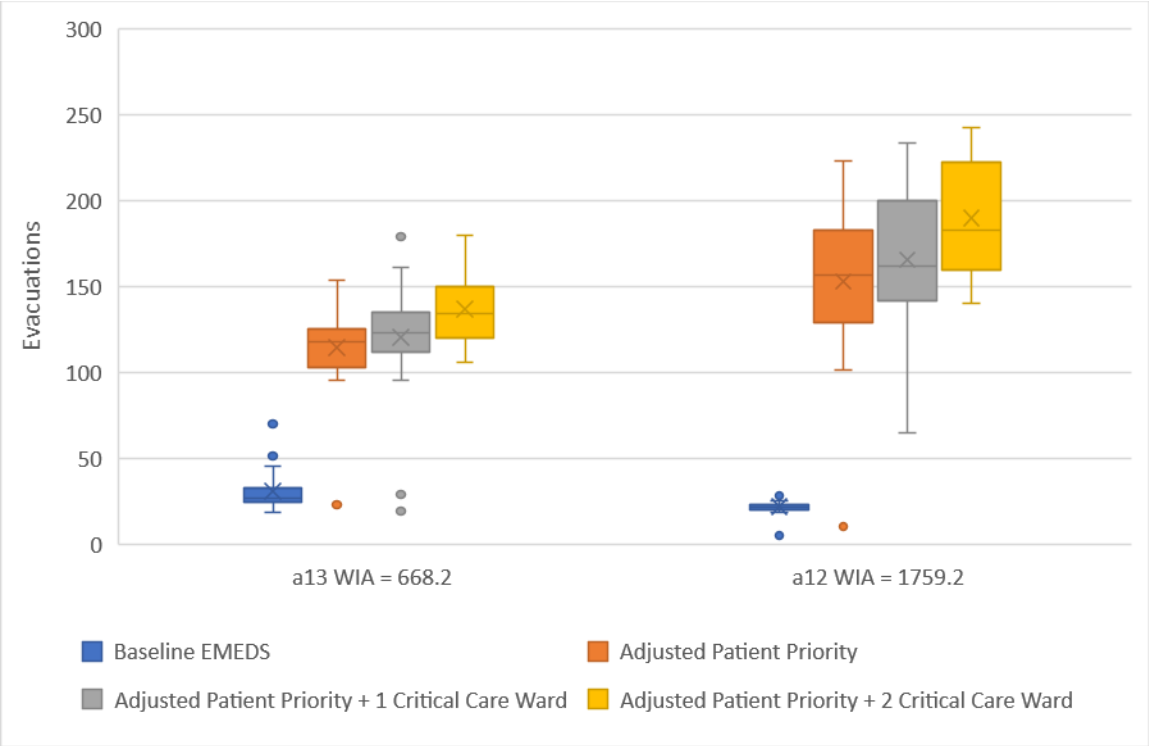
Patient Stream	Mean WIA Patients	Baseline Mean Evacs	Adjusted Priority Strategy Mean Evacs	+ 1 Critical Care Bed Mean Evacs+	Adjusted Priority Strategy + 1 Critical Care Bed Mean Evacs	Adjusted Priority Strategy + 2 Critical Care Bed Mean Evacs
a1	51.0	24.7	27.4	25.6	27.5	27.6
a3	220.9	45.1	70.2	35.8	73.3	74.5
a7	315.9	39.5	83.3	60.4	92.6	96.2
a10	392.2	41.8	89.3	61.2	100.2	110.9
a16	394.6	39.6	93.9	63.1	105.3	109.6
a2	416.8	42.6	92.8	62.6	101.8	107.7
a13	668.2	30.7	114.3	47.9	120.5	137.0
a4	1045.8	25.8	146.3	33.2	152.9	158.9
a8	1191.7	23.7	142.4	29.8	159.5	165.0
a12	1759.2	21.7	152.8	28.6	165.8	190.1
a17	1917.7	20.6	160.1	29.7	179.8	193.0
a14	3200.7	18.0	188.0	26.4	230.0	220.0
a5	4490.7	20.9	151.3	25.9	169.4	170.4

+In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding one bed to the Critical Care Ward relative to the other adjustments presented above.

With the adjusted priority strategy, patient stream a1 improves slightly from its baseline evacuation number of 24.7 to 27.4. However, because the patient stream is small to begin with there is little remaining room for improvement. Therefore, once the Critical Care Ward is expanded the additional beds are not able to service additional patients. This results in the

additional beds not providing statistically significant improvements for the patient stream. This does not explain why the samples for patient streams a12 or a13 are not statistically significant. The following figure presents a boxplot for these patient streams. Each box consists of the results from the thirty replications in which the patient stream was tested using the corresponding EMEDS or EMEDS adjustment. We can observe that for both patient streams, the average number of evacuations increases. However, compared to the already adjusted EMEDS the improvement appears minimal. For patient stream a13 two outliers remain far below the mean, offsetting the mean difference calculation that the mean is statistically greater than the mean of the adjusted EMEDS without an additional critical care bed.

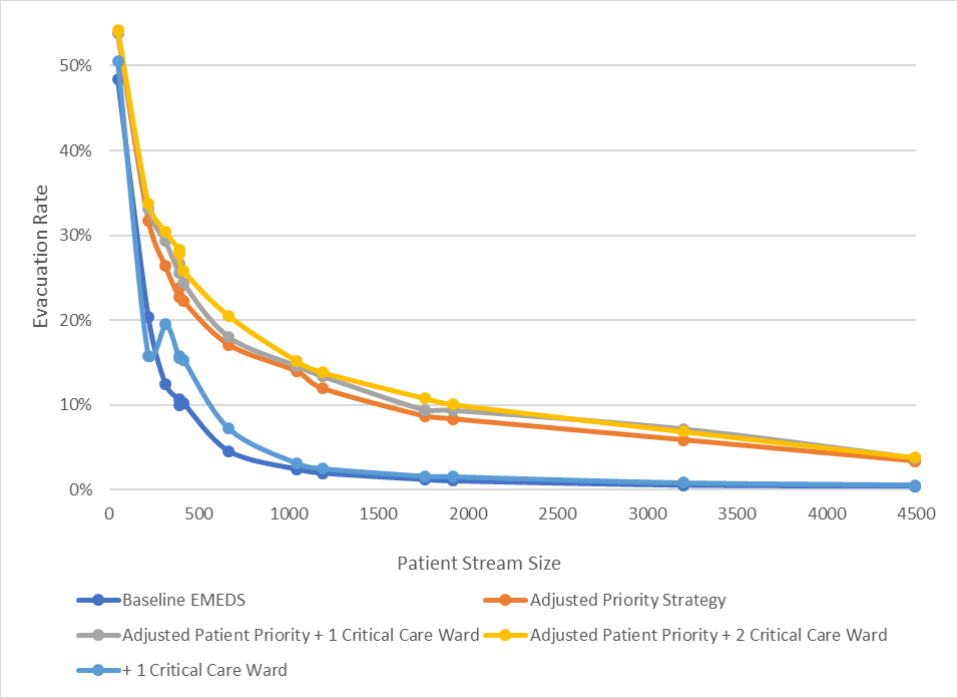
Figure 6.23 Patient Streams a13 and a12 Evacuations from an EMEDS using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios



For all thirteen of our attack scenarios, adding two critical care beds was shown to be statistically significant when compared to only adjusting the patient priority scheme. The figure below illustrates, however, that the adjusted priority strategy, in orange, produces the largest increase in evacuations compared to the baseline. The improvements beyond that point are minimal, though statistically significant.

The figure below also includes a light blue line which reflects the evacuations from only adding one critical care bed with the traditional patient priority scheme[30]. Expanding the Critical Care Ward improves evacuations for patient streams with fewer than one thousand patients. Beyond that, the figure illustrates the need for an adjusted priority strategy in order to improve evacuations. The figure also demonstrates combining these two adjustments can lead to modestly improved results.

Figure 6.24 Evacuations Rates from an EMEDS with and without using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios



Combined Effect of Different EMEDS Adjustments on Returns-to-duty in Combat Casualty Scenarios

Previously, we have shown that when the baseline patient priority strategy is adjusted to prioritize patients who have a reduced or no stabilization time the EMEDS is able to return a significant number of additional patients to duty. Furthermore, when the baseline EMEDS is given an additional critical care bed, the number of RTDs also increases but only for patient streams with fewer than one thousand patients. When these two adjustments are combined the EMEDS is further improved, albeit only slightly.

T-tests show that for seven of our thirteen attack patient streams, adding a bed on top of the adjusted patient priority strategy produces samples which are statistically significant when

[30] The data presented for this sample were generated separately from the rest of the figure and as a result were generated using thirty different random values. These values were not generated using common random numbers and as such have higher variances.

compared to the samples where the bed had not been added. However, when a second bed is added this number improves to ten of thirteen.

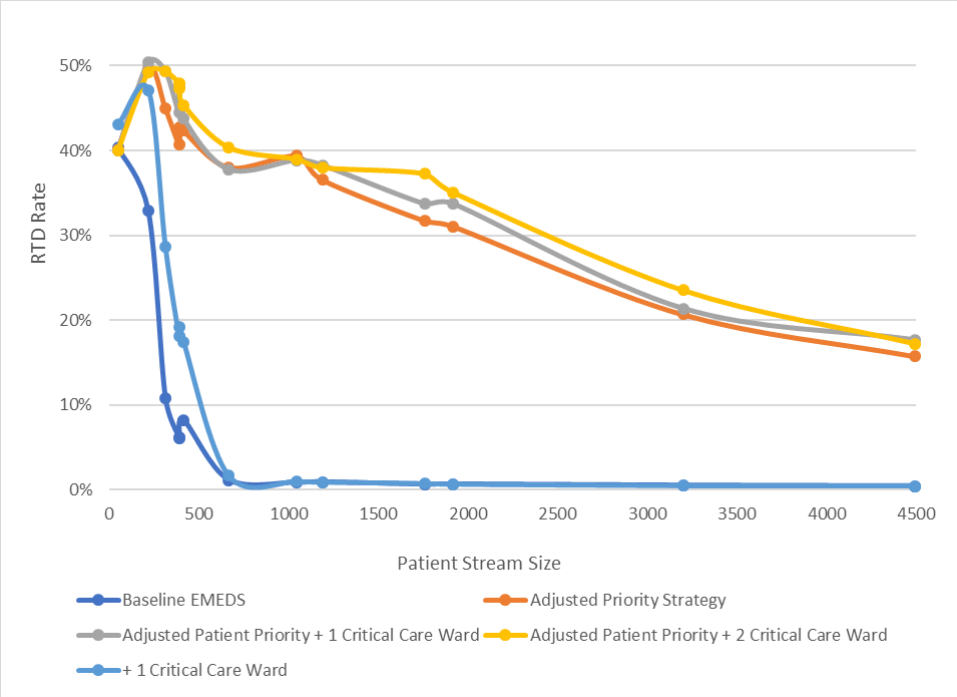
Table 6.17 Combined Effect of Different EMEDS Adjustments on RTDs in Combat Casualty Scenarios

Patient Stream	Mean WIA Patients	Baseline Mean RTDs	Adjusted Priority Strategy Mean RTDs	+ 1 Critical Care Bed Mean RTDs+	Adjusted Priority Strategy + 1 Critical Care Bed Mean RTDs	Adjusted Priority Strategy + 2 Critical Care Bed Mean RTDs
a1	51.0	20.6	20.4	19.0	20.4	20.4
a3	220.9	72.8	109.7	116.9	111.3	108.8
a7	315.9	34.3	142.0	147.2	155.9	155.9
a10	392.2	24.3	159.8	124.2	174.3	188.0
a16	394.6	24.1	168.7	127.9	188.2	186.9
a2	416.8	34.4	176.4	129.7	182.6	189.2
a13	668.2	7.8	254.0	38.4	252.2	269.8
a4	1045.8	9.2	411.6	10.7	406.1	407.9
a8	1191.7	11.0	435.4	10.0	455.6	452.8
a12	1759.2	11.4	558.2	12.1	592.8	655.7
a17	1917.7	12.8	595.8	13.0	646.5	672.7
a14	3200.7	17.0	662.3	16.9	683.6	753.2
a5	4490.7	20.3	707.8	19.5	793.4	774.6

+In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding one bed to the Critical Care Ward relative to the other adjustments presented above.

The table above illustrates that although a dramatic improvement is made when the adjusted priority strategy is employed compared to the baseline strategy, the same scale of improvements is not seen when additional bed capacity is added. However, for ten of the thirteen patient streams, adding two beds is statistically significant. Two of the three patient streams which are not further improved by adding two critical care beds are patient streams a1 and a3, the smallest two patient streams. This is likely due to the fact that the EMEDS is already handling these patient streams as well as possible. Patient stream a8 is the only other outlier. This patient stream actually has fewer RTDs when a second bed is added as compared to only one additional bed is added.

Figure 6.25 RTD Rates from an EMEDS with and without using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios



The figure above illustrates the RTD rate across the thirteen patient streams when sorted based on their patient population size. The baseline EMEDS is able to return a large portion of its population back to duty for small patient streams, but this quickly drops off to less than 1% when there are as fewer as a thousand patients. Adding one Critical Care Ward improves the initial performance and delays the drop off, but inevitably the same results are seen. When the adjusted priority strategy is employed as much as 15% of the population can RTD even for extremely large scenarios. A clear yet small improvement is shown between the orange and yellow lines when two additional critical care beds are added in conjunction with the adjusted priority scheme.

Combined Effect of Different EMEDS Adjustments on Mortality in Combat Casualty Scenarios

Although adjusting the patient priority strategy dramatically increased evacuations and RTDs, we previously showed that those improvements in patient processing came with an increase in overall mortality. When using the baseline patient priority strategy, expanding the Critical Care Ward was shown to have no corresponding increase in overall mortality. Unfortunately, when these adjustments are combined an increase in overall mortality remains.

Overall mortality increases slightly when the patient priority strategy is adjusted. When critical care beds are added on top of that adjustment the mortality drops slightly. The following table presents the average mortality for thirty replications of each patient stream tested across four MTFs.

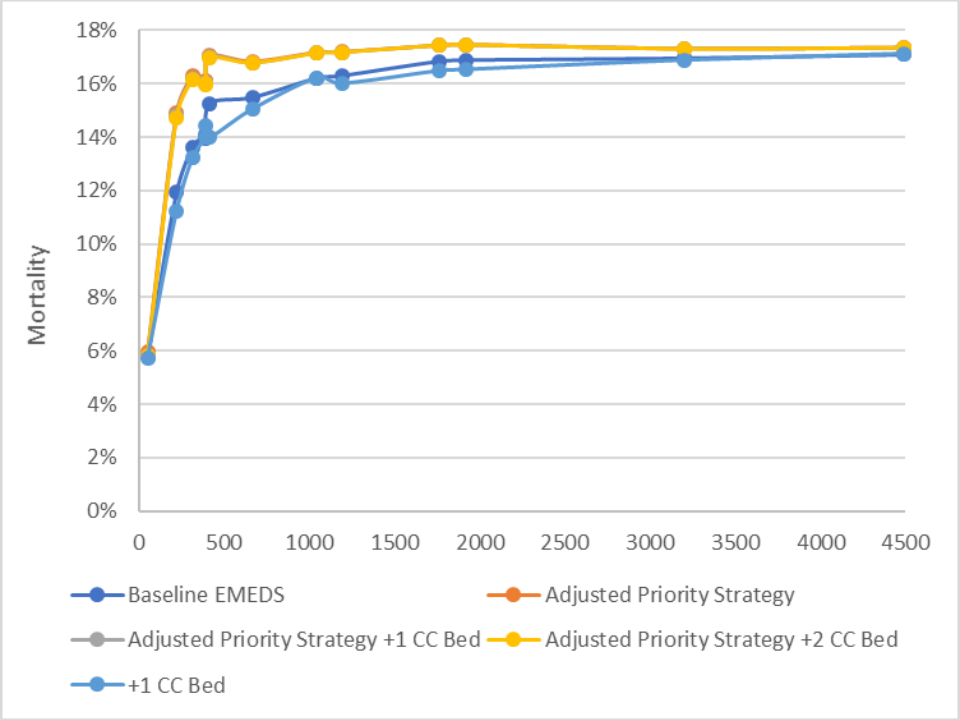
Table 6.18 Combined Effect of Different EMEDS Adjustments on Mortality in Combat Casualty Scenarios

Patient Stream	Mean WIA Patients	Baseline Mean Deaths	Adjusted Priority Strategy Mean Deaths	+ 1 Critical Care Bed Mean Deaths+	Adjusted Priority Strategy + 1 Critical Care Bed Mean Mortality	Adjusted Priority Strategy + 2 Critical Care Bed Mean Mortality
a1	51.0	2.9	3.0	2.9	3.0	3.0
a3	220.9	26.3	32.9	25.8	32.7	32.5
a7	315.9	43.0	51.4	40.5	51.2	51.0
a10	392.2	55.3	63.2	51.7	62.7	62.6
a16	394.6	55.1	63.6	51.9	63.4	63.2
a2	416.8	63.6	71.0	59.1	70.9	70.7
a13	668.2	103.5	112.4	101.4	112.1	112.1
a4	1045.8	169.6	179.5	169.5	179.3	179.2
a8	1191.7	194.3	204.7	198.0	204.6	204.6
a12	1759.2	296.3	306.5	290.9	306.5	306.5
a17	1917.7	323.9	334.6	320.3	334.5	334.5
a14	3200.7	542.7	553.8	541.5	553.7	553.5
a5	4490.7	767.5	778.6	760.1	778.5	778.4

+In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding one bed to the Critical Care Ward relative to the other adjustments presented above.

When comparing the EMEDS when it employs the adjusted priority strategy with the help of either one or two additional beds, the overall mortality drops for all thirteen patient streams. However, for only seven of those thirteen patient streams is the drop statistically significant when one bed is added and for only nine of the thirteen is the reduction significant when two beds are added. Furthermore, regardless of how many beds are added if the adjusted priority scheme is used the mean mortality is always statistically larger than the baseline mortality. This is shown in the figure below.

Figure 6.26 Mortality from an EMEDS with and without using an Adjusted Priority Strategy with and without Added Critical Care Beds in Combat Casualty Scenarios



In the figure above there are three trends plotted for the adjusted priority strategy. These plots include the adjusted priority strategy on its own and when it is given one or two additional critical cared beds. These trends all overlap each other to the point where they cannot be distinguished from one another. This further illustrates that even when the additional beds are added to the Critical Care Ward, once the adjusted priority strategy is adhered to for the duration of the 30-day scenario there is a relatively fixed, statistically significant increase in mortality.

Conclusion

The EMEDS system can become easily overrun with patients during large-scale combat operations, particularly during a surge event such as a missile strike. This chapter has focused on ways in which the EMEDS system could be strengthened to better process large numbers of patients during such events. This analysis showed that there are two ways to strengthen the EMEDS system. The first is to expand capacity and the second is to adjust how patients are prioritized within the system.

If the EMEDS were to be expanded by adding one or two additional beds, the additional beds should be allocated to the Critical Care Ward. The baseline Critical Care Ward only has three beds. Table 6.9 showed that expanding this functional area to five beds could increase the weighted average number of evacuations from the EMEDS system after 30 days by 95.4%. Furthermore, such an expansion could increase RTDs, particularly for small patient streams, and

could lead to fewer deaths. When this adjustment is utilized and the EMEDS is given three additional Patient Vital Signs monitors patient outcomes improve further.

An alternative to changing the size of the EMEDS+25 is to adjust how the MTF prioritizes patients. Figures 6.18 and 6.19 showed the drastic improvements that can be made to baseline evacuation and RTD rates when an adjusted priority strategy is used. However, as shown in Table 6.15 utilizing such a strategy can result in a statistically significant increase in overall mortality. The Air Force could consider instituting a patient or operational threshold where instituting such an alternative patient priority strategy would be beneficial.

Ultimately, this chapter showed three things. First, when faced with a large number of trauma patients the EMEDS+25 is unable to process through more than 34 during a thirty day simulation. This is shown in Figure 6.7. Second, this analysis illustrated that the functional area primarily responsible for this backlog is the Critical Care Ward. This functional area is too small and severely injured patients require too long a stabilization time for the FA to process the numbers of patients generated during missile strikes. And finally, expanding the size of the FA or adjusting how patients are prioritized can produce small but statistically significant and meaningful improvements to overall patient outcomes during combat operations. The following chapter will apply these same adjustments to HA/DR scenarios.

The following table illustrates the net effect potential adjustments to the EMEDS system could have on overall weighted patient outcomes. It is clear from this table that when compared to only expanding the Critical Care Ward, adjusting the patient priority strategy leads to significantly larger net increases in evacuations and RTDs. However, such an adjustment also comes with an expected increase in overall mortality.

Table 6.19 Change in Weighted Average Patient Outcomes from an EMEDS+25 in Combat Casualty Scenarios

Patient Stream	+ 1 Critical Care Bed	+ 2 Critical Care Beds	Adjusted Priority Strategy	Adjusted Priority Strategy + 2 Critical Care Beds
Change in weighted average evacuations	10.2	20.8	126.5	151.2
Change in weighted average returns-to-duty	3.2	8.3	531.3	591.4
Change in weighted average deaths	-0.9	-1.9	10.3	10.1

7. EMEDS Improvements for HA/DR Events

The Air Force has used the EMEDS system to respond to a variety of HA/DR scenarios. The EMEDS, although not specifically designed for these occurrences, has provided vital care when utilized. Examples include responding to the 2009 Indonesian and the 2010 Haitian and Chilean earthquakes. The Air Force would like to be able to provide the strongest care possible when asked to respond to HA/DR cases. There is no reason to believe that naturally occurring events which require large-scale medical responses will cease to occur in the years to come.

This research's primary focus is on how the EMEDS can be improved to address casualties from combat. However, this chapter presents an analysis on how previously introduced adjustments would affect the care provided during a variety of HA/DR cases.

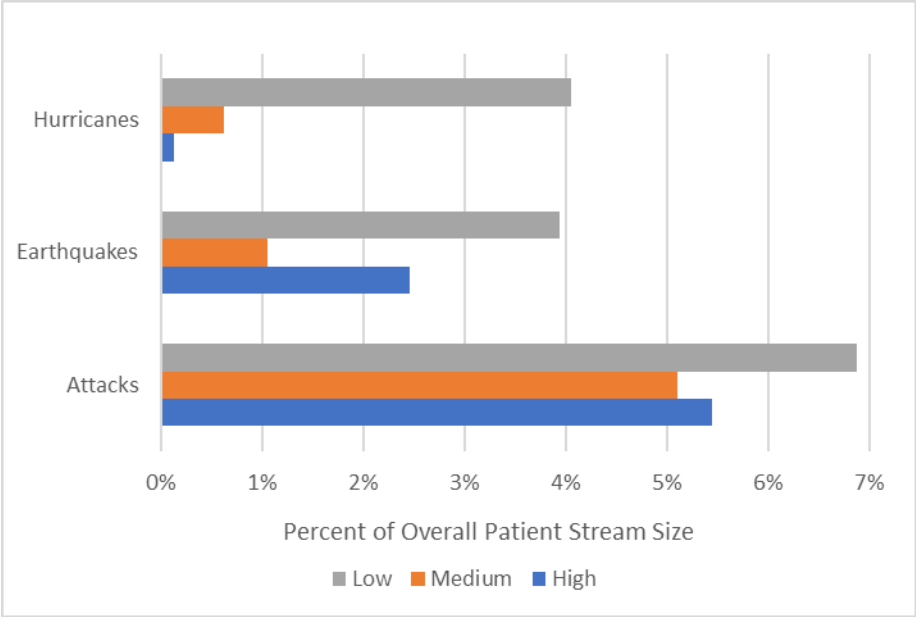
Scenarios

The adjustments shown to improve the EMEDS's ability to treat combat casualties were compared across twenty-four HA/DR disaster scenarios across two types of disasters; earthquakes and hurricanes. The disaster scenarios, as explained, were designed using historic data and were parameterized across three variables: event magnitude, economic development, and population density.

Across these three dimensions, earthquake scenarios produce more casualties than hurricane events. Across the twelve generated hurricane scenarios there are an average of 2282 patients generated whereas the twelve earthquake scenarios generate an average of 4971 patients. Therefore, the two types of events are not directly comparable. However, the intent was not to compare EMEDS performance in earthquakes to EMEDS performance in hurricanes. Rather, the aim was to produce a plausible range of disaster events and analyze how well different EMEDS adjustments are able to perform in those scenarios.

The figure below, figure 7.1, shows the average distribution of patient types for hurricanes, earthquakes and attacks. Each bar shows the mean distribution of patients of each mortality risk type for each event type. Attacks, shown on the bottom, have the highest rate of patients with a mortality risk. In total, 17% of casualties who are generated from an attack are at risk of dying. On the other hand, only 5% and 7% of patients are at risk of dying from hurricanes and earthquakes respectively. About 4% of patients of both HA/DR event types have a low mortality risk. However, less than 1% of the patients generated from hurricanes have either a medium or a high mortality risk. Earthquakes are both larger in size and produce higher rates of patients with medium and high mortality risks relative to hurricanes.

Figure 7.1 Patient Stream Mean Mortality Risk Distributions



Design

HA/DR patient streams were tested against a variety of EMEDS configurations. The first was a baseline test using an unadjusted EMEDS+25. Subsequent tests included using an EMEDS with additional beds, an EMEDS which employed the alternative patient priority strategy introduced in Chapter 6, and an EMEDS which used a combination of both of these adjustments. This analysis follows the same methodological process of simulation design and hypothesis testing that was explained in Chapter 5 and followed in Chapter 6.

Hurricane Findings

Patient Types

Hurricane patients suffer from 115 unique injury codes. Of those patients, 94.1% are assigned one of 97 different injury codes which never correspond to a mortality risk. In fact, fewer than 5% of patients who are injured in a hurricane are assigned a mortality risk when they arrive at the EMEDS. Eight different injury codes represent over 50% of the total patient population. These injuries include wounds and fractures to various body parts such as the trunk, limb, knee, or thigh.

Mortality Risk Outcomes

100% of patients who die in a baseline hurricane scenario die waiting for care in the triage functional area. 80.1% of these patients have a low mortality risk. On average, when a hurricane scenario begins only 5% of patients are assigned a mortality risk, but during simulations only a

fraction of them ever enter the EMEDS (11% of medium risk patients and 6.0% of low risk patients). Meanwhile, of the 95% of patients without a mortality risk, on average 2.6% of them eventually get treated by the MTF. The scale of the hurricane events (the twelve generated patient streams had an average of over 2000 trauma patients), and the distribution of mortality risk patients hinders the EMEDS system's performance.

The Value of an Additional Bed for Hurricane Scenarios

The previous chapter demonstrated that, when treating combat casualties, there is value in adding a bed to the EMEDS. Furthermore, the value of placing that bed in each of four different functional areas was quantified. The most effective place to put a second additional bed is in the Critical Care Ward. Placing an additional bed in the Critical Care Ward could improve the weighted evacuation rate by as much as 50% while producing a slight reduction of 0.65% in the overall mortality.[31] Beyond that, however, improvements to the weighted return-to-duty rate, a mean improvement of 180%, could be captured for patient streams with fewer than a thousand patients. It was also demonstrated that the value of adding a second bed to the Critical Care Ward almost doubles the effect of adding the first bed. This section analyzes whether those same improvements occur when the patient stream is generated using a hurricane scenario rather than an attack scenario.

Design

To test whether adding an additional bed would provide similar results for hurricanes the same approach was followed. In total, the results from four hurricane scenarios were analyzed. Their baseline data is presented in the following table:

Table 7.1 Hurricane Patient Stream Parameters and Mean Number of Trauma Patients

Patient Stream	Hurricane Category	Regional Economy	Population Density	Mean TRA
h7	3	Emerging	Medium	673.9
h10	4	Emerging	Medium	1048.2
h8	3	Emerging	High	1674.5
h11	4	Emerging	High	2316.7

These hurricane scenarios were chosen due to their increasing number of trauma patients. For each scenario, a statistically significant positive increase in overall evacuations and return-to-duty rates could be shown by adding an additional bed to an individual functional area. It is important to note the column labeled "Mean TRA." During disaster events, MPTk labels injured

[31] The concept of hurricane and earthquake mortality is the same as mortality in combat scenarios. Disaster event mortality is defined as patients who survived the initial hurricane or earthquake and sought care but ultimately died within the EMEDS medical network.

patients who suffer from physical injuries as trauma patients. Trauma patient differ from patients who have diseases. JMPT assigns less than 1% of disease patients a mortality risk. For that reason, disease patients were not included.

As before, the six patient streams were tested against five EMEDS configurations. The first was the baseline EMEDS with no additional beds. The second test consisted of identical patient streams tested against an EMEDS with an additional critical care bed. The same was done for the third, fourth, and fifth test using an additional bed in the ER, OR, and Flight Medicine FAs respectively.

For each test, thirty replications were done to determine the most effective location to place an additional bed. Once the best functional area was determined for the first added bed, four more MTFs were designed. These MTFs consisted of two more beds than the baseline EMEDS has in which the first bed was allocated to the FA where it was shown to have the largest impact. The second bed was put into a different FA for each of the four new MTFs. Thirty replications against all four new MTFs were tested for each of the four patient streams.

Value of Additional Bed on Hurricane Evacuations

As was the case for attack scenarios, the most impactful functional area to place an additional bed in the EMEDS for hurricane scenarios is the Critical Care Ward.

Table 7.2 Comparison of Baseline vs. 1 Additional Beds on Hurricane Evacuations

Patient Stream	Mean TRA	Baseline EMEDS	+1 Critical Care Beds Mean Evacs	+1 ER Beds Mean Evacs	+1 OR Beds Mean Evacs	+1 FLT Beds Mean Evacs
h7	673.9	63.6	75.7	68.3*	66.6*	64.5*
h10	1048.2	61.3	70.3	61.9*	59.7*	57.2*
h8	1674.5	48.5	56.1	47.5*	51.9*	45.7*
h11	2316.7	47.6	59.5	50.9*	52.3*	53.7
Weighted Average		52.5	62.5	54.1	55.3	53.3

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level.

Adding an additional bed to the Critical Care Ward increased the average number of evacuations by an average of 10.2 patients whereas the other functional areas, when expanded, only evacuated an average of 1.9, 2.4, and 0.0 additional patients. Furthermore, 95% confidence intervals of the mean difference in the means show that for each of the four patient streams the sample of evacuations was statistically different when comparing the expanded Critical Care Ward to the baseline EMEDS. Of the other twelve comparisons of expanded FAs vs. the baseline EMEDS, only the sample with an expanded flight medicine FA was statistically significant for patient stream h11.

For the four hurricane scenarios, the baseline EMEDS is able to evacuate a weighted average of 3.9% of trauma patients. When the Critical Care Ward is expanded to four beds this rate increases to 4.6%. These values are presented in table 7.3 below.

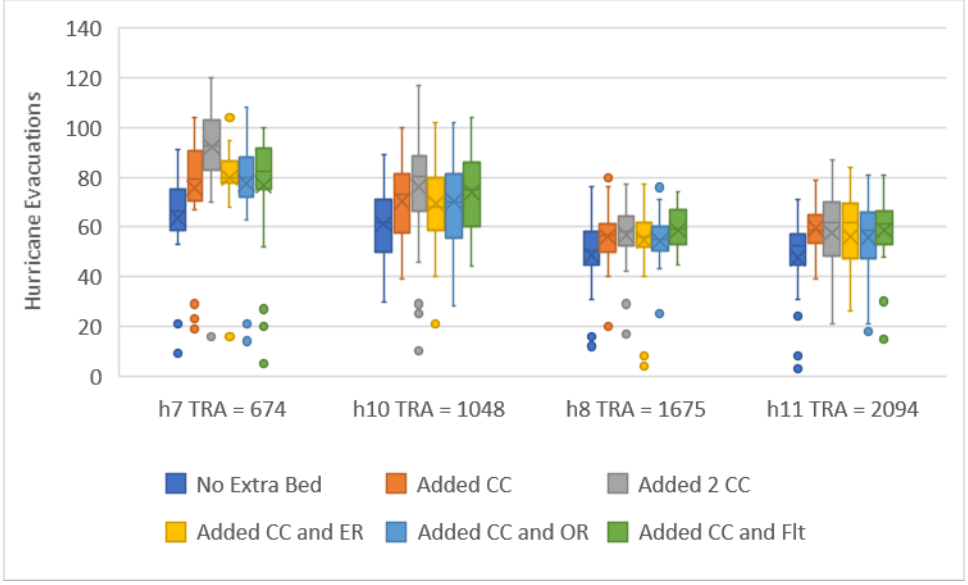
Table 7.3 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Hurricane Evacuations

Patient Stream	Mean TRA	Baseline Mean Evacs	+1 Critical Care Beds Mean Evacs	+2 Critical Care Beds Mean Evacs	Baseline Mean Evac Rate	+1 Critical Care Beds Mean Evac Rate	+2 Critical Care Beds Mean Evac Rate
h7	673.9	63.6	75.7	92.1	9.4%	11.2%	13.7%
h10	1048.2	61.3	70.3	76.3~	5.8%	6.7%	7.3%
h8	1674.5	48.5	56.1	56.8~	2.9%	3.4%	3.4%
h11	2316.7	47.6	59.5	57.7~	2.1%	2.6%	2.2%
Weighted Average		52.5	62.5	65.2	3.9%	4.6%	4.0%

A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which had already been given an additional critical care bed at the 95% confidence level

In terms of evacuations, it is not statistically clear where the second additional bed should be placed in the EMEDS for hurricane scenarios. Unlike for attack scenarios, a second added bed does not result in the same improvements as the first added bed. Rather, samples comparing an MTF with two additional beds in the Critical Care Ward and one in which the first additional bed was given to the Critical Care Ward and the second was given to the ER are not statistically different from the MTF with only one additional bed in the Critical Care Ward. Further, when compared against each other the facilities with two additional bed are not statistically different from one another for three of the four hurricane patient streams. This is shown in the table above and in the figure below. For patient streams h8 and h11 in which the mean patient stream size is over 1500, the number of evacuations are not increased when a fifth bed is added to the Critical Care Ward.

Figure 7.2 Patient Streams h7, h10, h8, and h11 Evacuations from an EMEDS+25 with up to Two Additional Beds in Hurricane Scenarios



Although table 7.3 shows that adding two bed in the Critical Care Ward increases evacuations relative to the EMEDS with one additional critical care bed, three of the four samples were not found to be statistically significant. Only the sample comparing adding two critical care beds vs. adding one critical care bed for scenario h7, the scenario with the fewest casualties, was statistically significant.

Value of Additional Bed on Hurricane Returns-to-duty

Much like was the case for evacuations, the most effective FA in which to put an additional bed in the case of hurricane returns-to-duty is the Critical Care Ward.[32] Again, however, the improvements are most clearly seen for small patient streams. This can be seen in the row for patient stream h7 in table 7.4.

Table 7.4 Comparison of Baseline vs. 1 Additional Beds on Hurricane Returns-to-duty

Patient Stream	Mean TRA	Baseline EMEDS	+1 Critical Care Beds Mean RTDs	+1 ER Beds Mean RTDs	+1 OR Beds Mean RTDs	+1 FLT Beds Mean RTDs
h7	673.9	30.2	37.5	31.8	31.1*	30.6*
h10	1048.2	41.9	42.6	43.1	42.0*	41.9*
h8	1674.5	57.5	58.3	57.8*	58.1	58.0*
h11	2316.7	72.0	72.9	72.9	72.7	72.8
Weighted Average		56.7	58.3	57.6	57.3	57.2

[32] For hurricane and earthquake scenarios, the concept of returning-to-duty is not as clear as it is in the case of combat operations. However, RTD is still an important outcome variable and it reflects a successful patient discharge from the medical facility.

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level.

The above table demonstrates that, again when the ER, OR, and Flight Medicine are expanded the mean RTD rates do not drastically change. Even when a bed is added to the Critical Care Ward there is not a sharp increase in RTDs. However, four confidence intervals comparing the samples which comprise the baseline EMEDS and +1 Critical Care Mean RTDs columns show statistical significance. Shown using asterisks in table 7.4, three of the four samples are statistically significant for the ER, two for the OR, and only one for Flight Medicine relative to the baseline EMEDS configuration at the 95% confidence level. Therefore, the first bed should be allocated to the Critical Care Ward in order to have the greatest likelihood of improving mean hurricane RTDs.

The baseline weighted average RTD rate for our hurricane patient streams is 3.7% of the overall patient population. When a bed is added to the Critical Care Ward this value increases to 3.9%. This represents an increase of 4.8% of the overall weighted RTD rate. These values are shown in the following table.

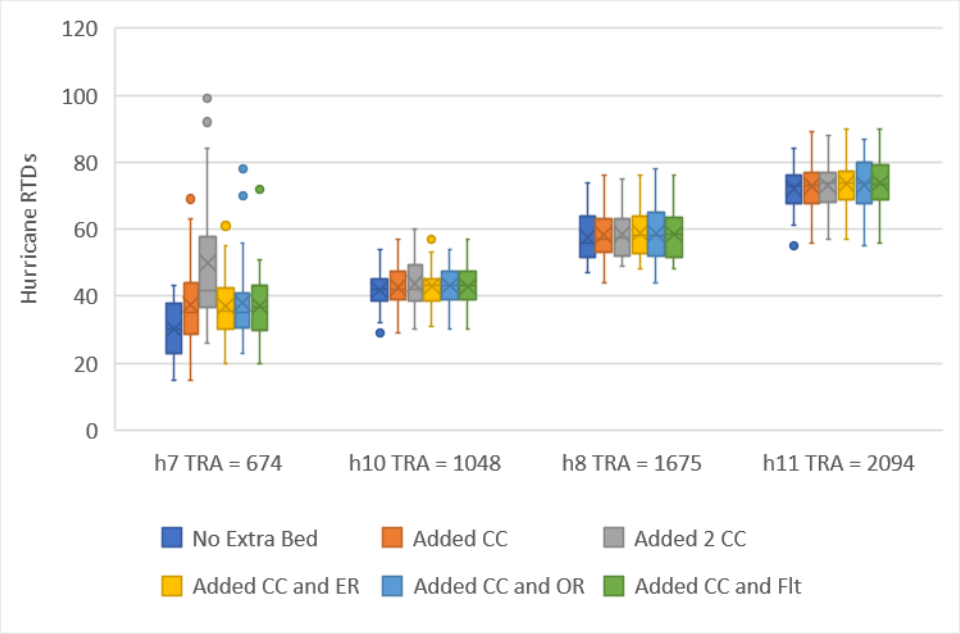
Table 7.5 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Hurricane RTDs

Patient Stream	Mean TRA	Baseline Mean RTDs	+1 Critical Care Beds Mean RTDs	+2 Critical Care Beds Mean RTDs	Baseline Mean RTDs Rate	+1 Critical Care Beds Mean RTD Rate	+2 Critical Care Beds Mean RTD Rate
h7	673.9	30.2	37.5	49.9	4.5%	5.6%	7.4%
h10	1048.2	41.9	42.6	43.8~	4.0%	4.1%	4.2%
h8	1674.5	57.5	58.3	58.5~	3.4%	3.5%	3.5%
h11	2316.7	72.0	72.9	73.0~	3.1%	3.1%	3.1%
Weighted Average		56.7	58.3	60.2	3.7%	3.9%	3.6%

A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which had already been given an additional critical care bed at the 95% confidence level

As was the case for evacuations, it is not clear where the second bed should be allocated. Statistical analysis comparing MTFs in which a second bed was allocated to each of the four FAs (conditional on the first having been given to the Critical Care Ward) does not show any consistent difference between the expanded MTFs and the MTF with only one additional critical care bed. Again, only the sample in which two beds were added to the Critical Care Ward for patient stream h7 is statistically significant when compared to the MTF with only one critical care bed. This is shown in the above table, the sample with the 7.4% RTD rate beneath the +2 Critical Care Beds RTD Rate column for patient stream h7 is 33% larger than the 5.6% value under the +1 Critical Care Bed RTD Rate column for the same patient stream. However, for the larger patient streams the same statistical significance is not observed. This is most clearly shown in the figure, figure 7.3, below.

Figure 7.3 Patient Streams h7, h10, h8, and h11 RTDs from an EMEDS+25 with up to Two Additional Beds in Hurricane Scenarios



Value of Additional Bed on Hurricane Mortality

For all four hurricane scenarios, mean mortality when the Critical Care Ward is expanded is statistically significant when compared to the samples in which the baseline EMEDS is used. None of the other FAs produce more than one statistically significant sample. The mean for each patient stream across each MTF adjustment is shown in the following table.

Table 7.6 Comparison of Baseline vs. 1 Additional Beds on Hurricane Mortality

Patient Stream	Mean TRA	Baseline EMEDS	+1 Critical Care Beds Mean Mortality	+1 ER Beds Mean Mortality	+1 OR Beds Mean Mortality	+1 FLT Beds Mean Mortality
h7	673.9	25.0	23.8	24.8*	24.7*	24.6*
h10	673.9	43.9	42.8	43.4*	43.6*	43.9*
h8	1048.2	75.0	74.1	74.1	74.3	74.8*
h11	1674.5	103.0	101.7	103.0*	102.7*	102.6
Weighted Average		73.6	72.5	73.2	73.2	73.3

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level.

Adding one bed to the Critical Care Ward reduces mean mortality for hurricanes from 4.32% to 4.22%. Adding a second bed reduces it further to 4.19%. These are small net reductions but represent an overall improvement in mean mortality of 2.26% or 3.17% respectively.

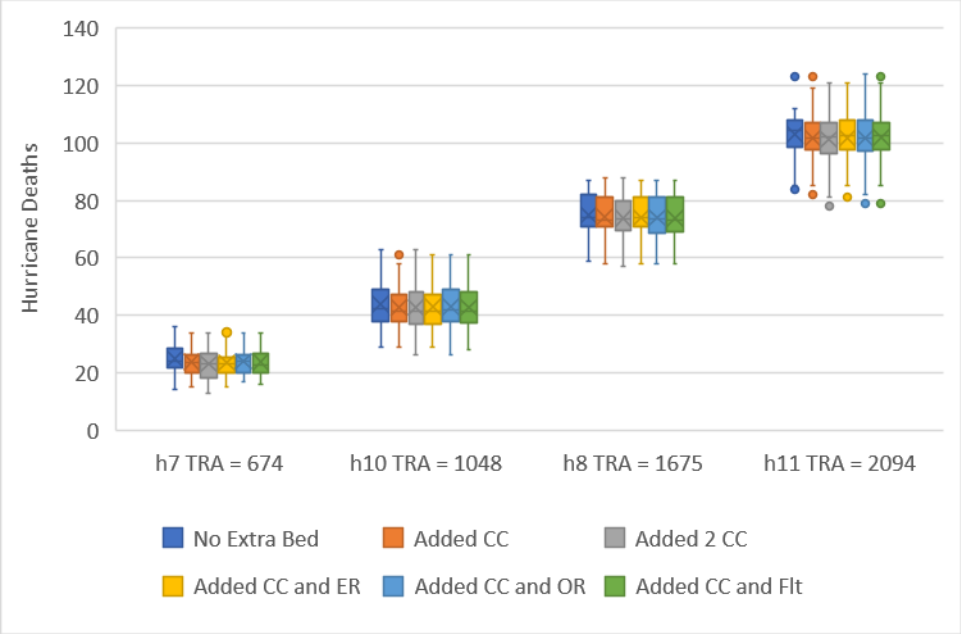
Table 7.7 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Hurricane Mortality

Patient Stream	Mean TRA	Baseline Mean Deaths	+1 Critical Care Beds Mean Deaths	+2 Critical Care Beds Mean Deaths	Baseline Mean Mortality	+1 Critical Care Beds Mean Mortality	+2 Critical Care Beds Mean Mortality
h7	673.9	25.0	23.8	23.1	3.70%	3.54%	3.43%
h10	1048.2	43.9	42.8	42.6	4.19%	4.08%	4.07%
h8	1674.5	75.0	74.1	73.9	4.48%	4.43%	4.41%
h11	2316.7	103.0	101.7	101.3	4.4%	4.4%	4.4%
Weighted Average		73.6	72.5	72.1	4.3%	4.2%	4.2%

All four of the samples which comprise the values beneath the +2 Critical Care Beds Mean Mortality column in table 7.7 above are statistically significant when compared to the samples which comprise the means beneath the +1 Critical Care Beds Mean Mortality column. This shows that although the improvement may appear small, when a second bed is added to the Critical Care Ward, having already added one bed there, the mean mortality is statistically lower than when only one bed is added.

Adding an additional bed to the Critical Care Ward reduces weighted average hurricane mortality by 1.8%. A difference in mean mortality when a bed was added to the Critical Care Ward compared to the baseline EMEDS was shown to be statistically significant for all four patient streams we analyzed. Furthermore, adding a second bed to the Critical Care Ward reduces mean mortality by 2.4%. Unlike for evacuations or RTDs, the four patient streams each show a statistically significant reduction in mean mortality when a second bed is added relative to when only one bed is added. This is shown in the following figure.

Figure 7.4 Patient Streams h7, h10, h8, and h11 Deaths from an EMEDS+25 with up to Two Additional Beds in Hurricane Scenarios



Patient Outcomes from an Adjusted Priority Strategy in Hurricane Scenarios

The previous chapter introduced an alternative patient priority strategy in which patients with injury conditions that do not require a stabilization time are elevated in the priority queue in order to quickly receive treatment. These patients are treated and allowed to exit the MTF to either be evacuated or return-to-duty. Once these patients are treated, the MTF is able to devote more resources and space to patients with more advanced medical requirements. The chapter found that even for patient streams with more than a thousand patients, such a priority strategy can drastically improve return-to-duty rates and evacuation rates, while increasing overall weighted mortality from 16.5% to 17.2%. This section analyzes how the same priority strategy impacts the patient outcomes of casualties caused by a hurricane.

Design

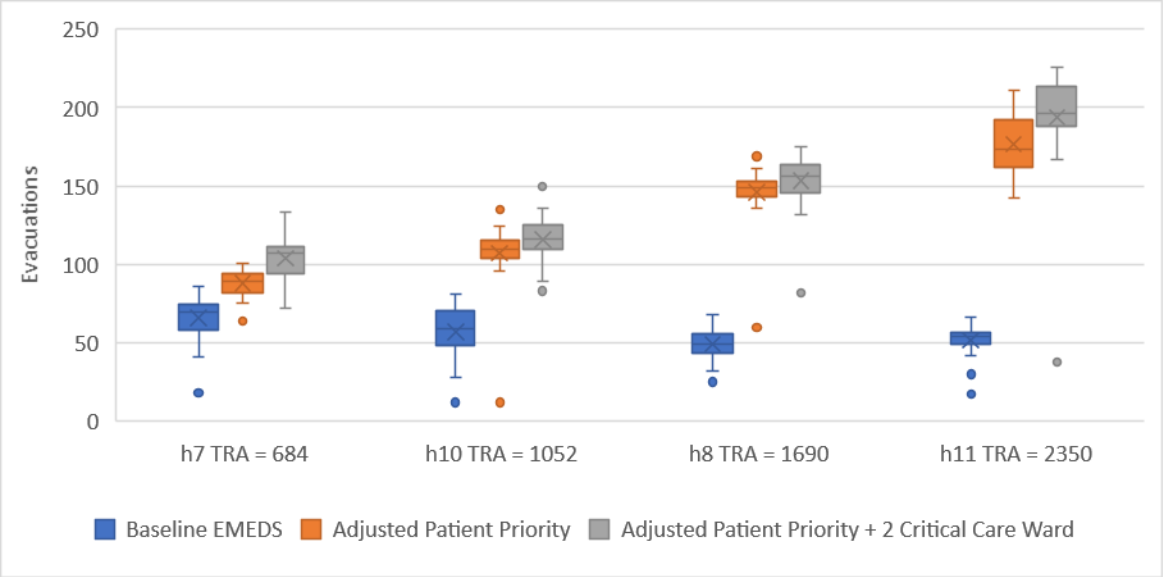
For this section, four hurricane scenarios were tested using three MTFs. As in the previous section, the first MTF was the baseline EMEDS+25 without any adjustment. A second set of simulations was done using an MTF where the adjusted priority strategy was used. Finally, a third MTF was employed which combined the adjusted priority strategy with the addition of two critical care beds.[33]

[33] In this section, the data generated using these configurations are shown in tables along with data used in the previous section in which the EMEDS configuration with two additional critical care beds were added. Since these data were generated previously, they were compiled using different random number seeds. However, it is important to see each combination of EMEDS configuration: with no adjustment, with additional critical care beds, with the adjusted priority strategy alone, and with both the adjusted priority strategy and additional critical care beds.

Impact of Adjusted Priority Strategy on Evacuations in Hurricane Scenarios

Evacuations can be statistically improved for hurricane patients when an EMEDS+25 is used that employs an alternative priority strategy. The following figure, figure 7.5, shows the evacuations from thirty replications for four different patient streams when using three different EMEDS configurations.

Figure 7.5 Patient Streams h7, h10, h8, and h11 Evacuations from an EMEDS using an Adjusted Priority Strategy with and without Two Added Critical Care Beds in Hurricane Scenarios



As shown above, even larger patient streams benefit from using the alternative priority strategy in terms of evacuations. The baseline EMEDS evacuations, shown in the blue boxes, decrease as patient streams increase. However, when the adjusted priority strategy is used, large patient streams are able to evacuate even more patients than smaller patient streams. This is due to the change in how patients are prioritized. Larger patient streams have more patients who suffer from injuries which can be quickly treated and evacuated.

The following table, table 7.8, shows that for hurricane evacuations, the adjusted priority strategy can lead to an increase in evacuations from a weighted average of 5.0% to a weighted average of 9.8%. This represents almost twice as many net evacuations.

Table 7.8 Combined Effect of Different EMEDS Adjustments on Evacuations in Hurricane Scenarios

Patient Stream	Mean TRA	Baseline Mean Evacs	Adjusted Priority Strategy Mean Evacs	Adjusted Priority Strategy + 2 Critical Care Beds Mean Evacs	Baseline Mean Evac Rate	+2 Critical Care Beds Mean Evac Rate[+]	Adjusted Priority Strategy Mean Evac Rate	Adjusted Priority Strategy + 2 Critical Care Beds Mean Evac Rate
h7	683.8	66.0	87.9	104.0	9.6%	13.7%	12.9%	15.2%
h10	1052.1	56.9	107.2	115.8	5.4%	7.3%	10.2%	11.0%
h8	1690.1	49.1	145.9	153.2	2.9%	3.4%	8.6%	9.1%
h11	2350.0	51.5	176.6	193.9	2.2%	2.5%	7.5%	8.3%
Weighted Average		53.5	144.5	157.1	3.9%	5.0%	9.0%	9.8%

[+]In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding two beds to the Critical Care Ward relative to the other adjustments presented above.

Impact of Adjusted Priority Strategy on RTDs in Hurricane Scenarios

Likewise, adjusting the patient priority strategy statistically increases hurricane returns-to-duty. This can again be attributed to the pool of patients; larger patient streams have more net patients who have trauma injuries which can be quickly treated and successfully discharged (RTD) from the MTF.

Figure 7.6 Patient Streams h7, h10, h8, and h11 RTDs from an EMEDS using an Adjusted Priority Strategy with and without Two Added Critical Care Beds in Hurricane Scenarios

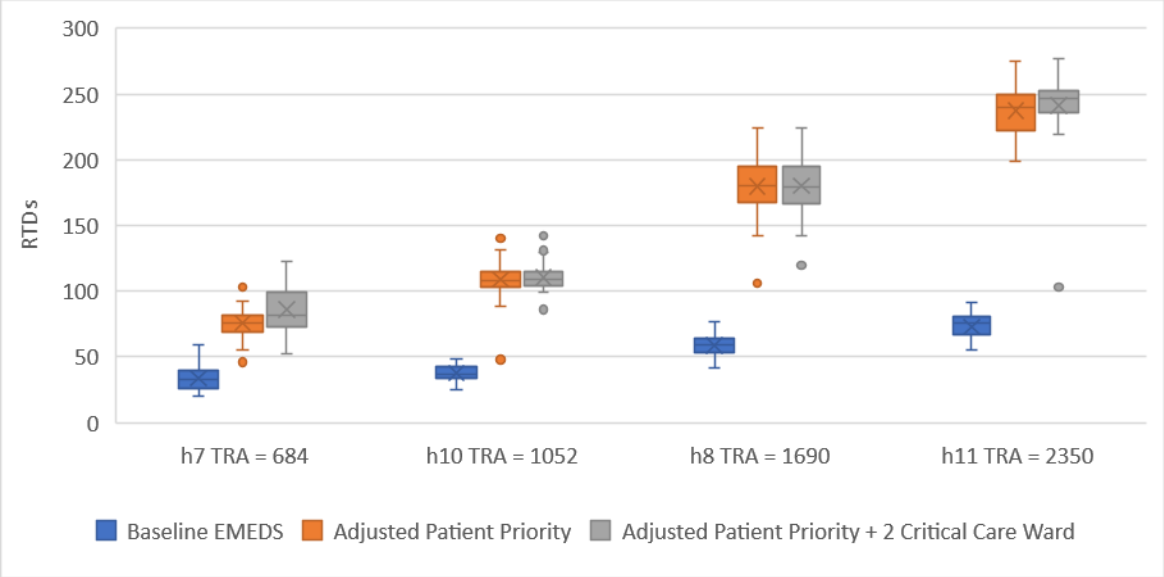


Figure 7.6 shows, however, that adding two additional critical care beds on top of the adjusted priority strategy does not always expand the improvements. For instance, for patient streams h10 and h8, which have mean of 1052 and 1690 patients, whether or not two additional beds are used, the returns-to-duty appear to remain the same. Relative to the configuration which only employed the adjusted priority strategy, these values were not found to be statistically significant at the 95% confidence level. This is shown in the table below. For patient stream h10, for instance, the mean difference in RTDs when two additional beds are added on top of the adjusted priority strategy is 1.3, but a 95% confidence interval for this value is between -3.2 – 5.8.

However, the mean change in the RTD rate is larger than it was for evacuations. When the adjusted priority strategy is used without additional critical care beds, the weighted average RTD rate increases to 10.4% from a baseline rate of 3.5%. These values are presented in table 7.9. This represents an increase of 194% relative to the baseline rate.

Table 7.9 Combined Effect of Different EMEDS Adjustments on RTDs in Hurricane Scenarios

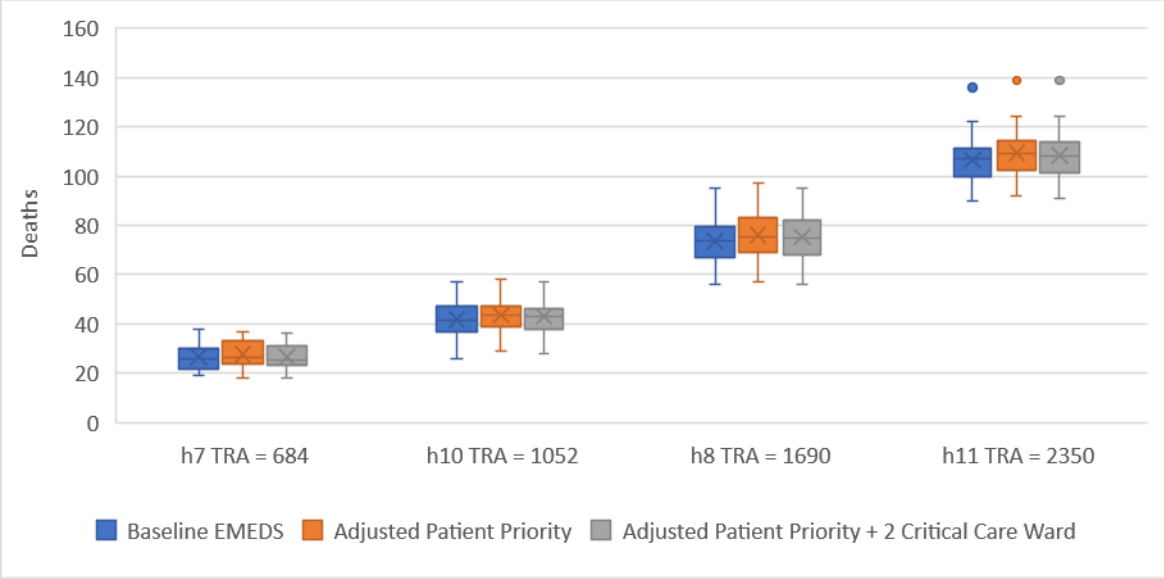
Patient Stream	Mean TRA	Baseline Mean RTDs	Adjusted Priority Strategy Mean RTDs	Adjusted Priority Strategy + 2 Critical Care Beds Mean RTDs	Baseline Mean RTD Rate	+2 Critical Care Beds Mean RTD Rate[+]	Adjusted Priority Strategy Mean RTD Rate	Adjusted Priority Strategy + 2 Critical Care Beds Mean RTD Rate
h7	683.8	33.9	75.7	86.0	5.0%	7.4%	11.1%	12.6%
h10	1052.1	37.6	109.1	110.4~	3.6%	4.2%	10.4%	10.5%
h8	1690.1	58.8	180.0	180.3~	3.5%	3.5%	10.6%	10.7%
h11	2350.0	73.0	237.1	241.4~	3.1%	3.2%	10.1%	10.3%
Weighted Average		57.8	178.0	181.3	3.5%	3.9%	10.4%	10.7%

[+]In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding two beds to the Critical Care Ward relative to the other adjustments presented above.
A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which had already been given an additional critical care bed at the 95% confidence level

Impact of Adjusted Priority Strategy on Mortality in Hurricane Scenarios

Adjusting the patient priority strategy within an EMEDS does not practically increase mortality from hurricane scenarios. As shown in figure 7.7, the number of deaths from each patient stream remains relatively constant across different MTF adjustments.

Figure 7.7 Patient Streams h7, h10, h8, and h11 Deaths from an EMEDS using an Adjusted Priority Strategy with and without Two Added Critical Care Beds in Hurricane Scenarios



Furthermore, table 7.10 demonstrates that the weighted average baseline mortality for an EMEDS+25 is 4.3% in hurricane scenarios. When the adjusted priority strategy is used, with or without additional critical care space, the mortality changes to 4.4%. The differences which make up this 0.1% net change in mortality were found to be statistically significant across all four patient streams when using the adjusted strategy and for the three largest patient streams when using the adjusted strategy and additional critical care beds.

For patient stream h8, which had the largest mean difference in deaths, a 95% confidence interval of the mean difference was between 0.9 – 2.7 when the adjusted priority strategy was used with two additional critical care beds relative to the baseline EMEDS. This shows that using the adjusted priority strategy may statistically increase the total number of deaths by 1 or 2 patients but is unlikely to dramatically increase mortality.

Table 7.10 Combined Effect of Different EMEDS Adjustments on Deaths in Hurricane Scenarios

Patient Stream	Mean TRA	Baseline Mean Deaths	Adjusted Priority Strategy Mean Deaths	Adjusted Priority Strategy + 2 Critical Care Beds Mean Deaths	Baseline Mean Mortality	+2 Critical Care Beds Mean Mortality[+]	Adjusted Priority Strategy Mean Mortality	Adjusted Priority Strategy + 2 Critical Care Beds Mean Mortality
h7	683.8	26.6	27.7	26.7*	3.9%	3.4%	4.1%	3.9%
h10	1052.1	41.8	43.5	43.0~	4.0%	4.1%	4.1%	4.1%
h8	1690.1	73.4	76.0	75.2	4.3%	4.4%	4.5%	4.4%
h11	2350.0	106.6	109.4	108.4	4.5%	4.4%	4.7%	4.6%
Weighted Average		75.6	78.0	77.1	4.3%	4.2%	4.4%	4.4%

[+]In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a

unique random number seed. These data are included in the table to illustrate the isolated effect adding two beds to the Critical Care Ward relative to the other adjustments presented above.
An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level.
A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which had already been given an additional critical care bed at the 95% confidence level

Hurricane Conclusions

If one bed is added to the EMEDS to improve its performance in hurricane scenarios, it should be placed in the Critical Care Ward. If a second bed is also added to the EMEDS, it should also be placed in the Critical Care Ward. However, the second bed will not necessarily further improve the already increased evacuation or RTD rates. However, using an adjusted priority strategy will result in larger increases in overall evacuations and returns-to-duty with a slight increase in overall mortality.

Table 7.11 Change in Patient Outcome Rates When Different Adjustments are used for Hurricane Scenarios

Patient Outcome	Adding One Critical Care Bed	Adding Two Critical Care Beds	Adjusted Priority Strategy	Adjusted Priority Strategy + 2 Critical Care Beds
Change in weighted average evacuation rate	18.4%	28.0%	131.6%	153.6%
Change in weighted average return-to-duty rate	4.8%	11.7%	196.1%	204.0%
Change in weighted average mortality	-1.8%	-2.4%	3.3%	2.0%

The above table presents the percent change in the mean patient outcome rates for four hurricane patient streams when one or two beds are added to the Critical Care Ward and when an adjusted priority strategy is used as compared to the baseline EMEDS+25.

Hurricanes are unlike attacks in that they have far fewer patients with a mortality risk. When two beds are added to the Critical Care Ward, attack scenarios have a change in their weighted average evacuation rate of 95.4%. For hurricanes, this value is only 28.8% and was only shown to be statistically significant relative to the adjustment with only one additional critical care bed for three of the four patient streams. However, expanding the Critical Care Ward to include two addition beds decreases hurricane average mortality by 2.4% whereas it only reduced attack mortality by 1.2%. The magnitude of the effect one change has on the EMEDS differs depending on whether or not the EMEDS is treating patients from an attack or from a hurricane. This is largely due to the distribution of patients across these scenario types. The baseline EMEDS hardly evacuates any patients from an attack scenario. However, once it is given additional capacity it is able to more than double its evacuations. Because the MTF is still overrun with life-threatened patients the adjustment is unable to reduce mortality by more than 1.2%. In the case of hurricanes, the baseline EMEDS is able to evacuate far more patients (weighted average of

4.0%) than it could during attacks (weighted average 2.2%) because so few require life-saving treatment. Because the EMEDS system's evacuation rate during hurricanes is almost double that of its evacuation rate during attacks, an adjustment of the same size has a smaller effect.

Earthquake Findings

The baseline EMEDS+25 struggles to process the patients which can be expected from earthquakes. This research looked at earthquakes ranging from magnitude 5.5 to 9.5 in both emerging and developing economies of varying population density. Even in the case of the least destructive earthquake, a 5.5 magnitude earthquake in an emerging economy with a moderate population density, the EMEDS system is only able to process 12.1% of the 3711 estimated trauma patients during a 30-day simulation. As was the case in attack scenarios, the quantity of patients overwhelms the EMEDS facility. This further illustrates that the AFTTP which states that an EMEDS HRT could process 350 to 500 patients a day during an HA/DR scenario is over-estimating the facilities capacity.

Patient Types

The types of patients in an earthquake differ widely from the patients seen in the attack scenarios. In the attack scenarios, a majority of the patient pool consisted of individuals with concussion and concussion-like injuries. In the case of an earthquake, a wider range of injuries occur. Across earthquake events, 118 different patient types occur. Six patient types, none of which are ever assigned a mortality risk, make up over 50% of the patients in a single earthquake scenario. These patients have the following patient codes: wounds to the trunk, limbs, thigh, or head without mention of complications and injuries having to do with the effects of thirst and hunger. Although these are serious conditions and the challenge of access to food and water during an earthquake scenario are critical, the EMEDS is not used as effectively as possible if it is treating patients with these or similar non-life threatening conditions while patients are present who do have life-threatening conditions.

It is also important to note that the priorities of treatment change slightly when treating civilians in a HA/DR scenario as compared to military patients during a combat scenario. Returning-to-duty is much less of a priority in civilian scenarios. In a combat scenario, it may be essential to the defense of the airbase or the maintenance of an operational mission that non-life threatened patients be treated so they can return-to-duty.

As a result of this difference in priorities, alternative triage protocols should be considered.

Mortality Risk Outcomes

Similar to the attack scenarios, 98.7% of patients who die within the EMEDS from an earthquake scenario die waiting for treatment in the triage functional area. The majority of these patients, 63.1%, have a low mortality risk. In the baseline test, of the 2.3% of patients who die

while or after receiving care, each have a high mortality risk. In these scenarios, as in the case of the attack scenarios, time and resources are being devoted to the patients who have the highest risk of passing away. As such, the patients who have less severe injuries, but still injuries which require serious treatment, pass away before being able to be treated.

Critical Care Ward Adjustments

The Value of an Additional Bed for Earthquake Scenarios

Chapter 6 demonstrated that the Critical Care Ward is the functional area that should be given an additional bed in order to improve patient outcomes. In this scenario, four representative earthquake scenarios were analyzed against three MTFs: a baseline EMEDS+25, an EMEDS with an additional critical care bed, and an EMEDS with two additional critical care beds. The following table, table 7.12, presents the mean number of trauma patients generated from these earthquake events.

Table 7.12 Earthquake Patient Stream Parameters and Mean Number of Trauma Patients

Patient Stream	Earthquake Magnitude	Regional Economy	Population Density	Mean TRA
e8	7.5	Emerging	Medium	4095.4
e5	7.5	Developing	High	5176.4
e11	7.5	Emerging	High	5401.7
e2	7.5	Developing	Medium	5516.9

Value of Additional Bed on Earthquake Evacuations

Expanding the Critical Care Ward increases evacuations during earthquake events. For all four earthquake scenarios, both one additional bed and two additional beds produce statistically more evacuations. However, the EMEDS can still only process a fraction of its overall patient load.

For patient stream e5, which has a mean of 5176 patients, the baseline EMEDS can evacuate 44.1 patients. This means the EMEDS evacuates an average of less than 1% of the patient stream. A 95% confidence interval of the difference in the mean number of evacuations when one bed is added to the Critical Care Ward is 1.7 – 9.5 with a mean difference of 5.6 additional evacuations. Although the total evacuations are still less than 1.0%, evacuating an average of 49.7 patients represents a 12.7% increase from the baseline evacuations. A second additional bed increases the mean evacuations to 53.8. These data are shown for this and three other patient streams in figure 7.8.

Figure 7.8 Patient Streams e8, e5, e11, and e2 Evacuations from an EMEDS+25 with up to Two Additional Critical Care Beds in Earthquake Scenarios

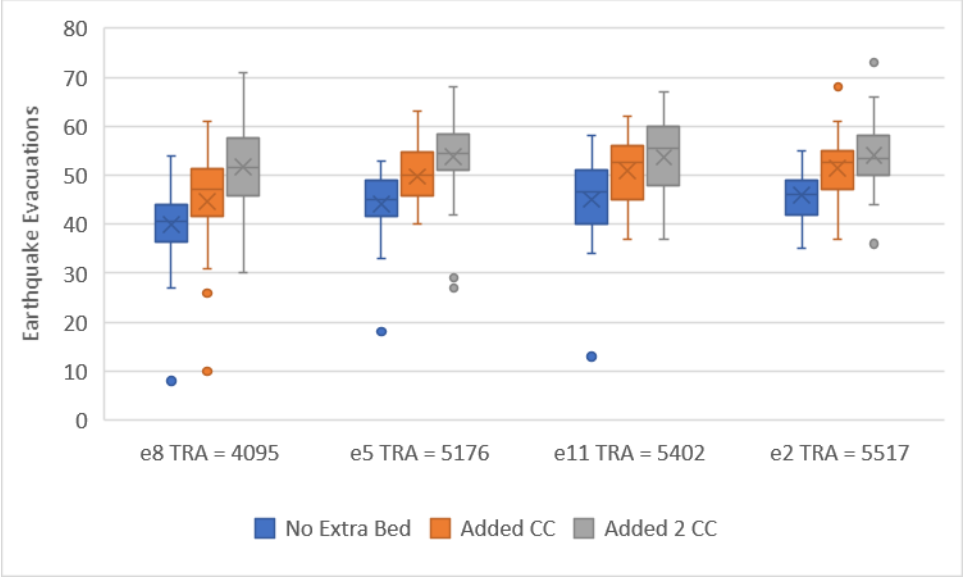


Table 7.13 presents the mean evacuations for each earthquake scenario using different EMEDS configurations. As shown in the table, the baseline EMEDS can evacuate a weighted average of less than 0.9% of earthquake patients. However, when the Critical Care Ward expands to 5 beds, this value improves to 1.05%.

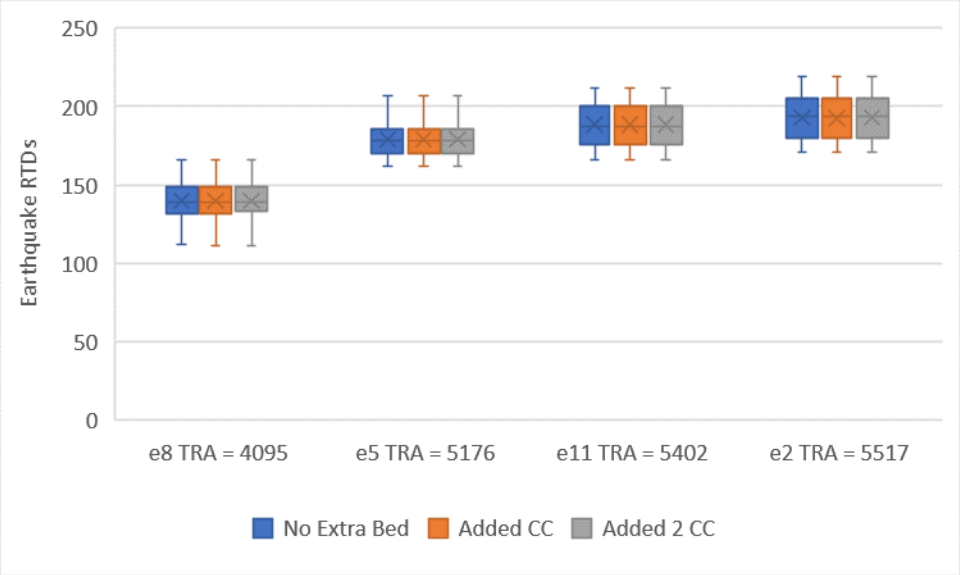
Table 7.13 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Earthquake Evacuations

Patient Stream	Mean TRA	Baseline Mean Evacs	+1 Critical Care Beds Mean Evacs	+2 Critical Care Beds Mean Evacs	Baseline Mean Evac Rate	+1 Critical Care Beds Mean Evac Rate	+2 Critical Care Beds Mean Evac Rate
e8	4095.4	39.9	44.6	51.7	0.97%	1.09%	1.26%
e5	5176.4	44.1	49.7	53.8	0.85%	0.96%	1.04%
e11	5401.7	45.0	50.9	53.6	0.83%	0.94%	0.99%
e2	5516.9	45.9	51.5	54.1	0.83%	0.93%	0.98%
Weighted Average		44.0	49.5	53.4	0.86%	0.97%	1.05%

Value of Additional Bed on Earthquake Returns-to-duty

Although the addition of a Critical Care Ward produces statistically more earthquake evacuations, the same is not the case of RTDs. The following figure illustrates the affect an expanded Critical Care Ward has on RTDs. Across all four earthquakes, whether one or two beds are added, there is no statistically significant change in RTDs.

Figure 7.9 Patient Streams e8, e5, e11, and e2 RTDs from an EMEDS+25 with up to Two Additional Critical Care Beds in Earthquake Scenarios



The fact that there are virtually no additional RTDs when the Critical Care Ward is expanded can be attributed to the scale of the patient streams and the distribution of mortality risk. The four patient streams have approximately 5200 mean patients. 93% of these patients do not have a mortality risk. In attack scenarios, the baseline EMEDS was overwhelmed trying to provide care to patients with a high mortality risk. When the facility was given additional space, it was able to better address the needs of patients with a mortality risk. In addressing those patients, the facility freed up space and resources to treat patients without a mortality risk. The same effect does not occur in earthquakes in which the baseline facility is predominately overrun with non-life threatened patients.

Table 7.14 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Earthquake RTDs

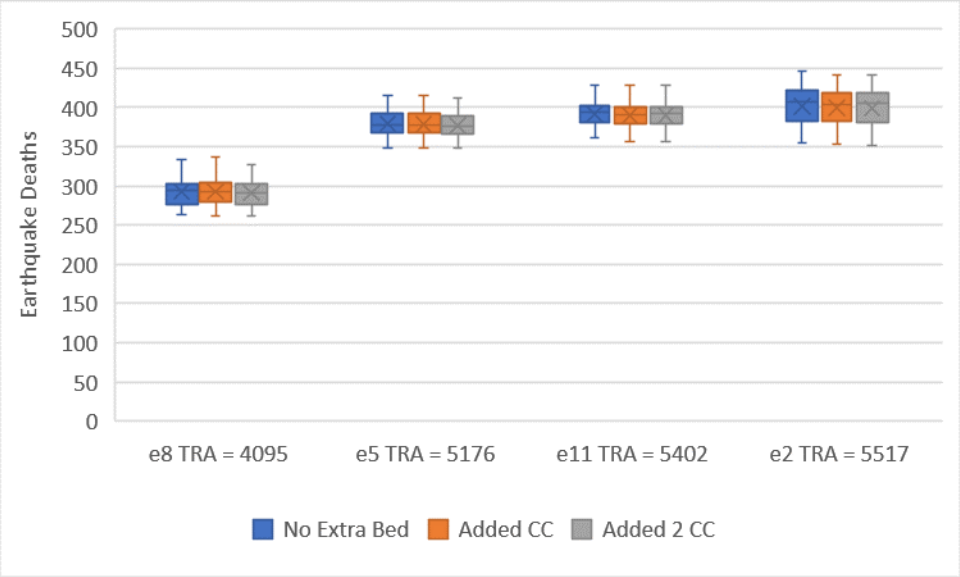
Patient Stream	Mean TRA	Baseline Mean RTDs	+1 Critical Care Beds Mean RTDs	+2 Critical Care Beds Mean RTDs	Baseline Mean RTD Rate	+1 Critical Care Beds Mean RTD Rate	+2 Critical Care Beds Mean RTD Rate
e8	4095.4	192.8	192.8*	192.9*	3.50%	3.49%	3.50%
e5	5176.4	139.9	139.8*	139.9*	3.42%	3.41%	3.42%
e11	5401.7	188.4	188.4*	188.4*	3.49%	3.49%	3.49%
e2	5516.9	179.2	179.2*	179.2*	3.46%	3.46%	3.46%
Weighted Average		174.3	174.3	174.4	3.47%	3.46%	3.47%

An asterisk denotes values which were not shown to be statistically different relative to the baseline EMEDS configuration at the 95% confidence level.

Value of Additional Bed on Earthquake Mortality

Expanding the Critical Care Ward statistically reduces mortality for all four earthquake scenarios. However, the reduction in death is not practically significant in relation to the scale of earthquakes. Figure 7.10 shows the small reduction in the mean number of deaths across fourth earthquake scenarios.

Figure 7.10 Patient Streams e8, e5, e11, and e2 Deaths from an EMEDS+25 with up to Two Additional Critical Care Beds in Earthquake Scenarios



When the baseline EMEDS is asked to treat patient stream a5, an average of 371.2 patients die. When the same patient stream is treated using an EMEDS with one or two additional critical care beds, a weighted average of one or two fewer patients die respectively. This is shown in table 7.15.

Table 7.15 Comparison of Adding 1 vs. 2 Additional Critical Care Beds on Earthquake Mortality

Patient Stream	Mean TRA	Baseline Mean Deaths	+1 Critical Care Beds Mean Deaths	+2 Critical Care Beds Mean Deaths	Baseline Mean Mortality	+1 Critical Care Beds Mean Mortality	+2 Critical Care Beds Mean Mortality
e8	4095.4	292.9	292.5	291.1	7.15%	7.14%	7.11%
e5	5176.4	379.3	378.6	377.2	7.33%	7.31%	7.29%
e11	5401.7	391.6	390.5	390.1	7.25%	7.23%	7.22%
e2	5516.9	401.6	400.2	399.1	7.28%	7.25%	7.23%
Weighted Average		371.2	370.2	369.2	7.26%	7.24%	7.22%

Although the effect on mortality is as small as one or two patients, the mean difference of all eight of the samples, relative to the four samples in which the baseline EMEDS was used, were found to be statistically significant. Virtually every patient who has a mortality risk still dies even after the Critical Care Ward is expanded. This can be attributed to the scale of earthquake events and the capacity constraints of the EMEDS. Even if an expanded Critical Care Ward can keep one or two additional patients alive, several hundred casualties remain in line and waiting for care. The longer they spend waiting for care the higher the likelihood that they die.

Conclusions

Earthquakes produce large numbers of casualties. The baseline EMEDS does not have the capacity to process the majority of these patients. Expanding the EMEDS to have one or two additional Critical Care beds can improve the EMEDS system's performance in such scenarios. The following table summarizes the effect expanding the Critical Care Ward would have on different patient outcomes. Although it is unlikely that such an adjustment would practically change the RTD rates or mortality rates, significant improvements can be made in terms of evacuations.

Table 7.16 Change in Patient Outcome Rates When Beds are added to the Critical Care Ward for Earthquake Scenarios

Patient Outcome	Adding One Critical Care Bed	Adding Two Critical Care Beds
Change in weighted average evacuation rate	12.7%	22.3%
Change in weighted average return-to-duty rate	-0.13%*	0.00%*
Change in weighted average mortality	-0.29%	-0.55%

An asterisk denotes a sample which was comprised of one more or values not shown to be statistically different from the baseline EMEDS configuration at the 95% confidence level.

Patient Outcomes from an Adjusted Priority Strategy in Earthquake Scenarios

Design

It was shown that adjusting how the EMEDS+25 prioritizes patients can significantly impact patient outcomes. In this section, two additional tests are done where an EMEDS facility employs the adjusted priority strategy introduced in Chapter 6. For the second of these tests, the MTF is also given two additional Critical Care Ward beds. The data generated from these simulation runs are presented in the following sections in conjunction with data generated from previous tests in which a baseline EMEDS was used and one in which an EMEDS with an additional two critical care beds was used.[34]

[34] These data samples were generated separate from one another and as such they are built from separate random number seeds. Therefore, the data are not presented graphically because the output of individual replications can not

Impact of Adjusted Priority Strategy on Evacuations in Earthquake Scenarios

Patient stream e8 has a mean evacuation rate of 1.0%. When the baseline EMEDS is given two additional critical care beds this mean increases to 1.3%. When the additional beds are removed and an adjusted priority strategy is used instead, the mean increases from 1.0% to 3.6%. However, when these adjustments are combined the final evacuation rate is 4.5%. These data are presented for patient stream e8 and three other earthquake scenarios in table 7.17. The data show that for earthquakes rather than only expanding the Critical Care Ward, adjusting the priority strategy can more than double the weighted average number of evacuations.

Table 7.17 Combined Effect of Different EMEDS Adjustments on Evacuations in Earthquake Scenarios

Patient Stream	Mean TRA	Baseline Mean Evacs	Adjusted Priority Strategy Mean Evacs	Adjusted Priority Strategy + 2 Critical Care Beds Mean Evacs	Baseline Mean Evac Rate	+2 Critical Care Beds Mean Evac Rate[+]	Adjusted Priority Strategy Mean Evac Rate	Adjusted Priority Strategy + 2 Critical Care Beds Mean Evac Rate
e8	4095.4	39.9	148.8	185.4	1.0%	1.3%	3.6%	4.5%
e5	5176.4	44.1	155.9	180.7	0.9%	1.0%	3.0%	3.5%
e11	5401.7	45.0	158.7	176.4	0.8%	1.0%	2.9%	3.2%
e2	5516.9	45.9	165.3	192.7	0.8%	1.0%	3.0%	3.5%
Weighted Average		44.0	157.8	183.8	0.87%	1.06%	3.09%	3.62%

[+]In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding two beds to the Critical Care Ward relative to the other adjustments presented above.

Impact of Adjusted Priority Strategy on RTDs in Earthquake Scenarios

On average, the EMEDS+25 facility is able to return 3.5% of earthquake patients to duty after a thirty day simulation. When the EMEDS facility is expanded to include two additional beds however, this value does not change. In fact, the EMEDS returns the exact same number of patients to duty for each of the patient streams except patient stream e2, which on average RTDs 0.1 additional patients. However, when an adjusted priority strategy is used instead, the RTD rate increases from 3.5% to 3.8%. For three of the four patient streams a statistically significant increase in RTDs is not seen when two additional beds are added relative to when only the adjusted priority strategy is used. This data is presented in table 7.18.

Table 7.18 Combined Effect of Different EMEDS Adjustments on RTDs in Earthquake Scenarios

Patient Stream	Mean TRA	Baseline Mean	Adjusted Priority	Adjusted Priority	Baseline Mean RTD	+2 Critical Care Beds	Adjusted Priority	Adjusted Priority

be compared directly to one another across samples. However, the mean of each simulation run across thirty replications provide estimates of the overall sample mean for each outcome variable.

		RTDs	Strategy Mean RTDs	Strategy + 2 Critical Care Beds Mean RTDs	Rate	Mean RTD Rate[+]	Strategy Mean RTD Rate	Strategy + 2 Critical Care Beds Mean RTD Rate
e8	4095.4	139.9	156.5	160.3	3.4%	3.4%	3.8%	3.9%~
e5	5176.4	179.2	205.3	188.3	3.5%	3.5%	4.0%	3.6%
e11	5401.7	188.4	201.9	201.8	3.5%	3.5%	3.7%	3.7%~
e2	5516.9	192.8	210.4	213.3	3.5%	3.5%	3.8%	3.8%~
Weighted Average		177.4	195.9	193.1	3.48%	3.48%	3.82%	3.74%

[+]In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding two beds to the Critical Care Ward relative to the other adjustments presented above.
A tilde denotes values which were not shown to be statistically different relative to the EMEDS configuration which was already using the adjusted priority strategy at the 95% confidence level

Impact of Adjusted Priority Strategy on Mortality in Earthquake Scenarios

Adjusting the patient priority strategy does not reduce overall patient mortality for earthquake patients. The following table illustrates that regardless of what adjustment is used, whether the Critical Care Ward is expanded and/or an adjusted priority strategy is used, patients still die and the same rate. This can be attributed to the size of earthquake patient streams. Regardless of how an EMEDS+25 is adjusted, the facility is still too small to provide medical care to the majority of patients when there are more than 4000 or 5000 patients. The previous sections showed that although small improvements can be made to the number of expected evacuations, it is difficult to influence the overall patient outcome rates for RTDs and deaths. In fact, hypothesis testing showed for each patient stream that, as in combat scenarios, the number of patient deaths will increase slightly when the adjusted priority strategy is used.

Table 7.19 Combined Effect of Different EMEDS Adjustments on Deaths in Earthquake Scenarios

Patient Stream	Mean TRA	Baseline Mean Deaths	Adjusted Priority Strategy Mean Deaths	Adjusted Priority Strategy + 2 Critical Care Beds Mean Deaths	Baseline Mean Mortality	+2 Critical Care Beds Mean Mortality[+]	Adjusted Priority Strategy Mean Mortality	Adjusted Priority Strategy + 2 Critical Care Beds Mean Mortality
e8	4095.4	292.9	298.4	297.9	7.2%	7.11%	7.3%	7.3%
e5	5176.4	379.3	387.5	386.4	7.3%	7.29%	7.5%	7.5%
e11	5401.7	391.6	387.7	387.3	7.3%	7.22%	7.1%	7.1%
e2	5516.9	401.6	410.0	408.9	7.3%	7.23%	7.4%	7.4%
Weighted Average		371.2	375.6	374.8	7.28%	7.22%	7.33%	7.33%

[+]In the above table, this column present data that were simulated and aggregated separately from the rest of the data in the table. In other words, individual replications were done with different stochastically generated patients and a unique random number seed. These data are included in the table to illustrate the isolated effect adding two beds to

the Critical Care Ward relative to the other adjustments presented above.

Earthquake Conclusions

Earthquakes produce a large number of casualties. The four patient streams analyzed in this section are composed of, on average, over 5,000 patients. As shown in Chapter 6, it is difficult to improve the patient outcomes for patient streams with more than 4000 or even 1000 patients. However, earthquakes and attack scenarios differ largely in the percentage of patients who have a mortality risk. As shown in Figure 7.1, 17% of attack patients have a mortality risk whereas only 7% of earthquake patients do.

When adjustments are made to the EMEDS system, earthquake patient outcomes can be improved. Table 7.20, shown below, presents a summary of average impact four adjustments have on overall patient outcome rates from four earthquake patient streams.

Table 7.20 Change in Patient Outcome Rates When Different Adjustments are used for Earthquake Scenarios

Patient Outcome	Adding One Critical Care Bed	Adding Two Critical Care Beds	Adjusted Priority Strategy	Adjusted Priority Strategy + 2 Critical Care Beds
Change in weighted average evacuation rate	12.7%	22.5%	257.3%	318.2%
Change in weighted average return-to-duty rate	-0.13%*	0.0%	9.9%	7.5%
Change in weighted average mortality	-0.29%	-0.8%	0.6%	0.6%

An asterisk denotes a sample which was comprised of one more or values not shown to be statistically different from the baseline EMEDS configuration at the 95% confidence level.

Ultimately, during an earthquake event an EMEDS+25 would be overrun with patients. Adjusting how patients are prioritized or expanding the facility, especially the Critical Care Ward, by adding beds can improve the MTFs ability to process and treat the surplus of casualties.

HA/DR Conclusions

Table 7.20 illustrates that adjusting the size of the Critical Care Ward can lead to small improvements in earthquake evacuations while having relatively little impact on other outcome variables. This contrasts with the effect expanding the Critical Care Ward had on hurricane scenarios. For hurricane scenarios, adding two beds to the Critical Care Ward increased weighted average evacuations 28% and returns-to-duty to 12%. However, hurricanes produce far fewer patients and therefore the contrast shown above is reflective of the diminishing impact adjustments have on larger patient streams.

Interestingly, when the adjusted priority strategy is used for hurricanes the weighted average evacuation rate is improved 131% and the average RTD rate is improved 196%. However, when the same adjustment is made for earthquake scenarios, the weighted evacuation rate increases 257% but the RTD rate only increase 9.9%. Again, this difference can be attributed to size of the patient streams. Because the earthquake scenarios are so much larger, adjusting the patient priority strategy allows the MTF to quickly process through patients who require treatment. These patients ultimately evacuate to higher levels of care rather than returning-to-duty. In hurricane scenarios, the MTF has fewer patients to treat and can benefit patients regardless of whether they ultimately evacuate or return-to-duty.

As in combat scenarios, the EMEDS system can become overwhelmed by large numbers of patients generated from natural disasters. For both hurricanes and earthquake scenarios, it was observed that the EMEDS system's performance can be improved by expanding the Critical Care Ward or adjusting how patients are prioritized.

8. Research Limitations and Additional Considerations

Research Limitations

This research uses historic data and simulation software to analyze complex and multi-dimensional scenarios. Several assumptions were made to make the analysis possible. In reality, it is unlikely that an event will occur exactly how it was modeled in this research. Beyond that, it is unlikely that an EMEDS would be able to or would in fact choose to treat patients in the exact manner than JMPT models it. Recognizing these limitations, the conclusions are valid and this research remains useful. This chapter presents a number of limitations to this research and things a reader should consider. Nonetheless, this research provides original insights into how the EMEDS+25 system may perform in the face of a variety of MASCAL events and how several adjustments might impact that performance.

MPTk Scenarios

Each of the patient streams which were used in this analysis were generated using MPTk's CREstT tool. The accuracy and flexibility of this tool provide limitations for our research. We were limited in analyzing three types of scenarios due to the historic data within MPTk.

For our earthquake scenarios, the underlying patient data comes from records from the Haitian Earthquake in 2010. The hurricane scenarios were built from data from Hurricane Katrina in 2004. These events, while providing accurate depictions of largescale events, cannot be perfectly adjusted to meet other parameters. Therefore, our parameterization of these data, while an effective methodology, is limited by the accuracy of these historic data and MPTk's ability to transform historic injury distributions to fit events with different levels of economic development or population densities.

When CREstT is run, it simulates attacks and disaster scenarios in order to produce a time-series stream of patients. For disaster events, these patients can suffer from trauma related injuries and disease conditions. For the purposes of this research, we only exported trauma injuries because the disease conditions generally consisted of non-life-threatening conditions. In a test, a hurricane scenario's disease patients were exported and analyzed. In an average simulation run, the scenario consisted of over 4,800 disease patients and only 1 had a life-threatening illness. In a real-life scenario, these patients would require care and they would likely seek care at an EMEDS if it were present. A triage system would have to be in place to filter these patients to alternative treatment facilities if the EMEDS were unable to provide them with care.

Within the scenario design several parameters were selected, including population density. When selecting certain combinations of parameters such as an "emerging" economy that has a

"very high" population density, MPTk warns the user that the available data from which to parameterize the results are sparse. These scenarios were avoided in order to have as accurate data as possible, but it is still entirely possible that they would occur and that the EMEDS would be asked to provide medical assistance.

The population density parameter of MPTk adds an additional limitation. The "very high" population density category can be misleading. The criteria to be considered "very high" is to contain over 5,000 people per square mile. Many cities throughout the world have population densities greatly exceeding 5,000 people per square mile. An alternative tool may have to be used to analyze the effects of disaster events in areas which are so extremely dense.

Ultimately, MPTk was the best tool for this research but alternatives may need to be developed for more in-depth analysis or to answer questions that MPTk was not designed to address. The concept of focused empiricism however reaffirms the appropriateness of this research's design and methodology. Focused empiricism emphasizes the importance of combining the best data available with expertise in order to iteratively analyze alternatives and produce effective standards of care and policies (National Trauma Care System, 2016).

JMPT Network

The object-based simulation that was built in JMPT for this research looked at consisted of a patient stream and three connected medical objects. The first two medical objects consisted, consecutively, of a self-buddy aid object and a first-responder object. As mentioned, JMPT does not constrain the care, in terms of the number of providers, provided at Role 1 facilities. This research's model formulation collocated each of the facilities in order to remove the complication of transportation and isolate the impact of the EMEDS facility. These assumptions, while appropriate for this research, do not reflect the entirety of what might occur in real life. The following sections elaborate on some of the limitations to this research's JMPT simulations.

Transportation

This research did not analyze transportation in any way. A significant aspect of both combat operations and disaster relief scenarios is transportation. Patients must be able to get to an MTF in order to be treated. Furthermore, transportation must be available to move patients from one location to another. Lastly, ambulances and other transportation assets provide additional arenas in which care can be provided. None of these elements were modeled into our scenario. The objects within our medical network were connected by a transportation route which was assigned a distance of 0.0 kilometers and set to be a "walk-route." By setting the route to be a walk-route, JMPT did not require a physical transportation asset to be available to move patients from one object to the next.

In an attack scenario, patients will be wounded wherever they are located when a strike occurs. These patients will not necessarily have unlimited access to buddy or first responder care

and may require transportation. Similarly, in a disaster event patients may be spread out across even larger geographic areas and require transportation.

Scenario Length

The scenario length was set to thirty days. This, as was mentioned, was to reflect the AFTTP for how long the EMEDS will operate prior to being resupplied or replaced. Furthermore, in the same AFTTP it specifically says that "the typical mission duration for EMEDS personnel is less than 30 days (AFTTP 10.2.1)." However, particularly in the case of humanitarian and disaster relief efforts, the medical and economic relief process can take far longer than a month. This research is limited by its short time frame which only looks at the EMEDS system's ability to provide an immediate response.

Within JMPT, a medical network must be assigned a theater hospitalization day limit. This parameter governs how long an individual will be held prior to being evacuated. This value is set to seven days by default but was adjusted to three to reflect the theater modeling done by the Air Combat Command. Regardless of the value, this number represents a limit of the research because it comes with several assumptions. The first assumption is that a transportation asset will be available at the end of the theater hospitalization period to remove the patient. The second limitation is that this value would be perfectly adhered to in real-life when in fact there is likely more flexibility. The third limitation is that it requires you to know upfront how long an individual will need to rest and recover prior to being able to evacuate or return-to-duty. In real-life, the time someone will require to recover from an injury is stochastic and hard to predict.

Role 1 Care

Additional limitations have been mentioned concerning the care provided at the self-buddy aid and first responder objects within our simulated medical network. The limitation is that these medical providers are required to set a specific script of medical care that is predetermined within JMPT. By that, it means certain injuries will only ever be treated in certain ways by this level of care. In reality, a more skilled first responder, for instance, may be able to determine that additional methods of care could be provided which would be beneficial to the patient. However, in JMPT this cannot be modeled and the improvements of training airmen to provide higher levels of Role 1 care cannot be captured.

Modular EMEDS Buildup

In real-life when an EMEDS is deployed, it is not possible to deploy an EMEDS+25 before first deploying an EMEDS HRT and then developing that into an EMEDS+10. It is important to recall that the EMEDS+25 is the third and final development of a modular EMEDS system. JMPT models each of these individual modular units as their own MTF. This is an appropriate design when a user is interested in modeling the final state of the medical capability. However, it cannot be used to model the development from one modular subunit to another.

JMPT does allow a user to schedule an MTF as either on or off. Therefore, it is possible to have an HRT unit scheduled for the first few days of a conflict, then have that MTF turn off when a second MTF, a +10, could turn on. A user might believe this is the way to model the EMEDS system but there is a detail within the JMPT model which prevents this from working as intended. If this is done, any patients who are receiving care or are waiting for care in an FA beyond the triage ward would have to reenter the triage FA at the next MTF. This would restart their treatment and the results of such a simulation would underestimate the system's ability to provide care. In reality, an EMEDS HRT does not close for an EMEDS+10 to open. Rather, the HRT transitions into a +10 as items, equipment, and personnel are added onto the existing MTF.

An HRT can be set up in 12 hours and a +10 can be fully operationally capable 24 hours after that. It takes another full day for the +10 to transition into a +25. This research started with an EMEDS+25, thus forfeiting some resolution of how the MTF would treat patients during those reconfiguration processes and slightly overestimating the care provided at the facility during the first two and a half days.

JMPT does not allow this process to be accurately modeled. Therefore, this research is limited by the fact that it chose to start its scenarios with the final EMEDS design, when in reality a build-up period would be necessary before this could be possible.

CONUS Effects

A primary question this research originally sought to answer was what the effects are to patient outcomes when additional personnel, especially surgical care, are added to the EMEDS. Two questions this research did not look at were where that additional surgical care would come from and what the effect would be, at those locations, of the missing providers. Not answering those questions introduces a limitation to this research.

It was determined by this analysis that small expansions of the personnel assigned to the EMEDS do not make a significant change in the overall patient outcomes. Therefore, the negative effects of this limitation are minimal. However, it is important to note that these questions were not addressed. This research did include a calculation of the overall personnel numbers of Air Force members with Primary Air Force Specialty Codes (PAFSC) which aligned with the AFSCs assigned to the EMEDS. This calculation was done to determine the maximum number of personnel who could be drawn from to expand the EMEDS. This calculation showed that a significant number of surgical personnel were available within the Air Force to expand a single EMEDS in a crisis scenario. However, where these individuals are located or what disruptions would occur from removing them from their units was not analyzed.

Resource Management

A major concern for patient care in MASCAL scenarios is resource management. There may be a larger demand of physical resources than can be supplied. There may be logistical challenges in restocking resources which are depleted. Furthermore, there may be uncertainty at

the start of a crisis about how many resources are available, where they are located, if they can be accessed, and whether or not they have expired.

Critical resources include medical supplies such as bandages and dressings for wounds, medication, transfusable blood, food, and clean water. This research did not analyze the materials which would be required to treat different patient loads nor did it look at how to maximize the number of patients who can be treated based on a predetermined amount of resources. In the Battle of Fallujah, a Role 3 MTF used its entire blood supply by the third day of a ten-day scenario while treating fewer than fifty patients (Brennan, 2014).[35] Our scenarios consisted of more patients than this event and over a longer time period.

This research takes the approach that required resources were either negligible or limitless in their supply. Although neither of these is a fair assumption about how real-life HA/DR or combat scenarios would occur, they were appropriate to isolate the abilities and shortcomings of the EMEDS system as it exists on its own.

Utilization

JMPT does not provide the user with an in-depth understanding of personnel and equipment utilization. The program does not effectively allow the user to track personnel utilization in a way that was conducive for this analysis. This analysis is limited by the fact that it did not look at personnel utilization or scheduling. In a real-life scenario, scheduling is a massive challenge. Providers must balance the demands on their time with the need to get personal rest. Furthermore, JMPT does not provide great insight into equipment utilization. For one, only critical equipment is modeled. It would be valuable to have a better understanding of how limited access to supplies like bandages or blood would affect patient outcomes. Beyond that, however, critical equipment is not tracked in a way that is particularly useful. The only information that is provided is the overall utilization and the aggregate utilization over certain time periods within the overall simulation length. Without extensive modeling, it is impossible to match periods of high utilization with the individual patients who are being treated at that time. With the design of this research, it would not have been feasible to analyze equipment utilization across both patient streams and EMED configurations. Therefore, this research is limited to looking at overall patient outcomes after making equipment adjustments as a way to capture equipment utilization.

[35] JMPT does not model the use of blood by patients. However, a recent RAND report (Thomas et al., 2018) modeled the joint blood supply chain and provided the US military with several recommendations on how to strengthen the blood supply chain.

9. Conclusions and Recommendations

As discussed in chapter 2, the Air Force presently deploys modular EMEDS facilities to address patient needs around the globe. Chapter 3 highlighted the systematic development and maintenance of cruise and ballistic inventory by potential US adversaries. Chapters 4 and 5 introduced the modeling framework and methodology with which a baseline EMEDS or different configurations of an EMEDS can be analyzed across a variety of patient stream types. The next two chapters presented the results of that analysis in terms of how different EMEDS configurations, relative to the baseline EMEDS+25, can affect patient outcomes. This chapter summarizes a set of recommendations, including opportunities for future research, for both the AFMS, which oversees the EMEDS system, and the NHRC, which maintains MPTk and JMPT.

Improving the EMEDS system

The EMEDS's ability to handle patients during MASCAL events can be improved. The Air Force should conduct operational tests of modified EMEDS to confirm that the analyzed changes (expanding the Critical Care Ward and adjusting the patient priority strategy) produce the beneficial impacts measured by this research and thus strengthen the ability of the EMEDS to respond to mass-casualty events.

Accurate Patient Estimates

Before adjusting the current EMEDS system, the Air Force should build on this research and produce accurate patient estimates and determine how many patients the EMEDS+25 should be able to process during an MASCAL event. AFTTP 3-42.71 does not address MASCAL events or provide realistic estimates for how an EMEDS+25 would perform during such events. In fact, the document states that the "EMEDS HRT can triage and treat 350 patients per day with a surge capacity of 500" (AFTTP 3-42.71.2.4.2) during HA/DR events. Our research did not confirm these numbers and in fact illustrated that even the larger EMEDS+25 would not be able to triage and treat that many patients during a thirty day scenario. Across combat scenarios of increasing size, an EMEDS+25 can evacuate and RTD a combined total of 33.7 patients after thirty days when a large percentage of patients have severe injuries.

This research recommends the Air Force produce robust and comprehensive estimates for how many patients could be generated from a missile strike or other combat operations. The Air Force should then estimate, using JMPT, how the EMEDS+25 would perform if asked to treat those patient loads. The AFTTP document should present these values so individuals tasked with overseeing an EMEDS system have a better understanding of what the MTF is capable of and how it is expected to perform.

Triage Protocol

The Air Force should consider alternative triage procedures during mass-casualty conditions, particularly when there are more than a thousand critically injured patients. This research has shown that alternatives to the both the DIME triage process and JMPT's default patient priority process can be improved. The EMEDS structure and patient priority scheme should be designed to treat patients who have life-threatening conditions but do not require extensive stabilization times first. Furthermore, the EMEDS should attempt to triage and remove as many patients who do not have life-threatening conditions from the system as quickly as possible. Once these two patient populations have been addressed, there will be more time and space to devote to patients with longer required stabilization times.

As explained, the recommended treatment priority scheme would require the following adjustments to FAs within the EMEDS:

- Triage, ER and Flight Medicine FAs: Adjust treatment priority to ensure priority equity among those with low risk, predominately fracture-type injuries who require 0 hours stabilization in order to allow them to process further into the MTF.
- Operating Room FA: Leave unchanged as no patients require stabilization time within the OR and patients should be operated on in a FIFO manner.
- Critical Care Ward FA: Adjust treatment priority to ensure priority equity among all those who require 0 hours stabilization in order to quickly facilitate patient evacuation and return-to-duty prior to long-term stabilization of patients with longer stabilization times.
- Ward FA: Leave unchanged due to its large overall capacity.

This triage process increases the overall efficiency of the MTF while keeping overall mortality at practically the same rate. Shown in table 6.19 adjusting the patient priority strategy for combat casualty scenarios can lead to a weighted average net increase of more than 120 and 530 patients for evacuations and RTDs respectively. However, the weighted average number of deaths also increase by a mean difference of 10 additional deaths.

Critical Care Ward

The default EMEDS structure has disproportionate capacity constraints between the Critical Care Ward and the ICU ward. The default EMEDS+25 comes with 3 beds in the Critical Care Ward and 22 in the ICU ward. In our scenarios, we found that expanding the Critical Care Ward from 3 beds to 5 beds for patient streams of fewer than 1000 patients could dramatically improve patient outcomes. The ratio between the Operating Room and the Critical Care Ward is also out of balance. The baseline EMEDS+25 has two operating tables. Once two patients have exited the OR, the Critical Care Ward can become two-thirds full. A third patient can begin treatment at the OR, but a fourth cannot. In a way, this reduces the effective capacity of the OR to the ratio of Critical Care beds to OR beds: 1.5. Adding a bed to the Critical Care Ward increases this

effective capacity ratio from 1.5 to 2. This illustrates the positive influence an additional bed in the Critical Care Ward can have on other functional areas.

The Air Force should consider adapting the EMEDS structure to allow for up to two additional beds to be included in the Critical Care Ward in order to capture some of these potential benefits. Shown in table 6.9, for patient streams with less than 1000 average patients, increasing the Critical Care Ward to 5 beds can increase the weighted average return-to-duty rate 473% relative to the baseline rate. Further, such a change can result in an increase of 95.4% in terms of the weighted average evacuation rate across all patient streams. The change can also be expected to reduce mortality by 1.2% relative to the baseline EMEDS.

For patient streams with more than 1000 patients, the RTD advantages of the expanded Critical Care Ward alone were minimal. This was largely due to the fact that larger patient streams have more patients who require treatment with long stabilization times. These patients occupy the additional beds and prevent them from servicing numerous patients who otherwise go without receiving care. The high numbers of patients with low mortality risk end up never being treated and die waiting for care in the triage functional area. However, when combined with the adjusted priority recommendation we found that these benefits could be captured regardless of the patient stream size. The following table shows the net change in weighted average patient outcomes that can be expected across different events when two beds are added to the Critical Care Ward.

Table 9.1 Change in Weighted Average Patient Outcomes from an EMEDS+25 when 2 Beds are added to the Critical Care Ward across Combat, Hurricanes, and Earthquake Casualty Scenarios

Patient Outcome	Attack Scenarios	Hurricane Scenarios	Earthquake Scenarios
Change in weighted average evacuations	20.8	12.8	9.4
Change in weighted average returns-to-duty	8.3.	3.4	0.0
Change in weighted average deaths	-1.9	-1.5	-2.0

Uniform Triage Policies

Outside of the core medical community, Air Force triage procedures and protocols are not widely understood. Further, the task of properly triaging patients becomes more challenging during resource constrained environments such as following missile strikes or a natural disaster. During such an event, all individuals present will serve in a medical capacity in one form or another. Individuals will either be injured and/or be asked to act as a first-responder for someone who is injured. Individuals may be asked to assist in treatment or non-medical duties at an MTF. Any individual may be asked to assist in the triaging process. For triage to be effective individuals must clearly understand the process and be able to distinguish between different injury types. During a MASCAL triage process, time is of the essence in terms of minimizing

loss of life and physical suffering. Therefore, individuals must understand the individual airbase's triage procedure prior to the MASCAL event.

This research recommends the Air Force address this challenge in two ways. First, the Air Force must determine a uniform triage policy which can be implemented as a baseline process in the case of a large-scale event. During individual events, the process may need to be adjusted but there should be a standard procedure that is in place prior to the onset of an event. This will remove potentially conflicting sources of information and policies at different bases and commands. Secondly, the Air Force should consider a basic triage training program as part of annual first-aid training that educations airmen on how triage is to be done during MASCAL events and that includes more advanced exercises for members of the medical community. Such a uniform training process would ensure that all airmen are aware of how triaging should be conducted during the case of a missile strike or alternative MASCAL event.

This research also recommends the Air Force codify how it will address truly mass casualty events. During mass casualty exercises, bases will flood their MTF with a surge of patients which will barely exceed the surgical capacity of the MTF. However, these exercises often stop there and do not go beyond that amount. A hospital may be overwhelmed if it has ten patients who require advanced surgical care, but an exercise or a real-life scenario where there are ten patients is different than a scenario where there are a hundred even if the hospital is overwhelmed in both exercises.

In an example exercise at Bagram Airfield, the Air Force tested the ability of the Craig Joint Theater Hospital's ability to address a surge of thirteen patients as part of a mass casualty exercise. However, during the military's recent conflicts in the Middle East. a Role 3 MTF had to admit more than 50 trauma patients within a 24-hour period on at least two occasions (Brennan, 2014). Although valuable lessons were likely drawn from the exercise where Bagram Airfield was faced with thirteen patients, exercises in which a facility is faced with patient stream of fifty, a hundred, or even a thousand patients have not been undertaken. The Air Force should consider executing large-scale exercises and clearly specify how these types of scenarios should be addressed particularly by facilities such as the EMEDS system. This research showed that in such cases an alternative patient priority strategy may need to be employed. The Air Force should consider exercises where critical patient levels are met and alternative triage protocols are employed.

Recommendations for JMPT

Throughout this research, several possible improvements to the JMPT program were noted. Since JMPT is a tool which is used throughout the Department of Defense, it is important to strengthen it as much as possible. The following recommendations will be made to the developers of JMPT in order to maximize the potential for this software for future research.

Definitions

The definitions within the JMPT user manual should be clarified. Further, the user interface of the JMPT software should allow users to quickly access the definitions several currently unclear or undefined terms. There are several terms which appear within the software, particularly in the user reports, which are not explained or defined in the user manual. Users are left to their own interpretation as to what they mean.

A specific example of where definitions are provided but lack clarity is the difference between KIA and DOW. The definition for died-of-wounds is unclear. It states that it applies to all patients "who die after being seen by a physician." JMPT should clarify what is meant by the word "after." The current definition could be understood to mean, "a patient who dies any time after being seen by a physician." However, this is still potentially discontinuous with the definition of KIA which states that it applies to patients who "are assigned a patient code but die before they enter a medical treatment facility with a physician present." According to these definitions, it is unclear whether a patient who dies after having entered the emergency room but before being treated by a physician is counted as KIA. On one hand, they have entered a medical facility where a physician is present and thereby cannot be counted as KIA. On the other hand, they have not yet been seen by a physician so they cannot be counted as DOW. These definitions should be clarified or a third category should be added to account for patients who have arrived at a facility but have not yet been seen by a physician.

Missing KIA Patients

When a simulation is run in JMPT several datafiles are produced. The default datafile which is presented is a summation of the data and includes aggregated values for several key output variables. However, it was discovered through this analysis that, on occasion, these values are aggregated either incorrectly or are presented unclearly.

Casualty Statistics Summary

All values are average per replication unless noted

Casualty Type	Mean # Casualties	Percent
DIS	0	0
NBI	0	0
TRA	0	0
WIA	1052.73	100
Life Threatening	182.87	17.4
Non-Life Threatening	869.87	82.6

Final Disposition	Mean # Casualties	Percent
	0.23	0
DOW	3.43	0.3
Final Evac	133.67	12.7
In System	621.4	59
KIA	160.33	15.2
RTD	133.67	12.7

MTF	Total DOW (all reps)	Mean DOW	Total KIA (all reps)	Mean KIA
1RSP.1	0	0	421	14.03
EMEDS 25_pers.1	103	3.43	3351	111.7
SBA.1	0	0	947	31.57

The above figure illustrates a portion of this summary output page for a single simulation run. In this scenario, a patient stream has been run through a medical network consisting of a self-buddy aid (SBA.1) MTF, a first-responder (1RSP.1) MTF, and an adjusted EMEDS (EMEDS 25_pers.1) MTF. The mortality at each of these individual MTFs is presented on the right. On the top left, there is an overall summation of the scenario in terms of the number and type of patients across the 5 replications. On the bottom left, there is the aggregated values for the five output variables. In this scenario, the only place a patient can die is within an MTF because transportation is not modeled.

Note that the mean KIA values are 31.57 in SBA.1, 14.03 in 1RSP.1, and 111.7 in the EMEDS. This means that on average 157.3 individuals died at one of the three MTFs. However, note that on the bottom left of the file the mean number of KIA casualties is presented as 160.33.[36] These values do not match. This issue presented itself across a number of simulation runs. In other cases, the difference was far more significant than 2.97.

The value of 160.33 is accurate. In other datafiles, it is possible to track each individual patient. You can track the number of patients who arrive and depart from an individual MTF. Doing this, we found that the missing patients exit the first-responder but never arrive at the EMEDS. They are not counted as belonging to either MTF and therefore do not appear on the right side of this summary table. JMPT should rectify this calculation error and present the patients who die between MTFs on the far right.

[36] This example further illustrates the confusion surrounding the KIA/DOW definitions. It is unclear how patients can be classified as KIA at the EMEDS facility because JMPT defines KIA as patients who die "before they enter an MTF with a physician present."

EMEDS Buildup

As was explained in the discussion on the limitations of this research, the JMPT program does not allow the EMEDS buildup to be modeled in the way it would happen in the real world. It would be useful for the developers of JMPT to allow the EMEDS to, as a single object, develop from an EMEDS HRT into an EMEDS+10 and finally into an EMEDS+25 over a schedule determined by the user.

Patient Mortality Control

JMPT allows users to customize the treatment priority of individual injury types. However, individuals may suffer injuries of the same type but with differing severity. For that reason, JMPT should allow users to be able to customize the treatment priority based on patient mortality risks. For instance, future research may analyze the effect of treating medium mortality risk patients prior to treating high mortality risk patients. Such an analysis could not currently be performed within JMPT.

Further Research

There are many ways this research could be expanded upon. This section presents a number of ways in which the Air Force could further analyze the resilience of the EMEDS system or explore ways in which its handling of MASCAL events could be improved.

Additional MTFs

This research looked at the final development of the modular EMEDS system. Future research should investigate how different recommended MTF adjustments impact additional MTFs. The Air Force should investigate how expanding the Critical Care Ward or adjusting the patient priority scheme would impact the 58-bed Air Force Theater Hospital and the small-sized EMEDS subsystems.

Alternative Patient Streams

HA/DR Scenarios

This research focused on fixed-based missile strikes, earthquakes, and hurricanes. Future research should consider alternative patient stream sources. This research did not consider the patient streams which could be generated using historic tsunami, flood, landslide, fire, or other natural disaster data.

Chemical, Biological, Radiological and Nuclear

This research did not consider attacks which could include chemical, biological, radiological, or nuclear (CBRN) agents. These types of attacks come with additional challenges and are more

difficult to model. For instance, chemical attacks require decontamination efforts and more complicated triaging procedures. Biological or other attacks which consist of contagious agents further complicate the triaging process. Currently, JMPT does not allow users to model the effects of CBRN agents.

Improved Self-Buddy Aid and First Responders Care

This research did not quantify the impacts which could be captured from expanding the capabilities of Role 1 care in MASCAL scenarios. This research was unable to calculate these effects due to the limitations of JMPT. However, this research recommends that the Air Force analyze the potential improvements which can be made to overall patient outcomes if more advanced Role 1 care is available close to the point of injury.

The Air Force trains individuals to have a basic level of self-buddy aid. However, if more individuals were able to provide a higher level of care as first responders, the burden that is placed on the EMEDS MTF could be lessened. We attempted to analyze if this would occur using JMPT. However, within JMPT the first responders provide very little advanced medical care. The primary tasks performed by first responders within JMPT are to administer IV fluids, clean and dress wounds, immobilize injuries, and control bleeding. Although these are critical tasks, they do not require highly skilled individuals. Within JMPT, if the personnel assigned to the first responder MTF are replaced with orthopedic surgeons, in an effort to put highly skilled individuals in the role of the first responder, the medical care they provide does not change. In reality, all things being equal, an orthopedic surgeon would provide more advanced first responder care than an individual with less medical training. However, because in JMPT the tasks that are performed within the first responder conform to a finite list, the tool cannot capture these benefits. Therefore, although improving the care that first responders provide to patients in the case of a mass-casualty event could, and likely would, improve overall patient outcomes, JMPT is not the correct tool to analyze this hypothesis. However, an approximation of the second order effects of improved first responder care can be studied within JMPT using the *chance of treatment*. Such second order effects include the fact that if more patients survive their wounds at the point of injury, they may further contribute to the congestion of the facility where they seek medical care. These patients, who otherwise would have died at the POI, may be prioritized ahead of other patients who would have otherwise returned-to-duty. A more thorough analysis of these trade-offs should be done.

Chance of Treatment and Quarantined Care

Although not presented in this final report, this research analyzed JMPT's *chance of treatment* tool. This tool represents the probability that individuals with a certain patient code will be admitted to an MTF. Changing the chance of treatment for patients who have no mortality risk could be used to roughly approximate strengthened first responder care. For instance, under the baseline system, patients with minor scrapes are admitted into the EMEDS.

These patients do not have a mortality risk but can end up occupying space within the MTF. They are treated and resources and time are devoted to them which could be otherwise devoted to at risk patients. Adjusting individuals with their patient code to 50% prevents half the patients who attempt to enter the MTF with that patient code from being allowed to enter.

The most extreme form of this process would be to reduce the chance of treatment to zero for all patient conditions which never have a mortality risk. This would only be possible if first responders were able to effectively triage every single patient and determine if they have any of over a hundred different patient codes. Although this may be challenging to accomplish, it is worth analyzing what the effect of this policy would be.

In an initial test, using an earthquake scenario, the EMEDS+25 was programmed not to accept any patients who have one of 97 different patient codes which never correspond to a mortality risk. In this scenario, only 15.0% of the overall population who were treated by self-buddy aid were ever admitted into the EMEDS+25 and mortality drops from 7.2% to 6.0%. Future analysis could look more closely at what the effect of turning away individuals of different patient codes from the MTF would have on overall patient outcomes.

An alternative approach to this concept could be to quarantine patients of certain conditions. The Air Force could portion off part of the EMEDS resources in order to treat non-life threatened patients. However, modeling this type of patient handling is not possible within JMPT without multiplying the MTF's capabilities. This research recommends that the Air Force analyze whether there is a mechanism in which non-life threatened patients can be fast-tracked through the EMEDS or quarantined separately using only a portion of the EMEDS's resources and personnel.

10. Appendix

JMPT User-Defined Query

Within JMPT, the following SQL code can be run as a user-defined query to access the number of patients who had the final disposition of “Final Evac” across more than one simulation replication. To access the number of patients who were RTD, KIA, or DOW replace “Final Evac” with the final disposition of interest.

```
SELECT TML_Casualties.FinalDisposition,
  TML_Casualties.RepNum,
  TML_Casualties.FinalDisposition AS FinalDisposition1,
  Count(TML_Casualties.FinalDisposition)
FROM TML_Casualties
WHERE TML_Casualties.FinalDisposition = 'Final Evac'
GROUP BY TML_Casualties.FinalDisposition,
  TML_Casualties.RepNum,
  TML_Casualties.FinalDisposition
ORDER BY TML_Casualties.RepNum
```

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