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HADR OPERATIONS IN III MEF: OPTIMIZING AVIATION ASSETS FOR EFFECTIVE SUPPLY DISTRIBUTION IN DISASTER AREAS

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To support Humanitarian Assistance Disaster Relief (HADR) operations, the U.S. military maintains agile logistics capabilities, transportation networks, and response forces across the globe. III Marine Expeditionary Force serves as the first responder to HADR events for U.S. Indo-Pacific Command, where planners must optimize the throughput of relief assets from aerial ports of embarkation to aerial ports of debarkation to reduce response penalties (i.e., loss of life and human suffering). Our MBA project developed a model, Joint Transportation Optimization Planner—Aviation (JTOP-A), that assists in identifying how many organic KC-130J assets are necessary for cargo transport given required supply throughput. It also identified transportation gaps, which USAF C-5s and C-17s can fill. JTOP-A minimizes response penalties by selecting optimal solutions for movement of relief assets to the point of disaster. JTOP-A optimizes four scenarios replicating historic HADR events. Findings include: (1) The model supports optimal solutions to meet demand, recognizes aircraft/airfield compatibility, and allows Users to divert to available airfields when primary airfields are damaged. (2) The model is sensitive to the weighted coefficient, a parameter. (3) The model supports a "Day One" planning factor for response operations. We recommend the following for future research: expand the model to more locations, implement time horizons, and include tilt-rotor/rotary wing aircraft.

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To support Humanitarian Assistance Disaster Relief (HADR) operations, the U.S. military maintains agile logistics capabilities, transportation networks, and response forces across the globe. III Marine Expeditionary Force serves as the first responder to HADR events for U.S. Indo-Pacific Command, where planners must optimize the throughput of relief assets from aerial ports of embarkation to aerial ports of debarkation to reduce response penalties (i.e., loss of life and human suffering). Our MBA project developed a model, Joint Transportation Optimization Planner—Aviation (JTOP-A), that assists in identifying how many organic KC-130J assets are necessary for cargo transport given required supply throughput. It also identified transportation gaps, which USAF C-5s and C-17s can fill. JTOP-A minimizes response penalties by selecting optimal solutions for movement of relief assets to the point of disaster. JTOP-A optimizes four scenarios replicating historic HADR events. Findings include: (1) The model supports optimal solutions to meet demand, recognizes aircraft/airfield compatibility, and allows Users to divert to available airfields when primary airfields are damaged. (2) The model is sensitive to the weighted coefficient, a parameter. (3) The model supports a "Day One" planning factor for response operations. We recommend the following for future research: expand the model to more locations, implement time horizons, and include tilt-rotor/rotary wing aircraft.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARG	Amphibious Ready Group
AO	Area of Operation
AOR	Area of Responsibility
APOD	Aerial of debarkation
APOE	Aerial of embarkation
ATEM	Air Transportation and Efficiency Model
C-5	C-5 Galaxy Aircraft
C-17	C-17 Globemaster III Aircraft
CFE-DM	Center for Excellence in Disaster Management
CH-53E	CH-53E Super Stallion
COA	Course of Action
CR	Crisis Response
DoD	Department of Defense
DRAP	Disaster Relief Airlift Planner
FEMA	Federal Emergency Management Agency
FCM	Foreign Consequence Management
FDR	Foreign Disaster Relief
FHA	Foreign Humanitarian Assistance
FMF	Fleet Marine Force
G-4	Logistics Section (General Officer Staff)
GCC	Geographic Combatant Commander
HA	Humanitarian Assistance
HADR	Humanitarian Assistance and Disaster Relief
HA PUK	Humanitarian Assistance Pack Up Kit
HCA	Humanitarian Assistance and Civic Assistance
HO	Humanitarian organizations
JAAR	Joint After-Action Reports
JTOP-A	Joint Transportation Optimization Planner—Aviation
KC-130J	KC-130J Hercules

MAG	Marine Aircraft Group
MAGTF	Marine Air Ground Task Force
MASHPAT	Marine Assault Support Helicopter Planning Assistance Tool
MAW	Marine Aircraft Wing
MCEN	Marine Corps Enterprise Network
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MOS	Minimum Operating Strip
MLG	Marine Logistics Group
M-SHARP	Marine Corps Sierra Hotel Aviation Readiness Program
MV-22B	MV-22B Osprey
NDS	National Defense Strategy
NGO	Non-Governmental Organization
NPS	Naval Postgraduate School
NSS	National Security Strategy
OE	Operating Environment
OLM	Operations Logistics Management
OPCON	Operational Control
PAX	Passengers
PALS	Air Freight Pallet
SPMAGTF	Special Purpose Marine Air Ground Task Force
TPFDD	Time-phased Force and Deployment Data
UH-1Y	UH-1Y Huey
USAF	United States Air Force
USAID	U.S. Agency of International Development
USCENTCOM	Unites States Central Command
USG	United States Government
USINDO-PACOM	United States Indo-Pacific Command
USMC	United States Marine Corps
USN	United States Navy
VMGR	Marine Aerial Refueler Transport Squadron

EXECUTIVE SUMMARY

Our MBA project developed a model, Joint Transportation Optimization Planner—Aviation (JTOP-A), for the United States Marine Corps (USMC) that can assist planners in identifying how many KC-130J assets are required to support a HADR operation. Furthermore, JTOP-A identifies transportation gaps which United States Air Force fixed-wing assets, the C-17 and C-5, can fill. Ultimately, JTOP-A supports two objectives: (1) Outputs aid decision makers in minimizing response penalties (i.e., loss of life and human suffering). (2) JTOP-A determines the best asset allocation for the throughput of resources between supply and demand nodes and provides model-driven justification for additional aviation assets if required.

Research Question:

On a humanitarian mission ,what configuration of aviation assets minimizes response penalties by optimizing the efficacy of DoD responsiveness based on aircraft and airfield availability?

Research Activity:

Develop an optimization model that optimizes transportation time and/or fewer response penalties.

Our primary research activity develops an aviation capacity and allocation planner focusing on how to be responsive and cost effective in the distribution of resources during HADR. JTOP-A serves as an optimization model that runs on the free, open-source software OpenSolver, an add-in for Excel. We started with a transportation model which gave us the supply and demand structure we needed for the movement of resources. We incorporated three modes of transportation and expanded JTOP-A to five supply points and 128 destinations. Our objective function finds the optimal flow of resources and number of sorties required. It incorporates a weighted coefficient for each type of aircraft based on capacity, speed, cost per flight hour, and operational availability.

JTOP-A captures a short-term mission objective for the USMC and USAF. Moreover, it is customizable for scenarios with different asset allocations, supply

capacities, and demand signals to best address a HADR event. JTOP-A reduces the HADR planning processes time associated with manual aviation asset allocation and scheduling.

We ran four scenarios to test the viability of the model. Our findings include: (1) The model supports optimal solutions to meet demand at varying locations, recognizes aircraft/airfield compatibility, and allows users to divert to available airfields for alternative courses of action when primary airfields are damaged. (2) The model is sensitive to the weighted coefficient, a parameter. (3) The model supports a “Day One” planning factor.

Through our research activity, we created a model that serves as a foundation for optimizing aircraft allocation in response to HADR events. In its current state, JTOP-A provides support to planners as they develop courses of action for a HADR response. If modified or expanded, JTOP-A could serve a broader range of response operations for DoD and government/non-governmental agencies. Future research opportunities include: (1) Expand JTOP-A to capture more APOE/APOD combinations. (2) Expand JTOP-A modes of transport to include tilt-rotor and rotary-wing aircraft and include ship-to-shore movements. (3) Create additional infrastructure constraints, including material handling equipment and facilities, at APOEs/APODs. (4) Modify JTOP-A to automatically divert demand from non-functional or damaged APODs and reflect partial damage to an APOD which limits aircraft landing or material handling capabilities. (5) Implement time horizons to optimize asset allocation over the duration of a HADR operation. (6) Modify the weighted coefficient to increase efficacy. (7) Create additional constraints to incorporate aircraft cubic feet capacities.

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I. INTRODUCTION

The National Security Strategy (NSS) highlights the importance of humanitarian assistance as a driver of American influence in the global arena. While there are numerous avenues to further America's reach and reputation, Humanitarian Assistance and Disaster Relief (HADR) operations represent the extension of goodwill and cooperation from the American government to our foreign allies, areas of strategic interest, and regions plagued by instability and distress due to natural and man-made disasters. In order to support HADR operations, the United States Government (USG) leverages numerous agencies to provide expeditious relief. The Department of State (DoS), Department of Defense (DoD), and United States Agency for International Development (USAID) work in unison as the largest governmental organizations providing HADR.

Our MBA project serves to provide an optimization model, that we named the Joint Transportation Optimization Planner—Aviation (JTOP-A), for the United States Marine Corps (USMC) that can assist Marine Air Ground Task Force (MAGTF) planners in identifying how many Marine Aerial Refueler Transport Squadrons (VMGR) assets are required to support a HADR operation. It further identifies the transportation gaps that can be filled with United States Air Force (USAF) fixed-wing assets within a joint operating environment (OE). JTOP-A minimizes response penalties (i.e., loss of life, human suffering, further damage to an area, and stagnant or delayed recovery efforts) by selecting optimal solutions for the throughput of relief assets from a supply node to a demand node at the point of disaster.

We strive to highlight how the VMGRs are employed for HADR operations by posing the question: Does the VMGR meet the needs of a HADR mission? Can the Marine Corps support HADR efforts only using organic lift? The JTOP-A suggests that over short distances or during events requiring limited throughput capacity the Marine Corps can support a HADR mission with organic assets (i.e., the KC-130J Hercules). For larger disasters, does the Marine Corps in a joint OE require the assistance of the United States Air Force by employing C-17 Globemaster IIIs and the C-5 Super Galaxy? In short, the answer is yes. There are numerous scenarios where a heterogenous mix of fixed-wing cargo transportation assets are required for a given transportation flow. The question becomes, what is the right breakdown or allocation of aviation assets to meet the throughput of relief resources? The optimization tool created for III MEF will provide a data driven solution that can support planners as they create courses of action (COAs) in HADR mission planning.

A. OVERVIEW

Focusing solely on the DoD, we recognize all military services train to execute HADR operations; however, the USMC stands out as the military branch serving as America's force in readiness. Throughout the course of the service's illustrious history, Marines operate in numerous capacities: forward deployed, in combat, in garrison, supporting multinational security cooperation initiatives, and serving a spectrum of operations other than war. Most notably, Marines are considered the DoD first responders to global crises in both foreign and domestic HADR operations. As the United States shifts its national security focus to the Pacific theater, the Marine Corps must be prepared to act as the nation's response force in the event a disaster strikes throughout the Pacific Area of Responsibility (AOR) or global instability spurs crises in a region garnering our national interests and support (Mattis, n.d.). To execute these operations successfully, the Marine Corps must get "humanitarian logistics" right.

Thomas and Mizushima (2005) define humanitarian logistics as "the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information from point of consumption for the purpose of meeting the end beneficiary's requirements" (p. 60). To execute humanitarian support successfully requires a dynamic understanding of aviation, maritime, and ground logistics requirements that support the successful embarkation and debarkation of supplies and personnel tasked to support a given crisis response (CR) or HADR operation. Moreover, successful HADR operations require interagency coordination and a comprehensive understanding of the multifaceted operating environment in which relief operations occur.

To support complex interagency coordination, Apte, Gonclaves, and Yoho (2016) identify core competencies/capabilities for HADR stakeholders. Within their research, they surveyed HADR response personnel and found that 80 percent of relief efforts fall into seven categories: needs assessment, supply, deployment and distribution, health services support, collaboration, governance, and information and knowledge management (p. 247). Furthermore, Apte et al. hypothesize that organizations should focus on their core capabilities in the planning and execution of a HADR response effort to mitigate duplicity of efforts when it comes to humanitarian response. The DoS, USAID, NGOs and DoD each bring a host of capabilities to aid persons affected by natural or man-made disaster. For many large non-military humanitarian organizations (HO) and the military the capabilities overlap; however, "some capabilities are intrinsic to the military or to [the] HO" (p. 246). With this consideration in mind, our project emphasizes the employment of the DoD in what is considered its greatest contribution to HADR: deployment and distribution.

The DoD acts as a force multiplier by employing its logistical capabilities for the deployment and distribution of relief assets. While the DoD maintains HADR as a key mission, it recognizes that DoD personnel and infrastructure operate in support of USAID, private entities, and Non-Governmental Organizations (NGOs) in order for trained personnel to offer relief to a disaster area.

In a challenging operating environment, the ability to successfully implement humanitarian logistics requires capacity planning tools and optimization models that further support scenario-based planning. These models can support military planners, as decision support tools, when they look to tackle the exhaustive challenges associated with HADR operations. Optimization models also arm logistics personnel with the requisite justification to increase resource allocation in a given region and/or source relief assets from outside organizations.

More specifically, these optimization tools aid MAGTF planners in the justification of additional resources organic to the Marine Corps and requisite sourcing of joint assets within an AOR. Our project developed JTOP-A to provide data analyses on transportation requirements for a HADR operation or CR mission in the Pacific. For the purposes of brevity, HADR and CR will be referred to solely as HADR operations throughout this paper.

B. MOTIVATION

In the 2018 United States Indo-Pacific Command (USINDOPACOM) Posture Statement, Admiral Harris highlighted the prevalence of disaster relief efforts in the USINDOPACOM AOR and the importance of HADR operations to sustaining stability and strategic alliances within this region (Harris, 2018):

> The Indo-Pacific region continues to remain the most disaster-prone region in the world. About 75 percent of the Earth's volcanoes and 90 percent of earthquakes occur in the "Ring of Fire" surrounding the Pacific Basin. According to a 2015 UN report, disasters over the last ten years took the lives of a half a million people in the region, with over 1.5 billon people affected, and damages greater than 500 billion dollars.
>
> While disaster response is not a primary focus for USINDOPACOM, a key element of USINDOPACOM's Theater Campaign Plan (TCP) is building capacity with allies and partners to improve their resiliency and capability to conduct HADR. HADR cooperation is also an effective means to deepen and strengthen relationships. USINDOPACOM's Center for Excellence in Disaster Management (CFE-DM) serves as a regional authority on best practices for HADR and helps prepare regional governments for HADR events.

In February 2018, III Marine Expeditionary Force (III MEF) Logistics Section (G-4), headquartered out of Okinawa Prefecture, Japan presented a research proposal to the Academic Advisor and students of Naval Postgraduate School's Operations Logistics Management (OLM) curriculum. The research objective: to support III MEF contingency planning for HADR operations spanning the USINDOPACOM AOR. The III MEF staff recognized the challenges of providing HADR in an AOR that covers "more of the globe than any other geographic combatant commands and shares borders with all of the other five geographic combatant commands (COCOM) ("U.S. Indo-Pacific Command," n.d.). Moreover, III MEF recognized the importance of HADR as one of USINDOPACOM's strategic capabilities furthering the national interests of the United States Government. Prior to our project HADR planning in III MEF relied on subject matter expertise and manual aviation asset allocation scheduling supported by available aircraft attached to III Marine Expeditionary Brigade (III MEB).

Figure 1 is a visual depiction of the distributive nature of the USINDOPACOM AOR and the challenges faced by maritime and aviation assets supporting operations within the COCOM.

Figure 1. USINDOPACOM AOR. Source: United States Indo-Pacific Command (n.d.)

The motivation to execute our MBA project stems from the need to efficiently execute HADR operations and to align current HADR planning efforts with the Marine Corps' focus on expeditionary logistics ("Marine Corps Operating Concept," 2016). As a service, we strive to be a lethal, agile, and “right-sized” force (“Marine Corps Operating Concept”). More often than not, we believe agility is synonymous with less gear or lighter gear. Through a transportation lens, you would look for agility through the optimization of throughput for a given event rather than a reduction of resources and equipment.

The goals of JTOP-A’s implementation and outputs are how to be responsive and cost-effective in the distribution of resources during HADR. We do not limit the flow of relief assets and or supplies as these are based on needs specific to the crisis. Instead, we seek to optimize what type of aviation asset we employ, which supply hub it should come from, and how many sorties should be generated to provide relief while remaining cost effective for the DoD.

C. RESEARCH ACTIVITIES AND QUESTIONS

Our III MEF sponsor requested research support for two lines of effort specific to maritime and aviation assets. Our MBA project serves to support aviation asset allocation for supply distribution to a given disaster area.

Our primary research question and activity are listed below:

- Research Question

On a humanitarian mission ,what configuration of aviation assets minimizes response penalties by optimizing the efficacy of DoD responsiveness based on aircraft and airfield availability?

- Research Activity

Develop an optimization model that optimizes transportation time and/or fewer response penalties.

The primary goal of our model is to support users with the numbers of sorties required to execute a HADR mission based on a given amount of resource flow and the availability of Type/Model/Series (T/M/S) fixed wing assets, specifically the KC-130J, C-17 and C-5.

The secondary goal of the model is to put parameters in place that capture which Aerial Ports of Embarkation/Debarkation (APOE/D) are the most efficient in terms of responsiveness to a natural disaster at a given APOD based on aircraft availability and the compatibility of aircraft leaving an APOE with relief assets and landing at a given APOD.

D. SCOPE AND METHODOLOGY

1. Scope

To quote Mogilevsky (2013), "The aim of this work is to facilitate the logistics planning and decision-making process of transporting HADR material to states affected by a natural disaster. We also seek to minimize HADR commodity shortfalls delivered to the affected state while keeping transportation costs [response penalties] as low as possible" (p. 8).

We develop a USINDOPACOM specific airlift optimization tool which strives to "automate the current manual process of deciding which air routes to fly, which types and how many of each type of available aircraft to use, and which sources of supply to draw from" (Mogilevsky, 2013, p. 8). The end state of our project is to offer the tool to III MEF MAGTF planners that allows them to build multiple COAs based on user inputs, real-time asset availability, as well as infrastructure support at a given APOD. This supports rapid response and mitigates the man hours employed to contact different commands within INDOPACOM to manually develop a COA.

The scope of our research focuses solely on the transportation of resources in support of HADR by fixed-wing aviation assets. Throughput of relief supplies is designated in gross weight, pounds (lbs.), for a relief effort. Data analysis includes research analysis on C-5, C-17, and KC-130J capabilities, limitations, and airfield suitability from five APOEs to 128 APODs through the INDOPACOM AOR. More specifically, we looked at APOEs in: Guam; Hiroshima Prefecture (Iwakuni); Okinawa Prefecture (Kadena and Futenma); and Darwin, Australia. APODs are in Hawaii, South

Korea and the Philippines. All APOE/APOD airfield combability inputs are based on minimum operating strips (MOS) determined by length and width of available runways.

The Literature Review encompasses case studies cited from the Center of Excellence for Disaster Management and Humanitarian Assistance (CFE-DM), previous NPS projects, and Joint After-Action Reports (JAARs) outlining HADR support from the DoD. The data inputs for our model specific to the T/M/S and distances calculated between APOE and APOD were obtained primarily from online open sources, previous research conducted at the Naval Postgraduate School, and standard operating procedures for the VMGR out of Iwakuni, Japan.

2. Methodology

Our project develops a multi-layered optimization model that determines the type and number of aircraft that could be used to best support an HADR operation based on the throughput requirements. The model began is a standard transportation model in which we look to minimize response time through the selection of an APOE to an APOD by distance and the resources available at an APOE in consideration of the requisite demand at the APOD. After developing the initial transportation model, we identify airfields recognized by the International Civilian Aviation Organization (ICAO) and in the CFE-DM country handbooks that planners employ during a HADR operation. We capture the model's potential employment between APOE and APOD via three modes of transportation: KC-130, C-17, and C-5.

We build constraints into the model to capture how a disaster affects an APOD and throughput. Our first constraint is an airport/airfield physically not able to handle the planes (i.e., airstrips that are not conducive, or supply cannot be unloaded due to lack of capacity at the ramp). The second constraint is the airplane could have landed, but the airport is no longer functional due to the disaster. We incorporate capacity constraints for the aviation assets. We consider capability sets, equipment available, aircraft available, and gross tonnage supported by the United States Marine Corps and United States Airforce and the model provides a User Interface that adjusts to real-time data for asset availability and capacity supported. The Data & Methodology chapter provides a step-by-step breakdown on the model's utilization and the Excel OpenSolver add-in ("OpenSolver for Excel—The Open Source Optimization Solver for Excel," n.d).

3. Limitations and Assumptions

As the first of its kind for III MEF, this model has limitations and assumptions inherent to its creation. The scope of the model is limited to fixed-wing assets. We do not examine the tilt-rotor capabilities of the MV-22B Osprey, the rotary wing capabilities of the CH-53E Super Stallion, or the UH-1Y Huey within our project. In addition, we strictly look at APOE and APODs that are land-based. The model does not capture ship-to-shore movements that would include employment of assets from a Marine Expeditionary Unit (MEU) or an Amphibious Ready Group (ARG). Our model does not capture classes of supply and or equipment configuration aboard aircraft based on cubic feet available or pallet allocation. Aircraft embarkation configurations are a recognized shortfall within this model and will be discussed in the recommendations section of our project.

The most critical and sensitive limitation to our model are the parameters for coefficients that were applied to the distance/speed factor in our objective function for a given APOE/APOD combination. We create a weighted average that support planning factors beyond the capacity of an aircraft. Had we not built-in a weighted coefficient, the model would choose the aircraft with the largest capacity, the C-5 Super Galaxy, every time. This results in an average of planning factors deemed important by our advisors, our III MEF sponsor, and in consultation with VMGR air planners in Iwakuni, Japan. These factors include: Cost Comparison Ratio for reimbursable flight hours, Operational Control (OPCON) internal to the Marine Corps, and external assets from the Department of the Air Force (DOAF), Capacity of Aircraft Ratio, and the average of the above factors. Below is an explanation of the above factors; how they are incorporated into our model will be explained further on:

Cost Comparison Ratio: This is taking the cost per flight hour for each aircraft type based on the Office of the Undersecretary of Defense (Comptroller) FY2018 DoD Fixed Wing and Helicopter Reimbursable Rates (Office of the Under Secretary of

Defense, 2017). This results in a ratio that affects our model in the way we want while continuing to keep cost involved.

Operational Control: This is how much tasking control the USMC and III MEF have over the aircraft within our model. In our study, we are assuming that the USMC and III MEF have direct control over the VMGR KC-130s and no operational control (OPCON) over the C-17 and C-5 assets in INDOPACOM. OPCON remains with the Air Force and under United States Transportation Command (USTRANSCOM).

Capacity: We included capacity ratio to demonstrate the stark difference between the KC-130 capacity and that of the C-17 and C-5s.

Planning Factor Average: This is an average of all the above factors that is then applied to each APOE/APOD time and distance variable in the objective function.

This planning factor is heavily dependent on user inputs for the specific parameters. Moreover, these factors could change based on weather, seasonality, approved routing, and winds. We will discussion opportunities to further test different scenarios in our recommendations for follow-on research.

The following assumptions should also be considered when analyzing results from this model. First, this is considered a "Day One" planning tool. The ability to forecast for multiple days and/or the duration of an HADR event is not captured in the outputs of this model. Therefore, our model focuses on the immediate response to a disaster. Second, the model does not differentiate between permissive and non-permissive airfields. The use of permissive in this context refers to the authorization by a host nation to allow military aircraft take-off or land without issue, or threat of combative action by the host-nation against U.S. assets. All airfields identified as APODs within the model are considered permissive in the event of a natural disaster with the expectation being that a host nation would allow the relief assets into the country. Lastly, the airfields identified in the model are all assumed to be active runways and/or runways with the potential to receive aircraft. The material composition, latitude and longitudinal location, and runway length/marking/lighting assessments were pulled from online open sources and the United States Army transportation assessments.

II. BACKGROUND: HADR OPERATIONS AND CRITICAL STAKEHOLDERS

Chapter II defines Foreign Humanitarian Assistance (FHA), types of FHA relief missions, critical stakeholders involved in HADR operations, and it establishes the U.S. military role in FHA in a joint operating environment. Furthermore, the chapter highlights service specific capabilities within USINDOPACOM with special emphasis on the USMC and USAF fixed-wing cargo transportation assets. Lastly, the chapter provides a background on USTRANSCOM as a force enabler in the execution of aviation and maritime cargo transportation for HADR missions. Chapter II focuses primarily on aviation assets due to the scope of our MBA project; however, the Burgos & McLean MBA Professional Project (2018) provides exhaustive background information on available maritime cargo transportation assets organic to the Department of the Navy (DoN) and the assets employed by Military Sealift Command (MSC).

A. FOREIGN HUMANITARIAN ASSISTANCE, TYPES OF RELIEF, AND KEY STAKEHOLDERS

1. Foreign Humanitarian Assistance (FHA)

In Joint Publication 3–29 Foreign Humanitarian Assistance, the DoD defines FHA as:

> DoD activities conducted outside the U.S. and its territories to directly relieve or reduce human suffering, disease, hunger, or privation. These activities are governed by various statutes and policies and range from steady-state engagements to limited contingency operations. FHA includes foreign disaster relief (FDR) operations and other activities that directly address a humanitarian need and may also be conducted concurrently with other DoD support missions and activities such as dislocated civilian support, security operations, and foreign consequence management (FCM). FHA operations (including FDR operations) are normally conducted in support of the USAID or the DoD (Joint Chief of Staff (JCS), pg. I-1, 2014).

2. Types of FHA Relief Missions

Joint Publication 3–29 recognizes the following missions as types of FHA that the DoD supports:

> a. **FDR Missions.** FDR is assistance to alleviate the suffering of foreign disaster victims, including victims of natural disasters and conflicts, internally displaced persons (IDPs), refugees, stateless persons, and vulnerable migrants. Normally, it includes the provision of basic services and commodities such as food, water, sanitation, health care, non- food items (clothing, bedding, etc.), emergency shelter, as well as support to critical infrastructure and logistics necessary for the delivery of these essential services and commodities. The U.S. military normally will only be asked to provide FDR when it brings a unique capability or when the civilian response community is overwhelmed.
>
> b. **Dislocated Civilian Support Missions.** DoD may be requested to provide HA to dislocated civilians either to support the GCC's TCP or objectives or when the USG LFA requests DoD support due to its unique capabilities (e.g., specific engineering skills). A dislocated civilian is a broad term primarily used by DoD that includes a displaced person, an evacuee, an IDP, a migrant, a refugee, or a stateless person. These persons may be victims of conflicts or disasters.
>
> c. **Security Missions.** These missions may establish and maintain conditions for the provision of FHA by organizations of the world relief community. The delivery of humanitarian relief supplies often depends on the affected country having secure serviceable ports, air terminals, roads, and railways. In some cases, however, the affected country will not be able to meet this condition and may request assistance from the USG. Once the movement of supplies commences, secure areas will be needed for storage of relief material until it can be distributed to the affected population. Other tasks may involve providing routine clearance, security, and armed escorts for convoys and personnel delivering emergency aid, protection of shelters for dislocated civilians, and security for multinational forces, NGOs, and IGOs. (JCS, JP 3–29, pp. I-7-8)

The optimization model we created postures the USMC and USINDOPACOM for rapid response to each or any of these missions, should the situation arise. The ability to meet a variety of throughput requirements in a challenging AOR like INDOPACOM due to historical disaster prevalence and the distributed terrain, reinforces the need for an optimization tool that can minimize the number of sorties required to meet the flow of supplies from APOE to APOD and provide data driven justification for aviation assets given the finite resources INDOPACOM maintains.

3. Humanitarian Assistance Stakeholders

The DoD serves as the primary logistics enabler for FHA prior to, during, and after a disaster takes place. With extensive training in response operations, we as military planners must consider, “the number of civilian and non-USG actors involved in FHA activities, [that] command relationships outside DoD command structures may not be clearly defined, and unity of effort will be achieved with effective, timely coordination and cooperation” (JCS, pg II-1,2014). Figure 2 depicts the spectrum of HA stakeholders, outside of the DoD and military command and control (C2), for a given disaster. While Figure 2 is strictly an example, it reemphasizes the importance of relationship building and advocating for the correct allocation of relief assets in order to meet the cargo capacity requirements for each of these stakeholders as they focus on the recovery effort.

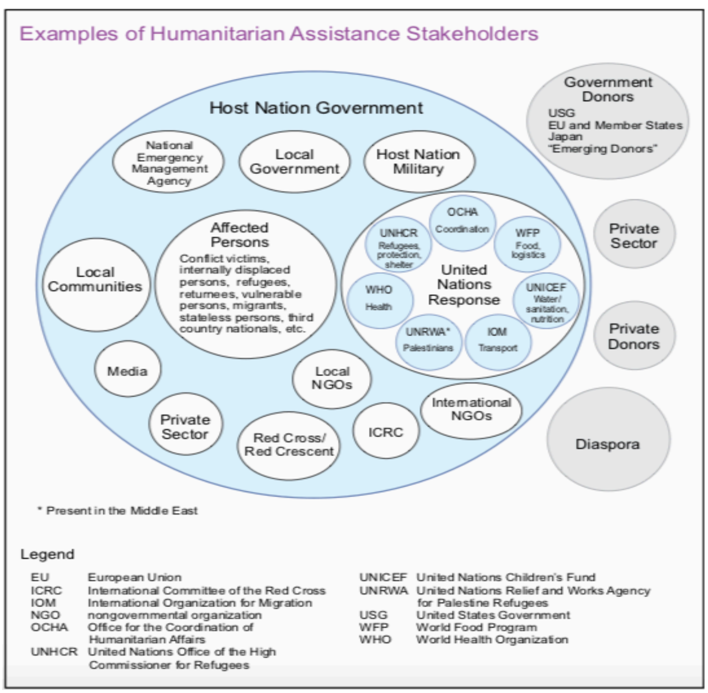

Figure 2. Example of Humanitarian Assistance Stakeholders.
Source: JCS JP 3–29 (2014).

B. HADR IN A JOINT OPERATING ENVIRONMENT

1. Department of State (DoS) HADR Programs

The DOS acts as a primary driver of humanitarian operations through the implementation of the Denton Program, the Excess Property Program, the Humanitarian Assistance (HA) Program, the Humanitarian Assistance and Civic Assistance (HCA) Program, and Funded Transportation Program ("Humanitarian Operations," n.d.). While the Excess Property, HCA, and HA programs focus on the execution of recovery efforts, the Denton Program and Funded Transportation Program specifically provide privatized industries transportation assets via aviation and maritime cargo assets for humanitarian relief. The DOS works jointly with USAID and the DoD to facilitate the planning and execution of these movements ("HA-Transportation | Denton Program | Funded Transportation Program," 2011). Described below are summaries for each program.

a. The Denton Program

The Denton Program is a DoD transportation program, working in conjunction with the DoS, to facilitate transportation support from private industries at "little to no cost to the donor" ("Humanitarian Operations," n.d.). It is "authorized by U.S. Statute (10 U.S.C. 402). The actual transportation portion of this program is contractually managed by USTRANSCOM utilizing a contractor operating out of Joint Base Charleston, SC" ("United States Transportation Command," n.d.). The Denton Program employs space available aircraft which includes the KC-130J, C-17, and C-5. In the event of a disaster within INDOPACOM the Denton Program could be employed by private donors to facilitate response in the AOR. MAGTF planners would work in tandem with the USTRANSCOM liaisons on the USINDOPACOM staff to capture these requirements.

b. Funded Transportation Program

The DoS website defines the Funded Transportation program as:

> The Funded Transportation program is conducted under the authority available for humanitarian assistance, title 10 U.S.C., section 2561. The Funded Transportation program permits transportation of cargo and Defense Department non-lethal excess property worldwide for non-governmental organizations and international organizations. This authority provides for the actual cost of transportation and payment of any associated administrative costs incurred ("HA-Transportation | Denton Program | Funded Transportation Program," 2011)

While the Funded Transportation program remains a critical capability for NGOs and international organizations, the cost of the program needs to be a consideration for military planners. In a fiscally constrained environment the cost to the USG can be reduced through the employment of our optimization tool. JTOP-A recognizes throughput requirements and the best heterogenous aircraft allocation to meet those requirements for a daily demand signal that mitigates excess movements and frees aircraft for follow on missions in the AOR.

Dozier (2012) provide more contextual information with regards to DoS current program operations and the linkage to appropriate transportation allocation.

2. USINDOPACOM

Established in 1947, USINDOPACOM is the oldest and largest of the unified combatant commands ("History of United States Indo-Pacific Command," n.d.). Figure 3 provides an "at a glance" view of USINDOPACOM military resources and strategic considerations based on area nations. The military resources encompass personnel, aircraft, and core competencies of each service. Figure 3 further highlights the expanse of aviation assets for both the USMC and USAF and the two expeditionary forces supported by the USMC.

Figure 3. United States Pacific Command at a Glance.
Source: DoD (2018)

USINDOPACOM is also home to Pacific Partnership, the "the largest annual multilateral humanitarian assistance and disaster relief (HA/DR) preparedness mission" executed by any COCOM (Affairs, 2018). Pacific Partnership began as Operation Unified Endeavor in response to the 2004 tsunami that devastated the southern portion of the AOR ("COMPACFLT - Pacific Partnership 2011 - History," n.d.). As of 2018, 13 iterations of Pacific Partnership were completed with multilateral engagement from the DoD, partner nations, NGOs and the USG. This exercise highlights the focus on rapid response employing multimodal transportation assets. With the U.S. Pacific Fleet at the helm of the exercise, the integration of the USMC assets out of III MEB and inter-theater assets from the USAF reemphasize the joint OE critical transportation capabilities created by each service to aid HADR missions. Figure 4 provides a visual depiction of successful HADR missions since 2004 in USINDOPACOM. Each of these missions required joint military assets and integration among the DoD, DoS and USAID.

Figure 4. Humanitarian Response Missions in USINDOPACOM. Source: "Defense.gov Special Report: Carter Focuses on Asia-Pacific Rebalance" (n.d.).

a. United States Marine Corps

The USMC supports USINDOPACOM with one organic VMGR squadron, VMGR-152; their call sign is "Sumos." The VMGR is comprised solely of KC-130Js that provide the Marine Corps and USINDOPACOM with 15 highly durable and versatile cargo transportation assets. Of all the three modes of transportation explored in our project, the KC-130 can land on more airfields within the AOR compared to the C-5 and C-17 due to the shorter and more narrow runway requirements for take-off and landing. The KC-130s are touted to be the most available and versatile fixed-wing airframe in the DoD arsenal for USINDOPACOM. This statement is reinforced by the squadron's website; since 2012 the Sumos "have been involved in exercises and operations throughout all of their Area of Responsibility to include Hawaii, Alaska, Australia, Thailand, Nepal, Cambodia and Mongolia. They continue to meet the high operational demand placed on them not only by the Marine Corps, but also by supporting joint operations with the Army, Navy, and Air Force" ("1st Marine Aircraft Wing > Subordinate Units > Marine Aircraft Group 12 > VMGR - 152 > About," n.d.). The VMGR-152 history also details their involvement in the 2008 Cyclone Nargis support, where the Sumos provided in aggregate "312 sorties to total 481.8 [flying] hours and delivered an impressive 2,808,954 pounds of cargo" ("1st Marine Aircraft Wing > Subordinate Units > Marine Aircraft Group 12 > VMGR - 152 > About," n.d.).

The employment of this asset puts the USMC at the forefront of HADR response, given it can land on APODs that may be damaged due to disaster and may only support a MOS and smaller parking ramp. In addition, the assets are pre-positioned between Marine Corps Air Station Iwakuni Japan on Hiroshima Prefecture and aboard Marine Corps Air Station Futenma on Okinawa Prefecture. This puts them at the advantage for rapid response when compared the USAF C-17 and C-5s. However, the KC-130 is limited by cargo capacity, speed, and range without refueling when compared to larger fixed-wing cargo assets. The KC-130 supports an average payload of 34,000 lbs., operates at an average speed of 417 mph, and flies without refueling at an average range of 2,041 statute miles (United States Air Force, 2018). In the next section we provide comparative statistics for the USAF C-17 and C-5 platforms.

b. United States Air Force and United States Transportation Command

The USAF maintains the largest fixed-wing cargo assets within the DoD: The C-17 Globemaster III and C-5 Super Galaxy. These assets support both inter-theater and intra-theater lift requirements and are employed for a variety of missions not limited to HADR. The C-17 supports an average payload of 164,900 lbs., operates at an average speed of 517 mph, and flies without refueling at an average range of 2,761 statute miles (United States Air Force, 2018). Pacific Air Force C-17 assets are pre-positioned out of Joint Base Pearl Harbor-Hickam, Hawaii. It is expected that, for an HADR event within INDOPACOM, these assets would deploy to Kadena Air Force Base (AFB) and Guam's

Andersen AFB to support the transport of supplies from those APOEs to the affected APODs. This additional movement in preparation for HADR recovery efforts places the C-17 at a disadvantage for initial response time when compared to the Marine Corps KC-130J.

The largest USAF cargo asset is the C-5. The C-5s are pre-positioned on each coast of the Continental United States. Like the C-17, if this asset were required and/or available for HADR support, it would deploy to Kadena or Guam's Andersen AFB from either Travis AFB in California or Dover AFB in Maryland. While at a disadvantage due to geographical proximity to INDOPACOM, the C-5 boasts the most robust capability of all fixed-wing cargo transportation assets in the DoD. The C-5 has a payload capacity of 281,000 lbs., operates at a speed of 518 mph, and maintains an unrefueled range of 5,424 miles when operating with 120,000 lbs. or less (United States Air Force, 2017). The massive transportation capability offered by the C-5 is countered by its limited operational availability for contingency operations.

While the C-17 and C-5 are operated and maintained by the USAF, it is USTRANSCOM that creates the time-phased force and deployment data (TPFDD) that schedules the C-17 and C-5 for global use. The planning and implementation of these assets for HADR operations can prove to be length and requires extensive coordination by the Joint Force executing the HADR mission. As stated in JP 3–29:

> USTRANSCOM provides movement schedules for deployment requirements in the sequence, or as near as possible to that requested by the joint force. The joint force staff should continually update all subordinate commands on deployment scheduling, situation, or mission changes. Such changes may require significant shifts in force deployment. Consideration should also be given to any deployment support requested by OFDA DART and USG departments and agencies, the UN, NGOs, and IGOs. FHA related movement of non-DoD people and relief supplies aboard DoD air and maritime assets usually requires specific lift authorizations from the CCDR and the Office of the Secretary of Defense (JCS, p. III-17).

With USTRANSCOM maintaining operational control over the use of C-17s and C-5s, the responding Joint Force can look internally to III MEF KC-130 assets as the most viable and quick solution to HADR.

3. Summary

USINDOPACOM maintains substantial HADR capabilities through the employment of its aviation and maritime assets. Our optimization model serves to highlight the strengths and weaknesses of each aviation asset through the implementation of the weighted coefficient in our objective function based on the type of response required and the availability of each aircraft within the AOR. Chapter III provides a literature review expanding on recent natural disasters and aviation assets employed to support the various stakeholders referenced within Chapter II. Moreover, Chapter III references previous optimization tools that support aviation asset allocation for DoD operations that we considered in the development of JTOP-A.

III. LITERATURE REVIEW

The literature surrounding HADR operations ranges from internal after-action reviews to external critiques, and from narrow, point driven analysis to broad, overarching themes. The design of this chapter is to highlight the contributions of previous work as well as to shed light on the gaps in the literature and analysis.

A. LITERATURE ABOUT THE PROBLEM

Previous work focuses on optimization modeling “to plan the strategic arrangement of budget-limited supplies and assets in advance of major disasters” (Salmeron & Apte, 2010, p. 573). This work finds that nearly half of the projected casualties during a disaster are caused by lack of commodities, or supplies. Salmeron and Apte (2010) suggest that assets must give priority to the critical population for transportation and medical care. However, this leaves a significant part of the population without proper supplies. Their study also finds that, “as the survival rate decreases, so does the picked-up critical population and the investment in health expansion,” which suggests that response time and delivery of the correct commodities is critical in reducing the number of casualties from a disaster (p. 570). Intuitively, we can also conclude that as the disaster severity increases the need for supplies and healthcare increases. While the priority of HADR is to enable rapid response and the implementation of recovery efforts through the delivery of these supplies and services. The execution of these operations come at a high cost. In a fiscally constrained operating environment, the DoD must analyze cost drivers associated with HADR operations and look for opportunities to mitigate costs while maintain the same level of responsiveness to a disaster event. As the service with the smallest budget allocation from the DoD, the Marine Corps must be a steward of financial responsibility. This is a daunting task for planners and budgeters when it comes to capturing costs of HADR events.

The Marine Corps does not have a budget set aside for HADR operations and therefore must ask for reimbursement of costs incurred through the initial response to a disaster. Timely responses reduce the number of casualties, so delays in authorizing funding would otherwise cause response times to be insufficient. The Marine Corps, therefore, needs to know the main cost drivers for HADR operations to plan correct responses to disasters. Ures (2011) looked at the cost drivers for HADR and finds that rotary-wing assets are the largest cost drivers for DoD HADR operations. The DoD is best suited for providing this type of asset for response, as the DoD "possesses the only ready fleet" of rotary-wing assets that are deployable in a timely manner and onboard ships with flight decks to bring the assets into range of the disaster area (p. 39). Ures focuses more on the cost drivers of response operations and less on the actual number of ships and aircraft the DoD should initially send to an area.

Previous research focuses on the cost of HADR operations with air assets but tends to leave out any kind of optimization of the aircraft used based on these costs. Herbert, Prosser, and Wharton (2012) finds that in Operation TOMODACHI, "fixed-wing flying hours are almost twice that of rotary-wing, 2,031 hours compared to 1,223 hours, and that the associated costs are nearly triple that of rotary wing flight operations" (p. 25). This is just one example of why fixed-wing aircraft need to be optimized in order to reduce overall costs. Figure 5, from Herbert et al., shows the breakdown for flying hour costs and the comparison between rotary and fixed-wing aircraft.

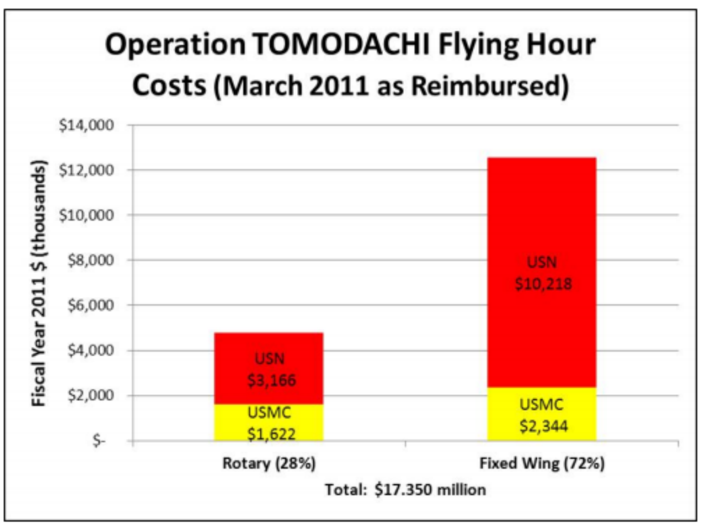

Figure 5. Operation TOMODACHI Flying Hour Costs by Aircraft Type and Category. Source: Herbert et al. (2012).

Moffat (2014) took the Ures (2011) and Herbert et al. (2012) findings a step further and broke down operating costs by different capabilities. The study provides a capability score for U.S. Navy ships per the HADR response capability of that type of ship. Moffat further identifies the costs associated with those ships by breaking down the cost per capability point given the mission skillset of those platforms. The study was conducted for Navy ships only, but the capability breakdown and associated costs lend insight into how to weight the response of certain modes of transportation (MoTs).

The development and evolution of cost estimations from previous literature was summed up by Apte and Yoho (2017) in Figure 6.

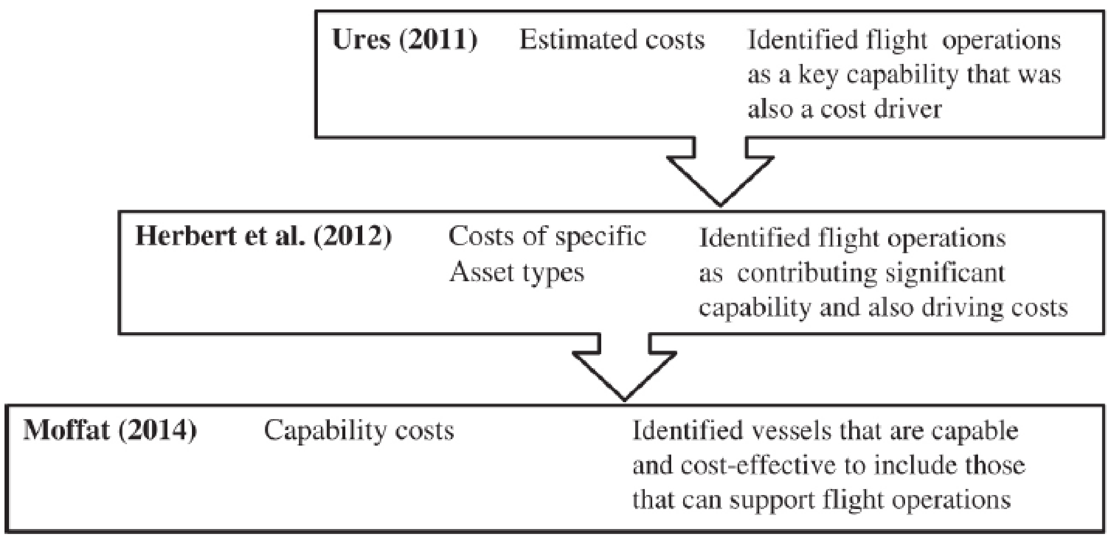

Figure 6. Summary of Existing USN HADR Cost Literature. Source: Apte and Yoho (2017).

All these works identify costs built from the cost drivers in previous literature. The chart (Figure 6) shows the relationships between the different cost literature and builds a picture of the increasing level of detail and scope.

B. EXISTING DECISION SUPPORT TOOLS FOR HADR OPERATIONS

As stated above, numerous MBA projects highlight fixed-wing assets as cost drivers for the DoD while failing to capture how best to optimize those assets in support of HADR. In our research, we identify four projects similar to our MBA project that attempt to build a decision support tool to facilitate efficient supply distribution in a military theater for both routine and contingency operations.

McCall (2006) developed a decision support tool employing stochastic optimization that captured the best product mix of relief assets to preposition as a Humanitarian Assistance Pack Up Kit (HA PUK) in the Pacific Theater. The model captured resource allocation that would minimize casualties for an HADR event. McCall's objective was to ultimately aid USTRANSCOM's planning for maritime and aviation asset allocation given a HA PUK configuration. While the project highlights key concerns with respect to classes of supply most employed to support HADR relief, it does not capture efficiencies in aircraft T/M/S and ability to move from a specific APOE to APOD.

In 2013 faculty and students in the Naval Postgraduate School's Operations Research department published an article outlining the development of an intra-theater Air Transportation and Efficiency Model (ATEM) designed "for quickly creating requirements channel routes, to help clear backlogged cargo, and to design high-quality weekly frequency channel routes for future demands. The solutions provided by ATEM maximized flow of passenger (PAX) and air freight pallet (PALS) on intra-theater airplanes (Brau, Brown, Carlyle, & Dell, 2013, p. 35)." This model was designed specifically for the U.S. military operating out of Iraq and Afghanistan and exclusively supported intratheater movements vice inter and intra air-based transportation.

ATEM maintains similarities to our model as it looks to optimize aviation assets in the throughput of supplies. Rather than a focus on minimizing response penalties for HADR, ATEM's most important impact was "convoy mitigation and the reduction of personnel casualties" (Brau et al., 2013, p. 50). However, the two models focus on different operating environments, III MEF's operating environment is assumed to be permissive while CENTCOM's is kinetic. Additional similarities arise from the project motivation, in which ATEM was created due to one of the author's experiences while forward deployed in United States Central Command (USCENTCOM). John Brau, Jr. found that most "air planners were manually scheduling CENTCOM intratheater airlift using basic tools such as whiteboards and simple Microsoft excel spreadsheets to keep track of assets and materiel" (Brau et al. p. 35). This model expanded the DoD's ability to successfully deploy assets based on of data analyses enabling planners to route aviation assets at the lowest cost to the government. Brown et al. recognized ATEM as a potential solution for Dantzig's and Ramser's (1954) research problem that captured issues with theater distribution known as the "vehicle routing problem (VRP)" (Brau et al., p. 36).

While the similarities between ATEM and the III MEF capacity planning tool are evident, there are many differences between Brown et al.'s (2013) research and that of our MBA project. First is scope of the APOE and APOD distribution. ATEM limits pre-existing routes between four APOEs and 27 APODs in CENTCOM. Whereas, JTOP-A considers five APOEs and 128 APODs distributed through INDOPACOM. The ability to expand the model to more APOEs and APODs throughout INDOPACOM is also possible. Second, the variability of demand and requisite APOD determination within our model is based on unpredictable events compared to the routine nature of the prescheduled flights in CENTCOM, even for requirement channel flights which generate additional sorties based on forecasted requirements. Third is the software employed to run the model. Brown et al. used the General Algebraic Modeling System (GAMS) vice our employment of the Open Solver excel add-in (Brown, Carlyle, & Dell, 2013). GAMS "is a high-level modeling system for mathematical programming and optimization. It consists of a language compiler and a stable of integrated high-performance solvers. GAMS is tailored for complex, large scale modeling applications, and allows you to build large maintainable models that can be adapted quickly to new situations ("GAMS - Introduction," n.d.). Within academia, GAMS is easily accessible and widely employed by OR Faculty and students. However, GAMS remain inaccessible on Marine Corps Enterprise Network (MCEN) making Excel and the Open Solver add-in more readily available to MAGTF planners and easier to replicate.

Moreover, our MBA project serves to highlight operational employment of an APOD in the wake of a disaster event, which may or may not be operational, whereas, ATEM assumes all APOE/APOD combinations to be viable. Additionally, the III MEF capacity planning tool models the capacity of aircraft by volume and weight with respect to the relief commodities; contrarily, ATEM models are based on PAX and PALS positions.

The distinction of capacity by volume and/or gross tonnage mirrors that of Mogilevsky's (2013) Disaster Relief Airlift Planner (DRAP), which was arguably the most similar optimization tool to ours. Mogilevsky's DRAP sought to expand on Brown's ATEM model with its implementation for crisis response operations in USINDOPACOM. In 2013, Mogilevsky took the ATEM framework and developed the DRAP to capture a "heterogeneous aircraft allocation" to support supply throughput for HADR in INDOPACOM. Similar to our model, Mogilevsky used "valid and well-established data points from open Internet sources including 'Factsheets' provided by the USAF" to support planning considerations and numerous APOE and APODs within PACOM to capture variability in demand locations (Moglivesky, 2013, p. 17). Like Brown, Mogilvesky employed GAMS to run the model. The main difference between JTOP-A and the DRAP is the outputs. Moglivesky captures optimality through the lowest transportation costs; he based these on operating costs and fuel consumption for a given aircraft (Mogilvesky, 2013). JTOP-A employs multiple parameters beyond monetary costs to support an optimal outcome as outlined in the Scope & Methodology section.

The last project we refer to is John Wray's Marine Assault Support Helicopter Planning Assistance Tool (MASHPAT) (Wray, 2009). Wray seeks to optimize helicopter routing and scheduling in a "high demand environment." In order to best employ a finite amount of rotary wing assets within CENTCOM, the MASHPAT "created all allowable routes for each helicopter type based on time and landing zone limitations. [Then] MASHPAT ranked each route by its ability to carry assault support requests in concert with all other candidate routes chosen for other helicopters and displays the selection of routes and assigned requests found" (Wray, p. xiv). The MASHPAT sought optimality in the same way our model does; however, MASHPAT maintains a more agile platform as rotary wing assets are not limited to the runway specifications required for the take-off and landing of a fixed-wing aircraft. Therefore, MASHPAT can expand the number of APOE/APOD combinations it chooses when determining a route. MASHPAT is notable for its impressive flexibility for delivery locations. Our model supports a greater amount of supply throughput in the immediate onset of disaster by providing greater capacity, the ability to transport multiple classes of supply, and the ability to transport engineering equipment and personnel into a disaster area. It should be noted, the MASHPAT tool could provide a basis for further research in support of the MV-22B with respect to HADR operations and contingency planning.

C. HADR LOGISTICS AND SUPPLY CHAIN COMPLEXITIES

Humanitarian supply chains are plagued by complexity and lack transparency for all stakeholders. Moreover, the system suffers from variability in requirements based on region and type of disaster. The ability to properly employ a United States Government supply chain in preparation for a disaster or after it occurs requires the DoD, DoS, and USAID to communicate and plan for a variety of contingencies dependent on the AOR and the resources available in that region. While communication and interoperability continue to improve with each new AAR, the logistics obstacles remain as one of the most challenging aspects of providing relief to a region.

Christensen and Young (2013) summarize the complexity of HADR relief logistics into three categories: governance, leadership, logistics. For the purpose of our project, Christensen and Young's (2013) analysis on logistics implications proves pertinent to our research objectives and the employment of our optimization model. Christensen and Young highlight in their own literature review:

> The most common logistical challenges to humanitarian supply chains [are] grouped in the following categories: *complex environment, customer, unsolicited donations, speed, and professional expertise*, which are presented in no particular order… To increase the speed of responses to natural disasters, both Tomasini and Wassenhove (2009b) and Ergun et al. (2010) highlighted the need for an agile supply chain that requires the leaning out of processes that add little value. There is plenty of room for

> improvement, especially regarding the total lead time of moving supplies in the humanitarian sector. (pp. 17–19).

Through the use of our optimization tool, we seek to mitigate the lengthy lead times associated with planning and executing a HADR operation. Furthermore, we seek to maximize speed and efficacy for III MEF in order provide rapid response via the right allocation of aircraft that not only meets the capacity of throughput relief assets but congruently reflects the most cost-effective allocation of aviation assets from an APOE to APOD immediately after the disaster strikes. The subsequent sections identify case analyses on previous disasters and how each event was handled in a joint operating environment.

D. CASE STUDY ANALYSIS

The Center for Excellence in Disaster Management and Humanitarian Assistance keeps an array of works related to HADR. This center seeks to not only compile information but also to create a knowledge base from which lessons learned from previous operations can be applied to planning efforts for future disaster responses. To put the information from previous academic works into real-world perspectives, we looked at reports and case studies from disasters in the Pacific. These studies give insight into the scale of the disasters and responses that the Pacific Theatre has encountered in the past and could encounter again.

The first report covers Operation DAMAYAN from the typhoon that hit the Philippines in November of 2013. Titled, “An Inside Look into USPACOM Response to Super Typhoon Haiyan,” the study focuses on the lessons learned and best practices that worked well during the operation instead of what went wrong (Center for Excellence in Disaster Management and Humanitarian Assistance [CFE-DM], 2015). One of the main points taken from the text states that, “Determining the allocation of resources and use of DoD assets was critical to the relief efforts. Satisfying a request for assistance was primarily based on field assessments” (CFE-DM, p. 8). This statement emphasizes the importance of correctly allocating resources. It also demonstrates that the gap in the knowledge base for this allocation must be filled in order to optimize DoD responses.

The second report is a case study of the Gorkha Earthquake in Nepal from April 2015. The emphasis on statistics in the case study gives us a snapshot of the scale of operations for this type of disaster. While the USG played a role in the response to this earthquake, it was not the biggest actor in the response efforts. This is an example of the host nation being able to coordinate response efforts and provide much of the needed resources itself. USAID still tasked the DoD with providing assets in response to the host nation's request for support. The case study shows that U.S. forces delivered an aggregate "120 tons of relief supplies," and "helped unload more than 200 aircraft" (Center for Excellence in Disaster Management and Humanitarian Assistance [CFE-DMHA], 2015, p. 12). Unfortunately, these statistics are not broken down into sorties by aircraft type or even amount of supplies delivered by aircraft type. The closest the case study comes to specific missions is to point out that the initial "Disaster Assistance Response Team (DART) and two Urban Search and Rescue (USAR) teams, which arrived via U.S. Air Force C-17 cargo aircraft on April 28" (CFE-DMHA, p. 9). The remainder of the missions are aggregated into the numbers discussed above. The study does point out "three Marine Corps UH-1Y Huey helicopters and four Marine Corps MV-22B Osprey, four Air Force C-17 Globemaster IIIs, four Air Force C-130 Hercules and four Marine Corps KC-130J Hercules aircraft, as well as various ground and aviation command and control assets were utilized' but again does not point out any number of sorties by type (Joint Task Force 505 News Release, 2015, p. 1).

E. GAPS IN THE LITERATURE REQUIRING FURTHER STUDY

The DoD literature surrounding Humanitarian Assistance and Disaster Relief operations tends to focus on the aggregate. After-action reviews and lessons learned papers talk about the total number of sorties flown but often do not separate the information into sorties by aircraft type. Another piece of missing information is the amount of personnel, equipment, or supplies in the loadout of each aircraft. The facts and figures in these papers, however, can still be very useful when paired with the academic literature on HADR response operations.

Unlike the prepositioning optimization model from Salmeron and Apte (2009), which covers a broad area of possible disaster zones prior to a natural disaster, our model seeks to optimize aviation assets utilization for a specific region after a disaster has occurred to minimize response time from major APOEs. It is intended to help fill the gap in the delivery of much needed commodities by optimizing aviation asset allocation from different APOEs to only the affected region.

IV. DATA AND METHODOLOGY

A. DATA SOURCES

The main source of information for the APOEs and APODs were the airfield studies performed by the Transportation Engineering Agency (2018) for the PACOM area of responsibility. These studies give runway dimensions, construction information, and various other site survey findings. The reports also include latitude and longitude coordinates for each APOE or APOD. We took the coordinates between each APOE and APOD and found the straight-line distance between them using the National Hurricane Center (2018) latitude/longitude distance calculator. This calculator gave us the straight-line distance in statute miles, which we could then add to the model as part of the weighted coefficients used in the objective function.

B. AERIAL PORT OF EMBARKATION AND DEBARKATION SELECTION

To create the model, we selected the most likely areas of response and III MEF priorities for analysis. The individual aerial ports of embarkation and debarkation were selected based on their ability to support larger fixed-wing aircraft, specifically the three types examined in this report. Runway length and construction were the main criteria for selection based on the TEA site surveys. For example, many of the smaller airfields in the Philippines were not included in the model because there were no site surveys conducted or the construction of the field does not align with standard operating procedures for takeoff and landing of these aircraft types.

C. MODEL

1. Indices and Sets

i	Aerial Port of Embarkation (APOE) [1, 2, 3, 4, 5].
j	Aerial Port of Debarkation (APOD) [1, 2, 3…128].
t	Mode of transportation [1, 2, 3] (1: KC-130J) (2: C-17) (3: C-5).

2. Input Data

C_t Capacity of aircraft.

C^0 Largest capacity of all modes of transport.

S_i Supply at APOE.

D_j Demand at APOD.

M A large number to force model to accept flow X at APOD j unless $Z_j = 0$ or $Y_{jt} = 0$.

A_{it} Number of operationally available sorties of mode t at APOE i.

S_i Amount of supply at APOE i (lbs).

D_j Amount of Demand at APOD j (lbs).

Y_{jt} = 1 if aircraft of type t can land at APOD j given runway length and type, 0 otherwise [(j= 1, 2, 3…128) (t= 1, 2, 3)].

Z_j = 1 if APOD j is operational and functional, 0 otherwise [(j= 1, 2, 3…128)] *User Input.

V_t Average cruise speed of mode of transportation t (miles per hour).

L_{ij} Distance from APOE i to APOD j (statute miles)

B_t Cost per billable flight hour to operate transportation mode t ($ US)

B^0 Lowest cost per billable flight hour ($ US)

O_t Operational Control OPCON factor for mode t

O^0 Highest operational control

3. Calculated Data

W_t
$$\frac{1}{3}\left(\frac{B_t}{B^0} + \frac{O^0}{O_t} + \frac{C^0}{C_t}\right) \quad (1)$$

E_{ijt} $$\frac{L_{ij}+V_t}{W_t} \tag{2}$$

4. Decision Variables

X_{ijt} Flow of Supplies in pounds transported from APOE i to APOD j via transportation mode t [(i= 1, 2, 3, 4) (j= 1, 2, 3…128) (t= 1, 2, 3)]

N_{ijt} Number of sorties sent from $APOE_i$ to $APOD_j$ by mode of transportation t [(i= 1, 2, 3, 4,5) (j= 1, 2, 3… 128) (t= 1, 2, 3)]

5. Objective Function

$$\text{Minimize} \quad \sum_{i=1}^{5} \sum_{j=1}^{128} \sum_{t=1}^{3} E_{ijt}\, X_{ijt} \tag{3}$$

6. Constraints

Supply Constraints:

$$\sum_{j=1}^{128} \sum_{t=1}^{3} X_{ijt} \leq S_i \qquad \forall\, i = 1,2,3,4,5 \tag{4}$$

Demand Constraints:

$$\sum_{i=1}^{5} \sum_{t=1}^{3} X_{ijt} \geq D_j \qquad \forall\, j = 1,2\ldots128 \tag{5}$$

Additional Constraints:

$$\sum_{i=1}^{5} \sum_{t=1}^{3} X_{ijt} \leq M\, Z_j \qquad \forall\, j = 1,2\ldots128 \tag{6}$$

$$\sum_{i=1}^{5} \sum_{t=1}^{3} X_{ijt} \leq M\, Y_{jt} \qquad \forall\, j = 1,2\ldots128 \;;\; \forall\, t = 1,2,3 \tag{7}$$

$$\sum_{j=1}^{128} N_{ijt} \leq A_{it} \qquad \forall\, i = 1,2,3,4,5 \;;\; \forall\, t = 1,2,3 \tag{8}$$

$$\sum_{t=1}^{3} C_t \; N_{ijt} \leq S_i \qquad \forall\ i = 1,2,3,4,5 \tag{9}$$

$$\sum_{i=1}^{5} \; \sum_{j=1}^{128} \; X_{ijt} \leq \sum_{i=1}^{5} \; \sum_{j=1}^{128} \; N_{ijt}C_t \quad \forall\ t=1,2,3 \tag{10}$$

$$X_{ijt} \geq 0 \tag{11}$$

$$N_{ijt} \geq 0 \text{ and integer} \tag{12}$$

7. Explanation of Objective Function and Constraints

Equation (3) is the objective function which seeks to minimize response penalties by choosing the optimal amount of resources, or the flow (X), in pounds. Each X term is unique in that it represents the flow of resources from a specific APOE to a specific APOD via one of the three modes of transportation. Therefore, we write the term generically as X_{ijt} to signify that it changes for each of the locations and modes of transport. Each X variable is multiplied by its unique coefficient (E) which is defined above in Equation (2). The Objective Function row in Table 1 shows an example of some of the unique coefficient terms (E) for each APOE to APOD route via the mode of transportation.

Table 1. Model: Coefficient Term for Operational Effectiveness (E_{ijt})

Distance/Speed					
	Iwakuni to Hilo In	Iwakuni to Daniel K. Inouye	Iwakuni to Ka	Iwakuni I	I
	36.89878685	35.11825833	35.922368	36.42	
Distances	Iwakuni to Hilo In	Iwakuni to Daniel K. Inouye	Iwakuni to Ka	Iwakuni	I
	4497	4280	4378	4439	
Locations					
Seosan Air Base					
Jinhae Air Base					
Yecheon Air Base					
Jeonju Air Base					
Mokpo Air Base					
Capacity of Aircraft	34000	34000	34000	34000	
A/C to Airfield Feasability	1	1	1	1	
Airfield Operability - MC or NMC (User Input)	0	1	1	1	
Total Capacity Supported	0	34000	34000	34000	
Obj Function (Min Time)	36.89878685	35.11825833	35.922368	36.42	
Decision Variables					
Sorties Actually Sent					

The E term is generically written in the same style as the X term. The term E_{ijt} simply means that E changes value for each APOE to APOD route and each mode of transport. The objective function is the sum of all E_{ijt} terms multiplied by the corresponding X_{ijt} term.

Equations (4) and (5) are typical of a transportation model. The sum of resources moving out of a given APOE to all APODs cannot exceed the aggregate supply at that APOE. The demand at each APOD must be met, so the sum of resources flowing into an APOD from all APOEs must be equal to or greater than the demand at that APOD. However, aggregate supply exceeding aggregate demand does not guarantee an optimal solution. Optimal solutions are also dependent on the number of sorties available.

The additional constraints are unique to our model. Equation (6) is the sum of resources flowing out of all APOEs to a certain APOD must be equal to or less than an extremely large number which forces the model to accept flow of X at that particular APOD unless that APOD is not functional ($Z_j = 0$). Equation (7) works in much the same fashion. The sum of resources flowing out of all APOEs to a certain APOD via a mode of transport must be equal to or less than an extremely large number which forces the model to accept flow of X at that APOD unless that particular mode of transport cannot land at that APOD ($Y_{jt} = 0$).

The last sets of constraints adjust the model for the number of operationally available sorties, input by the user. Equations (8) states that the sum of the actual number of sorties sent from each APOE for that mode must be equal to or less than the number of operationally available sorties from each APOE for that mode of transport. The sum of the capacity of each mode of transport multiplied by the actual number of sorties sent from each APOE for that mode must also be equal to or less than the supply of resources available at that APOE as seen in Equation (9).

Equation (10) says that the sum of the capacity of each mode of transport multiplied by the actual number of sorties sent from each APOE for that mode must be equal to or greater than the sum of the flow of resources from that APOE to all APODs via all modes of transport. All of these additional constraints ensure the model finds an optimal solution given the user inputs. Without these constraints, the model would always choose the shortest route between APOE and APOD and send the resources on the mode of transportation with the lowest Planning Factor Average.

Equation (11) describes the flow of supplies via X_{ijt} must be greater than or equal to zero. Equation (12) states number of sorties via N_{ijt} is both greater than or equal to zero and an integer.

8. Model Diagram

The diagram in Figure 7 shows our supply sources and destinations with demand for resources. This diagram follows the traditional transportation model format and shows any route from an APOE to APOD has the potential to be employed as long as the constraints allow.

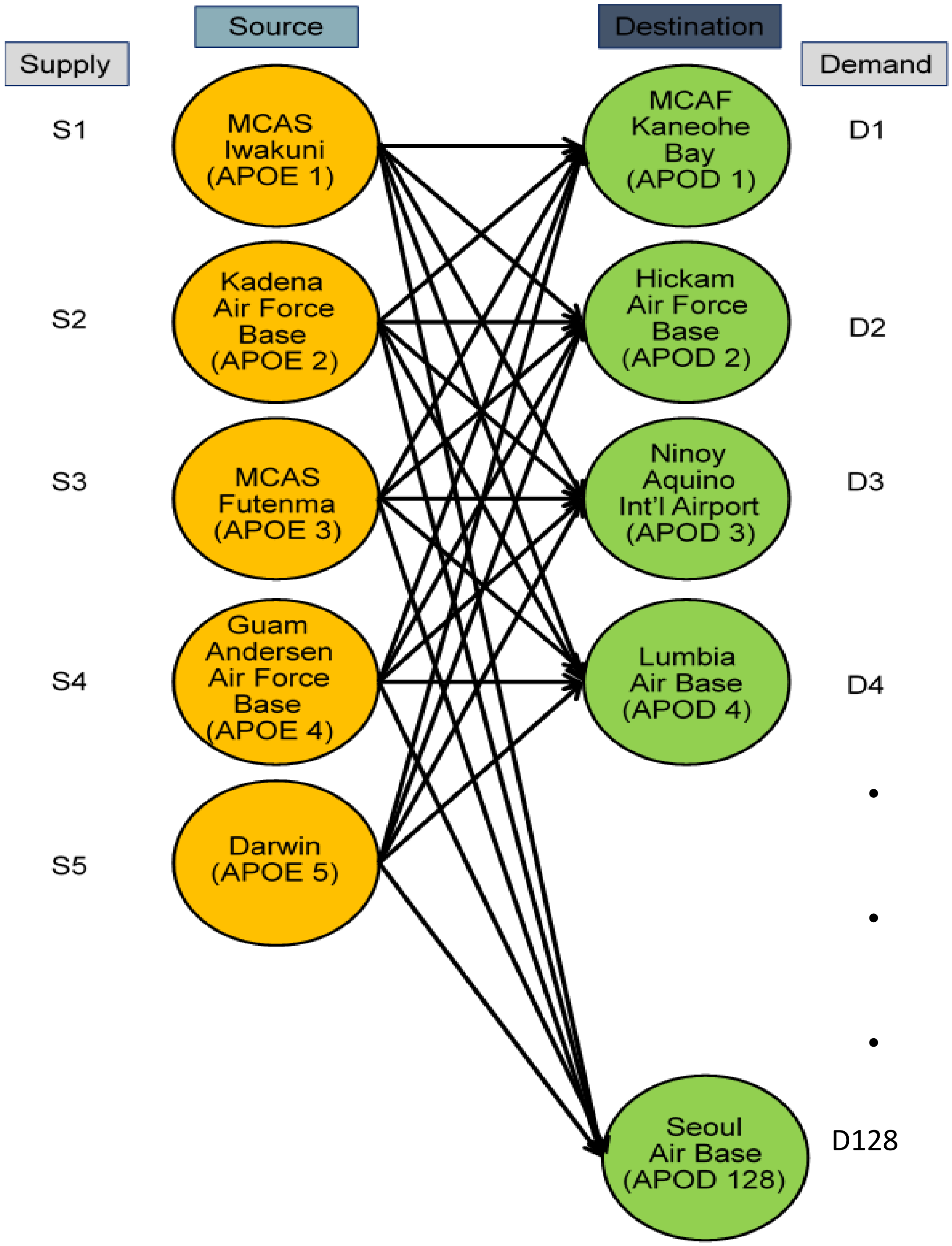

Figure 7. Transportation Diagram

D. MODEL FORMULATION

We start with a very simple transportation model to build the initial framework in Microsoft Excel. The transportation model gives us the basic supply and demand structure we needed to model the movement of personnel, equipment, and supplies from point of embarkation to the points of debarkation. This allows us to visualize how the resources move from supply points to locations of highest need and demand. The transportation model incorporates the “cost” of moving a unit of flow from each supply point to each point of demand.

From the basic transportation model, we incorporate three modes of transportation and expand the model from just a few supply and demand points to five supply points and 128 destinations with the possibility of demand. These expansions on the basic transportation model are simple to implement. The next step, however, is to incorporate some way to turn off airports if they become damaged from a disaster. We accomplish this by creating a binary variable that the user can change after assessing the airport’s post-disaster functionality. The binary variable equals “1” if the airfield is functional and operational and “0” otherwise.

We also implement a binary variable to essentially “turn off” the airport for certain modes of transportation. C-5s have different tarmac requirements than C-17s and KC-130Js, such as runway length and weight limitations determined by runway construction. This binary variable is equal to “1” if the aircraft of type “t” can land at that airfield based on the standard operating procedures for that aircraft and the limitations of the airfield. The variable is equal to “0” if the aircraft cannot land at the airfield according to the same procedures and limitations.

We then multiply these binary variables to the available capacity of each aircraft available to transport resources between each APOE and APOD. If either of the variables “turn off” the airport, then the whole term goes to “0” and there is no available capacity for that aircraft type between that specific APOE and APOD. The capacity to transport resources between the APOE and APOD also depends on the number of sorties available of that aircraft type from the APOE. The user inputs this value since the user has the most accurate operational readiness numbers for available aircraft. The model uses the amount of resources in pounds and the aircraft capacity to determine the number of sorties to send by aircraft type from each APOE to APOD to fill the demand at each location.

The original constraints of the model adhere to the standard supply and demand constraints that linear programming transportation models typically include. Table 2 shows that the amount of resources moving out of any APOE must be equal to or less than the available overall supply at that location, regardless of aircraft type. In other words, the combined total from a given APOE to each APOD cannot exceed the total supply at that APOE.

Table 2. Model: Supply and Demand Constraints

	Darwin to Jeonju Air Base	Darwin to Mokpo Air Base				
8	26.33113354	25.80134797				
	Darwin to Jeonju Air Base	Darwin to Mokpo Air Base				
0	3330	3263				
	Darwin to Jeonju Air Base	Darwin to Mokpo Air Base				
			0	<=	1000000	Supply
			0	<=	1000000	
			0	<=	1000000	
			0	<=	1000000	
1	1	1	0	<=	1000000	
			0	>=	0	Demand
			0	>=	100000	
			0	>=	10000	
			0	>=	100000	
			0	>=	100000	
			0	>=	100000	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	
			0	>=	0	

The objective function and constraints must be placed in OpenSolver in a different style than shown in the algebraic model due to the nature of Excel. Figure 8 shows the OpenSolver interface with all applicable constraints added to ensure the objective function is the optimal solution.

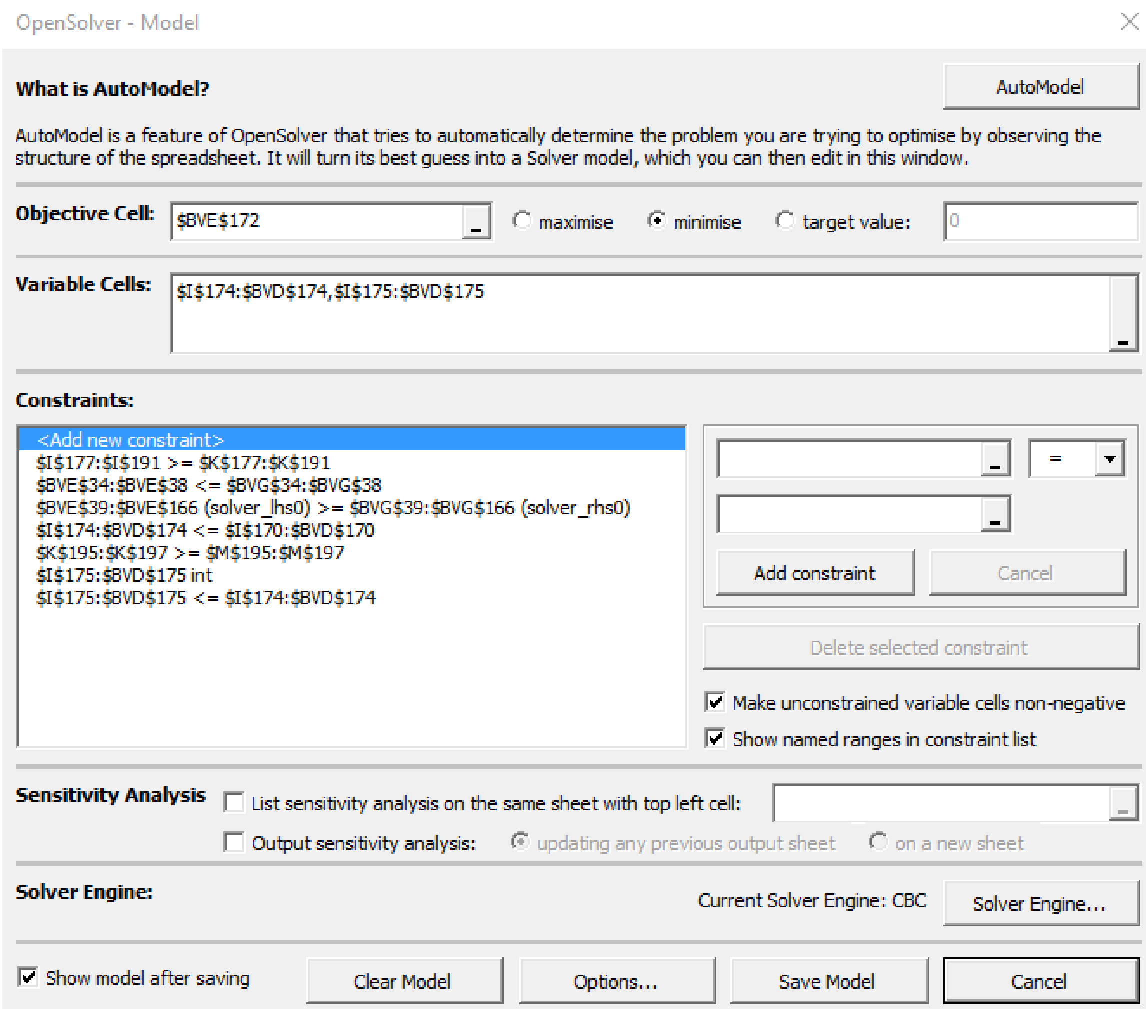

Figure 8. OpenSolver Interface

These constraints are linked to certain cells in the Excel spreadsheet and must not be manipulated by users or the model will not run correctly. The Variable Cells shown in Figure 8 are the decision variables for which JTOP-A finds the optimal values. These values are the outputs of JTOP-A and the most essential values for planners to develop courses of action.

E. USER INTERFACE

Users manipulate the inputs via the User Interface tab in the Excel spreadsheet. The User Interface allows a user to input the number of sorties available by type of aircraft from each APOE, supply at the APOEs, demand at the APODs, and the functionality of the APODs. The user manipulates the parameters of the model by entering values into the User Interface, which avoids tampering with the model itself. This allows a user to adjust the model's parameters as situations change, which enables mission adaptability to meet the needs of the affected area. The model itself, however, remains intact and the functionality of the Open Solver formulae will not be affected. Table 3 shows where the user inputs the number of sorties per day by aircraft type for each APOE and the overall supply of resources available at each APOE.

Table 3. User Input Number of Sorties and Supply at each APOE

			*PER DAY		
		# Of KC-130J	# Of C-17 Sorties	# Of C-5 Sorties	SUPPLY
RJOI	Iwakuni at MCAS Iwakuni	12	1	5	1000000
RODN	Kadena Air Force Base	12	1	5	1000000
ROTM	MCAS Futenma	12	1	5	1000000
PGUA	Guam at Andersen Airforce Base	12	1	5	1000000
YPDN	Darwin at RAAF Base Darwin	12	1	5	1000000

Once the model runs and optimizes the amount of resources and number of sorties from each APOE to each APOD, the number of sorties display in the User Interface tab as well. This allows for a quick reference to the optimum solution without needing to flip between the model worksheet and the User Interface tab. Everything with which the user needs to interact is located in the same tab for simplicity and ease of use. Table 4 gives an example of the APOD functionality input and demand for resources input by the user in the User Interface tab.

Table 4. User Input Functionality and Demand at each APOD

Hawaii		1=Available	User Input Demand	Demand Supported
PHTO	Hilo International Airport	0		0
PHNL	Daniel K. Inouye International Airport	1	100000	100000
PHOG	Kahului Airport	1	10000	10000
PHKO	Kona International Airport at Keahole	1	100000	100000
PHMK	Molokai Airport	1	100000	100000
PHNY	Lanai Airport	1	100000	100000
PHLI	Lihue Airport	1		0
PHHN	Hana Airport	0		0
PHMU	Waimea-Kohala Airport	1		0
PHJH	Kapalua Airport	1		0
PHJR	Kalaeloa Airport (John Rodgers Field	1		0
PHUP	Upolu Airport	1		0
PHDH	Dillingham Airfield	1		0
PHIK	Hickam Air Force Base	1		0
PHNP	NALF Ford Island	1		0
PHNG	MCAF Kaneohe Bay (Marine Corps E	1		0
PHBK	Pacific Missile Range Facility at Bark	1		0
PHSF	Bradshaw Army Airfield	1		0
PHHF	French Frigate Shoals Airport	1		0
PHHI	Wheeler Army Airfield	1		0

Table 4 also shows the Demand Supported column, which is the value of APOD functionality multiplied by the user input demand. If the APOD is non-functional (a value of “0”), then the Demand Supported for that APOD must be zero. Not only is this a realistic scenario in which demand at a damaged airport cannot be fulfilled, but it is also a failsafe for the model to ignore user input demand at APODs where sorties cannot be sent. The Demand Supported column is then transferred into the model on the second tab of the Excel workbook under the Demand column.

The model generates the optimal number of sorties from each APOE to APOD via each mode of transportation and transposes the solution into the User Interface. These numbers would be difficult to find if the user was forced to scroll across over 1000 variables in Excel. To make things simpler and easier to read, we incorporated the outputs from the sortie decision variable into the User Interface tab, as shown in Table 5 by the example for the KC-130J. All values are shown as zero due to the model being reset and ready for use.

Table 5. Model Outputs: Number of Sorties to Send by Aircraft Type from APOE to APOD

KC-130J (Sorties sent by location)				
Iwakuni	Kadena	MCAS Futenma	Guam	Darwin
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

The User Interface serves as an easier way to manipulate the very large optimization model. User input parameters into JTOP-A through very intuitive sections of the User Interface such as the number of sorties available at each APOE. The model does the "heavy lifting" for the user and presents the outputs in a readable format. These outputs will be further explained in the next chapter as we show some scenarios and analyze the results of the optimal solutions given by the model.

F. MODEL IMPLEMENTATION

JTOP-A finds the optimal flow of resources by amount, route, and mode of transportation. It also generates the number of sorties by aircraft type required to move that optimal amount of resources. While these are optimal solutions, they often fail to capture all real-world constraints or limitations. JTOP-A gives a baseline to work from to increase the speed of decisions and aid decision makers in identifying optimal courses of action.

To use JTOP-A, planners need the Excel Add-in: OpenSolver. Our hope is that this program is easier to implement within the Marine Corps Enterprise Network (MCEN) than other modeling software since it is a free, open-source software and compatible with Excel. Currently, MCEN computers host a Microsoft Office suite with Excel and should be able to accept additional add-ins. For III MEF to properly employ JTOP-A, MCEN needs to verify and authorize OpenSolver use on MAGTF planner computers. Without the proper software, JTOP-A cannot be utilized. Lastly, JTOP-A should be employed by planners in the G-3/5 and G-4 at a Major Subordinate Command (MSC) level or on a joint staff.

V. ANALYSIS AND RESULTS

A. SCENARIOS

We created four scenarios for our model to test its viability against the potential for real-life disasters. The model supply and demand inputs are based on daily demand from an APOE to an APOD. These inputs are in pounds. While the literature review reflects a gap in daily demand historical data, we took the aggerate demand from previous HADR events (i.e., The Nepal Earthquake and Super Typhoon Haiyan), and divided the aggregate data based on the response time in days. This provides a general idea of the daily demand requirements at an APOD over the course of a recovery effort. Ultimately this data will be up to by the user based on USAID requests and the known supply quantities at the APOEs. We created four scenarios for a spectrum of possibilities. Following are the scenarios.

- Scenario One: Hurricane strikes the islands of Hawaii.
- Scenario Two: Typhoon strikes the islands of the Philippines.
- Scenario Three: Typhoon and flooding strike South Korea.
- Scenario Four: Super Typhoon strikes the Philippines, limiting A/C compatibility to KC-130s.

The amount of supply in pounds at each APOE and the number of operationally available sorties are shown in Table 6. We realize that the operational availability of aircraft often changes with deployment cycles and maintenance periods. For consistency in the analysis, these parameters remain constant across all four Scenarios. The aggregate demand also remains constant at 250,000 pounds, but the demand is spread across different APODs in each Scenario.

Table 6. User Input: Number of Sorties

			*PER DAY	
		# Of KC-130J	# Of C-17 Sorties	# Of C-5 Sorties
RJOI	Iwakuni at MCAS Iwakuni	4	0	0
RODN	Kadena Air Force Base	0	2	1
ROTM	MCAS Futenma	3	0	0
PGUA	Guam at Andersen Airforce Base	0	2	1
YPDN	Darwin at RAAF Base Darwin	2	0	0

B. SCENARIO ANALYSIS AND RESULTS

1. Scenario One: Hurricane Strikes the Islands of Hawaii

Scenario One looks at the allocation of sorties and flow of resources given a disaster response mission in Hawaii after a hurricane. The demand for resources is spread among five different APODs, each with a demand signal of 50,000 pounds for the first day. Table 7 shows the breakdown of operationally available sorties by type of aircraft and APOE or point of origin.

Table 7. User Input: Supply, Demand, and APODs for Scenario One

Hawaii		1=Available	User Input Demand	Demand Supported
PHTO	Hilo International Airport	0	50000	50000
PHNL	Daniel K. Inouye International Airport	1	50000	50000
PHOG	Kahului Airport	1		
PHKO	Kona International Airport at Keahole	1	50000	50000
PHMK	Molokai Airport	1		0
PHNY	Lanai Airport	1		0
PHLI	Lihue Airport	1		0
PHHN	Hana Airport	0		0
PHMU	Waimea-Kohala Airport	1		0
PHJH	Kapalua Airport	1		0
PHJR	Kalaeloa Airport (John Rodgers Field	1		0
PHUP	Upolu Airport	1		0
PHDH	Dillingham Airfield	1		0
PHIK	Hickam Air Force Base	1	50000	50000
PHNP	NALF Ford Island	1		0
PHNG	MCAF Kaneohe Bay (Marine Corps E	1	50000	50000
PHBK	Pacific Missile Range Facility at Bark	1		0
PHSF	Bradshaw Army Airfield	1		0
PHHF	French Frigate Shoals Airport	1		0
PHHI	Wheeler Army Airfield	1		0

We take the inputs shown in Table 7 and run the optimization model in Open Solver. The model finds an optimal solution and meets all demand requirements. Next, the model transposes the optimal flow of resources into number of sorties by type location. Table 8 shows the sorties from each APOE to APOD required to transport the optimal flow of resources to meet demand at each APOD. In this Scenario, three APOEs were employed to send the optimal number of sorties and flow of resources.

Table 8. Model Outputs: Number of Sorties from each APOE to APOD via T/M/S Aircraft for Scenario One

		KC-130J (Sorties sent by location)					C-17			
Hawaii		Iwakuni	Kadena	MCAS Futenma	Guam	Darwin	Iwakuni	Kadena	MCAS Futenma	Guam
PHTO	Hilo International Airport	0	0	0	0	0	0	0	0	1
PHNL	Daniel K. Inouye International Airport	0	0	0	0	0	0	1	0	0
PHOG	Kahului Airport	0	0	0	0	0	0	0	0	0
PHKO	Kona International Airport at Keahole	0	0	0	0	0	0	0	0	1
PHMK	Molokai Airport	0	0	0	0	0	0	0	0	0
PHNY	Lanai Airport	0	0	0	0	0	0	0	0	0
PHLI	Lihue Airport	0	0	0	0	0	0	0	0	0
PHHN	Hana Airport	0	0	0	0	0	0	0	0	0
PHMU	Waimea-Kohala Airport	0	0	0	0	0	0	0	0	0
PHJH	Kapalua Airport	0	0	0	0	0	0	0	0	0
PHJR	Kalaeloa Airport (John Rodgers Field)	0	0	0	0	0	0	0	0	0
PHUP	Upolu Airport	0	0	0	0	0	0	0	0	0
PHDH	Dillingham Airfield	0	0	0	0	0	0	0	0	0
PHIK	Hickam Air Force Base	2	0	0	0	0	0	0	0	0
PHNP	NALF Ford Island	0	0	0	0	0	0	0	0	0
PHNG	MCAF Kaneohe Bay (Marine Corps Ba	0	0	0	0	0	0	1	0	0

The outputs of the model are transposed into the User Interface as stated earlier in Chapter IV: Data and Methodology and as shown in Table 8. III MEF planners can compare the required number of sorties with the number of aircraft available for tasking.

2. Scenario Two: Typhoon Strikes the Islands of the Philippines

In Scenario Two, we simulate a disaster response mission in the Philippines after a typhoon strikes. The demand for resources is kept at the same level as Scenario One but spread among three different APODs. Table 9 shows the breakdown of operationally available sorties by type of aircraft and APOE.

Table 9. User Input: Supply, Demand, and APODs for Scenario Two

		*PER DAY		
	# Of KC-130J	# Of C-17 Sorties	# Of C-5 Sorties	SUPPLY
Iwakuni at MCAS Iwakuni	4	0	0	75000
Kadena Air Force Base	0	2	1	100000
MCAS Futenma	3	0	0	100000
Guam at Andersen Airforce Base	0	2	1	100000
Darwin at RAAF Base Darwin	2	0	0	50000
	1=Available	**User Input Demand**	**Demand Supported**	**Iwakuni**
Clark International Airport	1	75000	75000	0
Mactan–Cebu International Airport	1	75000	75000	0
Francisco Bangoy International Airpo	1		0	0
General Santos International Airport	1		0	0
Iloilo International Airport	1		0	0
Kalibo International Airport	1		0	0
Laoag International Airport	1		0	0
Ninoy Aquino International Airport	1	100000	100000	0

The model, again, finds an optimal solution with the input parameters from Table 9. The number of sorties required and the APOE to APOD relationships transposed are output into the User Interface as shown in Table 10. All demand requirements are met using five APOE to APOD routes but only utilizing three different APOEs.

Table 10. Model Outputs: Number of Sorties from each APOE to APOD via T/M/S Aircraft for Scenario Two

		KC-130J (Sorties sent by location)					C-17			
Hawaii		**Iwakuni**	**Kadena**	**MCAS Futenma**	**Guam**	**Darwin**	**Iwakuni**	**Kadena**	**MCAS Futenma**	**Guam**
PHNG	MCAF Kaneohe Bay (Marine Corps Ba	0	0	0	0	0	0	0	0	0
PHBK	Pacific Missile Range Facility at Barkin	0	0	0	0	0	0	0	0	0
PHSF	Bradshaw Army Airfield	0	0	0	0	0	0	0	0	0
PHHF	French Frigate Shoals Airport	0	0	0	0	0	0	0	0	0
PHHI	Wheeler Army Airfield	0	0	0	0	0	0	0	0	0
Phillipines										
RPLC	Clark International Airport	0	0	2	0	0	0	1	0	0
RPVM	Mactan–Cebu International Airport	0	0	0	0	0	0	0	0	1
RPMD	Francisco Bangoy International Airport	0	0	0	0	0	0	0	0	0
RPMR	General Santos International Airport	0	0	0	0	0	0	0	0	0
RBVI	Iloilo International Airport	0	0	0	0	0	0	0	0	0
RPVK	Kalibo International Airport	0	0	0	0	0	0	0	0	0
RPLI	Laoag International Airport	0	0	0	0	0	0	0	0	0
RPLL	Ninoy Aquino International Airport	0	0	0	0	0	0	1	0	1

Again, the sorties present as continuous values and not discrete, whole numbers due to the conversion in the model. The model takes the amount of flow between each APOE and APOD then converts it to the number of sorties required to meet the capacity.

3. Scenario Three: Typhoon and Flooding Strikes South Korea

Much like the first two scenarios, Scenario Three examines a first day response to a disaster requiring 250,000 pounds of resources. Scenario Three looks at the optimal response given a typhoon hitting South Korea that creates flooding. Five major APODs require 50,000 pounds of resources each. The operationally available sorties remain constant across all scenarios. The input parameters for Scenario Three are shown in Table 11.

Table 11. User Input: Supply, Demand, and APODs for Scenario Three

		*PER DAY		
	# Of KC-130J	# Of C-17 Sorties	# Of C-5 Sorties	SUPPLY
Iwakuni at MCAS Iwakuni	4	0	0	75000
Kadena Air Force Base	0	2	1	100000
MCAS Futenma	3	0	0	100000
Guam at Andersen Airforce Base	0	2	1	100000
Darwin at RAAF Base Darwin	2	0	0	50000
	1=Available	User Input Demand	Demand Supported	Iwakuni
Incheon International Airport Corporati	1	50000	50000	0
Gimpo International Airport	1	50000	50000	0
Yangyang International Airport	1		0	0
Jeju International Airport	1	50000	50000	0
Ulsan Airport	1		0	0
Muan International Airport	1		0	0
Yeosu Airport	1		0	0
Wonju Airport	1		0	0
Daegu International Airport	1		0	0
Cheongju International Airport	1		0	0
Pohang Airport	1		0	0
Gimhae International Airport	1	50000	50000	0
Sacheon Airport	1		0	0
Gwangju Airport	1		0	0
Gunsan Airport	1		0	0
Uljin Airfield	1		0	0
Jeongseok Airfield	1		0	0
Seoul Air Base	1	50000	50000	0

Outputs for Scenario Three, shown in Table 12, require three APOEs and two modes of transport, KC-130 and C-17, in order to meet demand at all five APODs. It also requires six different routes between APOEs and APODs to minimize the response penalties. This optimal solution relies more heavily on KC-130J sorties than previous scenarios, possibly due to the close proximity of South Korea to Japan and the greater number of KC-130Js available in Japan compared to C-5s and C-17s.

Table 12. Model Outputs: Number of Sorties from each APOE to POD via T/M/S Aircraft for Scenario Three

		KC-130J (Sorties sent by location)						
Hawaii		**Iwakuni**	**Kadena**	**MCAS Futenma**	**Guam**	**Darwin**	**Iwakuni**	**Kadena**
RPLQ	Ernesto Ravina Air Base (formerly Crov	0	0	0	0	0	0	0
RPLV	Fort Magsaysay Airfield	0	0	0	0	0	0	0
RPML	Lumbia Air Base	0	0	0	0	0	0	0
RPPN	Rancudo Airfield	0	0	0	0	0	0	0
RPMB	Rajah Buayan Air Base	0	0	0	0	0	0	0
South Korea								
RKSI	Incheon International Airport Corporatio	0	0	0	0	0	0	1
RKSS	Gimpo International Airport	0	0	0	0	0	0	1
RKNY	Yangyang International Airport	0	0	0	0	0	0	0
RKPC	Jeju International Airport	0	0	2	0	0	0	0
RKPU	Ulsan Airport	0	0	0	0	0	0	0
RKJB	Muan International Airport	0	0	0	0	0	0	0
RKJY	Yeosu Airport	0	0	0	0	0	0	0
RKNW	Wonju Airport	0	0	0	0	0	0	0
RKTN	Daegu International Airport	0	0	0	0	0	0	0
RKTU	Cheongju International Airport	0	0	0	0	0	0	0
RKTH	Pohang Airport	0	0	0	0	0	0	0
RKPK	Gimhae International Airport	2	0	0	0	0	0	0
RKPS	Sacheon Airport	0	0	0	0	0	0	0
RKJJ	Gwangju Airport	0	0	0	0	0	0	0
RKJK	Gunsan Airport	0	0	0	0	0	0	0
RKTL	Uljin Airfield	0	0	0	0	0	0	0
RKPD	Jeongseok Airfield	0	0	0	0	0	0	0
RKSM	Seoul Air Base	1	0	1	0	0	0	0

We ran the first three scenarios to ensure the model optimized the responses to the three major disaster areas, each with varying distances between APOE and APOD. All three scenarios required a mix of KC-130J and C-17 sorties. Due to the limited availability of C-5s in INDOPACOM, the model did not employ these assets for Day One response. The aggregate supply was large enough to cover all demand inputs and the number of sorties available sufficiently covered all APODs requiring resources. We chose these parameters to show the model finds optimal solutions. Scenario Four is more complex and designed to test some of the limitations of the model.

4. Scenario Four: Super Typhoon Strikes the Philippines, Limiting A/C Compatibility to KC-130s

In Scenario Four, a Super Typhoon strikes the Philippines similar in scope to Super Typhoon Haiyan. Due to the severity of the hypothetical storm, we replicate destruction of multiple airfields in the model and place alternative relief nodes at several airfields with smaller runways. Our aviation asset allocation remains the same as in Scenarios 1–3; however, the limited APODs reduce modes of transport from three to one, eliminating C-17s and C-5s. Table 13 demonstrates how the User Interface looks when a User changes an APOD to unavailable and attempts to put a demand signal at the APOD. The User Interface prevents the demand signal from integration in the actual model. The "User Input Demand" column reflects the demand signal but the "Demand Supported" column captures the airfield destruction and changes demand supported to zero.

Table 13. User Inputs: Supply, Demand, and APODs for Scenario Four with Damaged Airfield

		*PER DAY		
	# Of KC-130J	# Of C-17 Sorties	# Of C-5 Sorties	SUPPLY
Iwakuni at MCAS Iwakuni	4	0	0	75000
Kadena Air Force Base	0	2	1	100000
MCAS Futenma	3	0	0	100000
Guam at Andersen Airforce Base	0	2	1	100000
Darwin at RAAF Base Darwin	2	0	0	50000
	1=Available	User Input Demand	Demand Supported	Iwakuni
Clark International Airport	0	50000	0	0
Mactan–Cebu International Airport	0	50000	0	0
Francisco Bangoy International Airpo	1		0	0
General Santos International Airport	1		0	0
Iloilo International Airport	1		0	0
Kalibo International Airport	1		0	0
Laoag International Airport	1		0	0
Ninoy Aquino International Airport	0	50000	0	0
Puerto Princesa International Airport	0	50000	0	0

Scenario Four removes the four major international airports in the Philippines as viable APODs. Table 14 depicts the 250,000 lb demand signal for relief assets spread across four smaller, KC-130-capable APODs; supply nodes remain the same, as does the available aviation assets.

Table 14. User Input: Supply, Demand, APODs for Scenario Four alternate APOEs

		*PER DAY		
	# Of KC-130J	**# Of C-17 Sorties**	**# Of C-5 Sorties**	**SUPPLY**
Iwakuni at MCAS Iwakuni	4	0	0	75000
Kadena Air Force Base	0	2	1	100000
MCAS Futenma	3	0	0	100000
Guam at Andersen Airforce Base	0	2	1	100000
Darwin at RAAF Base Darwin	2	0	0	50000
	1=Available	**User Input Demand**	**Demand Supported**	**Iwakuni**
Palanan Airport	1	50000	50000	0
San Fernando (Poro Point) Airport	1		0	0
Siquijor Airport	1		0	0
Mindoro (Vigan) Airport	1	50000	50000	0
Basilio Fernando Air Base	1		0	0
Cesar Basa Air Base	1	75000	75000	0
Danilo Atienza Air Base (formerly U.S	1		0	0
Ernesto Ravina Air Base (formerly Cl	1	75000	75000	0
Fort Magsaysay Airfield	1		0	0
Lumbia Air Base	1		0	0
Rancudo Airfield	1		0	0
Rajah Buayan Air Base	1		0	0

Once we adjust for the smaller APODs, we run the model and receive an error message annotating no feasible solution. Figure 9 reflects the error message a user receives when the model does not find a solution satisfying all requirements.

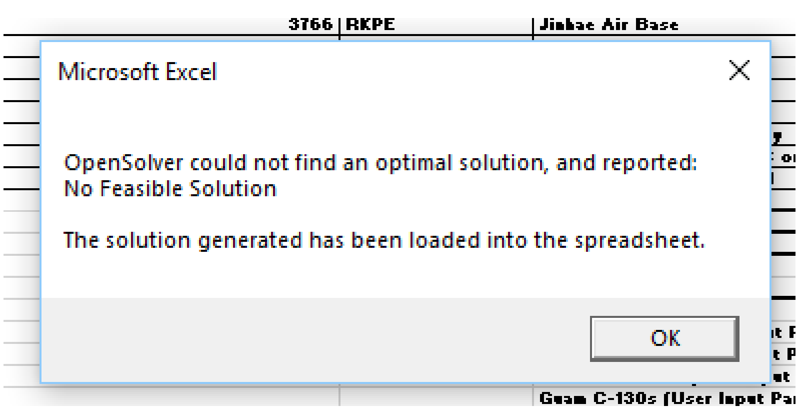

Figure 9. OpenSolver Report: No Feasible Solution

Concurrently, OpenSolver puts the closest solution it finds in the decision variables, which transpose into the User Interface. Table 15 depicts the solution generated. The solution demonstrates that demand could not be met at each APOD based on KC-130s available and the supply available at each APOE. Specifically, Iwakuni does not have enough supply available to meet demand at both APODs, Ernesto Ravina and Mindoro. Mindoro receives approximately 42,840 lbs. of the requested 50,000lbs.

Table 15. Model Outputs: Number of Sorties from each APOE to APOD via T/M/S Aircraft for Scenario Four

		KC-130J (Sorties sent by location)				
Hawaii		Iwakuni	Kadena	MCAS Futenma	Guam	Darwin
RPLN	Palanan Airport	0	0	1.4705882	0	0
RPUS	San Fernando (Poro Point) Airport	0	0	0	0	0
RPVZ	Siquijor Airport	0	0	0	0	0
RPUQ	Mindoro (Vigan) Airport	1.4705882	0	0	0	0
RPUL	Basilio Fernando Air Base	0	0	0	0	0
RPUF	Cesar Basa Air Base	0	0	0.20588235	0	2
RPLS	Danilo Atienza Air Base (formerly U.S.	0	0	0	0	0
RPLQ	Ernesto Ravina Air Base (formerly Crov	0.94117647	0	1.2647059	0	0
RPLV	Fort Magsaysay Airfield	0	0	0	0	0

We use Scenario Four to highlight how supply and available assets impact OpenSolver's ability to find an optimal solution. Moreover, we aspire to show that this scenario could happen with any given HADR event and should also be used as a planning consideration for MAGTF air planners. By recognizing a shortage of supplies or assets at an APOE, proper coordination can take place to either increase those resources by requesting additional support via USTRANSCOM, or sending aviation assets to alternative APOEs, with ample supplies, for follow-on tasking to the affected APOD.

C. SUMMARY OF FINDINGS

JTOP-A does provide optimal courses of action for III MEF planners to use in the planning of HADR operations. The model captures efficiencies in aircraft allocation and the choice of APOE to APOD combination. The model recognizes aircraft to airfield compatibility and successfully registers aircraft allocation from each APOE as a constraint. The model can support demand signals at more than one APOD and employs more than one APOE to transport the relief assets if required. While the model currently captures only five APOEs and 128 APODs, it can be increased to capture all APOE/APODs within the USINDOPACOM AOR. In the execution of our scenarios we also acknowledge the considerations listed below for those who employ this model in the future:

- The model generates sorties as integers. It identifies the optimal amount of materiel flow by, but the number of sorties needed compared to what aircraft are available at that APOE. Planners must recognize while the output is in integer form, there may be remaining capacity on the aircraft for more supplies depending on the scenarios and demand signal APOE to APOD. An example would be demand signal of 11,000 pounds for a KC-130 generates a requirement for one sortie; however, there is still 23,000 pounds of available capacity left on the aircraft.

- The model is heavily dependent on the weighted coefficient, a parameter. As stated in the limitations section of Chapter I, weather restrictions, seasonality, and authorized flight patterns directly affect the speed of the aircraft, cargo capacity, fuel consumption, refuel requirements, and distance between APOE and APOD. The variability introduced through these factors are not currently captured in the weighted coefficient. The coefficient can be manipulated by the users; however, as all parameters do, doing so drastically affects the optimal solutions. We will discuss this further in the follow-on research section.

- At this time the model does not redirect a demand signal from a damaged APOD to the next closest APOD supporting the disaster relief effort. The redirection must be inputted by the user as depicted in Scenario Four.

- If the APOD is only partially damaged and can no longer support larger aircraft but is able to receive KC-130s, then the binary variable in the model must be changed. At present, the damaged airport binary variable shuts down the entire capability of the APOD, which precludes use of a minimum operating strip if one is deemed available by host nation authorities.

With these considerations in mind, the model serves as a starting point for quantitative data analyses in III MEF. It gives planners the data driven justification for additional assets and/or a reallocation of assets within a joint OE. The model should be seen as a tool to make aide commanders in making decisions versus the solution being considered the only decision. Chapter VI provides recommendations for expanding the model, proper implementation techniques, opportunities for follow-on research and the project conclusion.

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VI. RECOMMENDATIONS AND CONCLUSION

JTOP-A provides III MEF and USINDOPACOM with an Excel-based optimization model that determines an optimal heterogenous aircraft allocation between USMC and USAF fixed-wing cargo assets to support a required demand signal at an APOD for a HADR event. While JTOP-A is presently limited to APOEs and APODs in USINDOPACOM, it can expand to support additional APOE/APOD combinations in the AOR and in other unified geographic combatant commands (COCOM).

The efficiency of the model results from the User's ability to turn an APOD on and off due to damage inflicted by a disaster and that the model recognizes aircraft to airfield compatibility. The Scenarios create optimal sortie generation by T/M/S aircraft and selection of APOE to APOD routes with the smallest weighted coefficients. Ultimately, JTOP-A aids decision makers in minimizing response penalties to a crisis and supports justification for an increase of assets if required.

As a "Day One" decision support tool, the model captures a short-term mission objective for the USMC and USAF. Moreover, it gives planners options to run through multiple scenarios with different asset allocations, supply capacities, and demand signals to best address a HADR event. JTOP-A reduces the HADR planning processes associated with manual aviation asset allocation and scheduling.

A. RECOMMENDATIONS AND OPPORTUNITIES FOR FOLLOW-ON RESEARCH

Listed below are multiple recommendations we annotated throughout the development of our model and after testing the model with multiple scenarios. These recommendations fall into three categories: JTOP-A expansion, JTOP-A modification, and recommendations beyond the scope of JTOP-A. Each of these recommendations can serve as follow-on research opportunities for NPS students and faculty.

1. Recommendations for JTOP-A Expansion

- Expand JTOP-A to capture additional APOE/APOD combinations to increase its applicability within USINDOPACOM and other COCOMs. Accomplish this by incorporating more airfields with ICAO codes and additional DoD installations across the globe.

- Expand the modes of transportation employed to capture tilt-rotor and rotary wing aircraft within the Marine Corps. Specifically, look at the MV-22B Osprey, CH-53 Sea Stallion, and UH-1Y Huey to give USINDOPACOM a wholistic approach to aviation-based HADR operations. These additional modes of transport significantly increase landing zone availability in disaster areas, thereby decreasing response time and corresponding response penalties. The use of these aircraft also reduces risk associated with larger fixed-wing assets if the infrastructure takes on catastrophic damage at a given APOD. In conjunction, incorporate ship-to-shore movements of aviation assets from the ARG or MEU to decrease distance from the APOD and decrease response time for a Day One planning scenario.

- If III MEF maintains JTOP-A for internal planning, it will only capture the Marine Corps' KC-130 assets compared to C-17s and C-5s. If Air Mobility Command under USTRANSCOM chooses to modify JTOP-A it could expand it to compare optimal heterogenous aircraft allocation across all services which would increase the model's utilization and efficacy when considering response time and cost effectiveness for a HADR operation.

- Create additional infrastructure and facility constraints at APOE and APODs. The current model captures runway length, width, and composition as the underlying infrastructure supporting a take-off or landing at a given APOD. This can be taken one step further where parking ramps, material handling equipment (MHE) availability, lighting/marking availably and air traffic control and air navigation tools are captured for each APOD to provide a more all-inclusive view of the APODs' operational availability after a disaster, and whether it can truly support an aircraft landing at its location.

2. Recommendations for JTOP-A Modification

- When a disaster strikes and damages APODs, the model requires the user to register the damaged APOD and the alternate APODs that they want to divert the demand signal too. Our first recommendation for modification would be to build into the model the proximity of APODs to one another, The user would be able to run the model without manually entering in secondary APODs; essentially the model would capture the next closest APOD to the original destination and redirect material flow automatically.

- Change the damaged APOD value to reflect whether the runway is completely destroyed, or if it maintains a minimum operating strip that can support a C-17, KC-130, or both. In the present model, a user effectively turns-off an APOD completely in the User Interface once the user determines it is damaged. By broadening this constraint to different levels of damage, the efficiency of the model increases.

- Implement time horizons within the model. At present, JTOP-A only serves as a planning tool for daily demand. Recovery efforts for disasters are lengthy. By building in time horizons the model could potentially serve for more efficient forecasting of aircraft over weeks, or even months, supporting a recovery effort from beginning to end.

- The weighted coefficient is the driver for response penalties within our model. Small manipulations of these variables can completely change an optimal solution. As stated in previous chapters, researching and implementing more planning considerations to incorporate into the weighted coefficient could increase the efficacy of the model.

- Combine the existing maritime and aviation asset optimization models into one model. Over the course of the year, two working MBA professional projects, Burgos & McLean (2018) and ours, respectively, developed maritime and aviation optimization models for USINDOPACOM. Ultimately merging these two models into one single User Interface and transportation model could provide planners with a comprehensive planning tool spanning the most popular transportation modes for the DoD.

- Create additional constraints for PAX and PAL. The model only supports throughput variables based on capacity in pounds. With additional constraints the model can capture pallet configurations and PAX maximums for each mode of transportation. These additional constraints can provide the embarkation sections with a useful planning tool that captures how to mobile load the aircraft with PALs or equipment. JTOP-A prepares the embarkation teams for customs and clearance considerations by recognizing the APOE and APOD configurations from the tool.

3. Recommendations beyond Scope of JTOP-A

- Our literature review highlights a lack of daily demand distribution requirements for a HADR event. We believe the solution to this issue is executing further research into how the DoD captures the daily demand distributions for HADR events via aviation and maritime assets. Most Joint AARs capture demand in aggregate. By looking at the KC-130 Marine Corps Sierra Hotel Aviation Readiness Program (M-SHARP) data or the USAF equivalent flight data for the C-5 and C-17 during previous HADR operations, JTOP-A could incorporate a better basis for demand signals. Moreover, JTOP-A could then look at simulation-based modeling capturing the logistics risk associated with meeting demand signals by certain aircraft from various APOE/APOD combinations.

B. CONCLUSION

Our motivation for the development of JTOP-A stems from the historical prevalence of natural and man-made disasters within USINDOPACOM and the strategic capabilities the United States maintains to aid in the relief of those disasters. We recognize non-military HOs, DoS, USAID, and the DoD maintain a vested interest in the continuous process improvement of HADR operations with a particular emphasis on logistics infrastructure and transportation assets. For Marines in III MEF this means operations and logistics sections must be equipped with the best tools to support rapid response in a HADR situation beyond their current resources. Marines need to be confident in their allocation of transportation assets as these are finite resources and major cost drivers within an HADR event. By employing model-driven analysis, planners maximize their chances of meeting material throughput on "Day One" of recovery efforts.

JTOP-A serves as the foundation for more effective HADR planning. Its primary utility is optimizing aircraft allocation in response to HADR events, which in turn aids planners with how to direct aircraft and/or relief supplies between APOEs and APODs and further determine the best mix of aircraft and APOE employment.

Our primary goal in the implementation of JTOP-A is that it operates as a data-driven justification for aircraft allocation and COA development in HADR situations. By implementing optimization models into our mission planning, the Marine Corps can reduce man-hours and logistics risk associated with manual scheduling that does not hold a basis in data analytics. Moreover, we expect the employment of JTOP-A will reduce time in the planning process which in turn reduces the initial response cycle time for the DoD.

We believe further research could expand JTOP-A's applicability as a global deployment and distribution too. Furthermore, JTOP-A serves as a basis for scenario-based modeling and simulation opportunities where risk of not meeting throughput requirements can be assessed for each T/M/S aircraft employed in a HADR operation. With modifications or expansion JTOP-A could serve a broader range of response operations for DoD and government/non-governmental agencies.

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