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**OPTIMIZING THE DISPOSITION AND RETROGRADE OF UNITED STATES  
AIR FORCE CLASS VII EQUIPMENT FROM AFGHANISTAN**

THESIS

Arthur R. Litchfield III, Captain, USAF

AFIT-ENS-14-M-18

**DEPARTMENT OF THE AIR FORCE  
AIR UNIVERSITY**

**AIR FORCE INSTITUTE OF TECHNOLOGY**

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**Wright-Patterson Air Force Base, Ohio**

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AFIT-ENS-14-M-18

**OPTIMIZING THE DISPOSITION AND RETROGRADE OF UNITED STATES  
AIR FORCE CLASS VII EQUIPMENT FROM AFGHANISTAN**

THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the  
Degree of Master of Science in Logistics Management

Arthur R. Litchfield III, BS

Captain, USAF

March 2014

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Arthur R. Litchfield III, BS

Captain, USAF

Approved:

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Dr. William A. Cunningham (Co-Chairman)

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Date

ABSTRACT

To meet the President's established OPERATION ENDURING FREEDOM drawdown date of 31 December 2014, the United States Air Force, while continuing to conduct and support combat operations, must begin to plan disposition and execute retrograde its Class VII equipment. Calling upon concepts utilized in the management of closed-loop supply chains and optimization, this research proposes a multiple objective linear program to optimize the alignment of Bagram and Kandahar Air Base positioned equipment with in-garrison demand. Closed-loop supply chains provide planning process guidelines necessary for second use value creation and efficient reverse logistical flows. Optimization concepts provide the methodology for model development and output.

The proposed multiple objective model provides solutions and equipment disposition instructions that minimize the deviations from the lowest total surface transportation cost and maximum average demand satisfaction values. To ensure compliance with Air Force guidance on equipment prioritization, cost-efficient transportation and maximum amounts of supply, multiple pre-process and model constraints limit the allocation of supply to demand bases. Combining situational specific user input values and constraints provides United States Air Force equipment managers the ability to test multiple courses of action for both real-time and future equipment movements.

*To the love of my life – I couldn't have done this without you. Every husband should be so fortunate to have a wife as gracious and loving as you. I'm blessed among men*

*Mom and Dad – thank you for teaching me the value of hard work. Dad, I'm your biggest fan. Mom, you showed me what it means to step out in faith and chart a new path*

## **Acknowledgments**

*Do not be anxious about tomorrow, for tomorrow will be anxious for itself. Sufficient for the day is its own trouble*  
*Matthew 6:34*

First and foremost I must thank my Lord and Savior Jesus Christ – I am consistently humbled by his blessings and thankful for his perfect provision in my life.

I must extended grateful appreciation to my two advisors Dr. William Cunningham and Lieutenant Colonel Joseph Skipper. Dr. Cunningham worked with me through this thesis and a previous unsuccessful topic. As an Oklahoma State University alumnus, I would have asked Dr. Cunningham to help guide my research efforts irrespective of his or my academic area of emphasis. Dr. Cunningham being knowledgeable and enthusiastic about the topic made my research that much easier. Lieutenant Colonel Skipper immediately provided a relevant and actionable research topic when my first thesis attempt was unsuccessful. His subject matter knowledge and eagerness to work with me both as a student and logistics readiness officer peer made this thesis more than just an academic marker that must be checked before graduation.

Thank you to Major Craig Lane – he expended great effort to facilitate my attendance at the Air Force Institute of Technology; I wouldn't be completing this program without his help.

Through this research process, each of the following individuals helped me in some unique way. Colonel Linda Hurry, Colonel Hilary Feaster, Chad Wynkoop, Clayton Kelleher, Captain Marcus McNabb, Captain Christ Arendt, Captain Chris Jones, Lieutenant Aaron Nelson and Lori Jones – I am in your debt and cannot thank you enough.

Arthur R. Litchfield III



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# OPTIMIZING THE DISPOSITION AND RETROGRADE OF UNITED STATES AIR FORCE CLASS VII EQUIPMENT FROM AFGHANISTAN

## I. INTRODUCTION

### **General Issue**

Since the United States government launched its military response to the September 11, 2001 terrorist attacks, the United States Air Force (USAF) has been procuring, staging and deploying equipment in support of OPERATION ENDURING FREEDOM (OEF). Rapidly changing mission requirements, surges in personnel, equipment modernization, safety requirements, etc. individually and aggregated have necessitated USAF logisticians fill demand for supplies and equipment in a manner similar to permanently established in-garrison bases. Established at major Afghan military airfields, Bagram and Kandahar Air Bases serve as the USAF's primary operating locations, OEF's major theater air hubs and focal point locations for this research.

In late June 2011, President Barack Obama in his *Way Forward in Afghanistan* speech announced his intention to end military operations in Afghanistan and have all US forces out of the country by 31 December 2014. Since that day, USAF logistics planners have wrestled with the requirement to sustain the mission while initiating steps to drawdown equipment. The USAF has consistently shown the ability to move personnel and resources forward in support of contingency operations and disaster relief. As it is the path that delivers products to the customer, forward logistical flows garner much

attention and deliberation. This is especially true of the products delivered by the USAF; the days leading up to combat operations or the hours immediately following a natural disaster garner significant attention and necessitate the immediate movement of materials through those forward logistical flows.

In contrast to forward logistical flows, and of much more significance as the drawdown progresses, reverse logistics (RL) is the process of planning and controlling the cost-effective and efficient movement of materials from the point of consumption to the point of origin (Rogers and Tibben-Lembke 2001). Well-developed reverse product flows offer significant benefit to process owners and customers while poorly defined and operated systems add significant cost and produce slow responsiveness (Kocabasoglu et al. 2007). With the drawdown deadline now less than 12 months away, the USAF has little time to formalize and implement necessary reverse logistical flows.

A launching point for planning and course of action analysis as well as a basis for comparison is the drawdown and egress from Iraq. There are many similarities between current drawdown operations in Afghanistan and those of Iraq - bases must be consolidated and closed, force strength reduced, equipment moved and missions transitioned to host-country military units all while engaging a hostile enemy. Though the similarities are many, the differences are significant and stand to complicate disposition and retrograde operations.

Three critical factors stand to complicate any comparisons between the drawdown operations in Iraq and Afghanistan. First, unlike Iraq, Afghanistan does not have direct nor easy access to a seaport. Second, the U.S. does not have secure storage and staging areas like it did at its bases in Iraq's neighboring country Kuwait. The American

military was able to temporarily store equipment in Kuwait and wait for formal disposition instructions. Finally, USAF planners will not benefit from a concurrent major military operation that provides a logical next destination for equipment thereby eliminating the need to identify and align supply with in-garrison demand. To meet drawdown milestones, USAF equipment custodians must systematically determine what equipment must be retained in place for the continuing mission, returned to fill in-garrison demand, given to the Government of Afghanistan or transferred to the Defense Reutilization and Marketing Service for disposal. The focus of this thesis will be the disposition and retrograde process of Class VII equipment. Joint Publication 4-09 *Distribution Operations* (2010) defines this equipment as major end items: racks; pylons, tracked vehicles, generators, engines stands, etc. However, vehicles will not be considered in this research.

To meet the operational demands imposed by the drawdown timeline, USAF leadership established the Retrograde Management Planning Team (RMPT). Sharing one goal with multiple tasks, the RMPT is comprised of approximately 20 individuals from in-garrison and deployed locations as well as varying levels of USAF command. The main effort of the team is to develop, coordinate, validate and communicate disposition instructions for equipment items within the U.S. Air Forces Central (AFCENT) area of responsibility (AOR). One of the primary lessons learned from the drawdown in Iraq was the importance of readily available previously coordinated equipment disposition instructions. This an effort to prevent or reduce queuing in staging and transportation yards while equipment handlers and transporters await formal disposition instructions (Government Accountability Office; 2012).



The challenges posed by the drawdown - issues that require formalized decision logic, calculation and analysis to optimize - are not unique to the USAF, sister services nor other contingency supporting organizations. Much can be learned from managers of civilian logistics systems who, responding to increasing environmental regulations or business incentives have created completely closed-loop supply chains (CLSC). The CLSC provides a similar level of coordination to the firm's reverse logistical flows as the forward flows – conceptually joining the two together in a continuous loop. The CLSC is designed to recover value or products from users irrespective of the duration between first and last use (Guide and Wassenhove; 2009). Closing the loop on the USAF supply chain (SC) begins the transition from individual logistics systems optimization to a more enterprise approach. A characteristic of the enterprise approach is that it emphasizes logistical considerations in the formulation of broader corporate decisions and strategic planning. Enterprise systems further demonstrate the importance logistical processes play in the development of competitive advantages (Poist 1986). A significant strategic advantage of the USAF and American military is the ability to disposition and retrograde equipment while sustaining the mission and upon mission completion returning home with all required equipment for rest, recuperation, and reconstitution.

### **Problem Statement**

As of 01 September 2013, the USAF is tracking 12,571 individual Class VII assets valued at \$213.5 million for final disposition in preparation for the termination of Afghanistan military operations scheduled for 31 December 2014. When compared with the Iraq drawdown, multiple factors stand to complicate the impending retrograde

operations. The geography of Afghanistan, limited multi-modal infrastructure as well as the political and security situation of the region will significantly limit exit routes making egress far more difficult than previous retrograde actions. Further, retrograde transportation is costly, limited and will grow increasingly more variable as the drawdown deadline nears. The USAF can ill afford to consume limited resources planning, staging and retrograding equipment with limited or no in-garrison demand. Not considering these variables increases the risk of staging area saturation, moving unneeded equipment, delaying priority movement, backlogs in transportation incorrect destination assignments and missing the last opportunity to fill existing demand.

### **Research Question**

Can the United States Air Force Class VII equipment disposition and retrograde process be improved with a multiple objective decision analysis tool that produces equipment disposition instructions by considering factors affecting the alignment of supply with demand and the cost of necessary transportation?

### **Investigative Question**

1. Upon what objective functions should the United States Air Force base a multi-objective decision analysis tool.
2. How do user defined inputs and constraints effect optimal supply and demand alignment solutions?
3. Would a multi-objective decision analysis tool enable the United States Air Force to utilize closed-loop supply chain concepts in its Class VII equipment disposition and retrograde process?

## **Methodology**

The methodology selected for this research is deriving a multiple objective linear program (MOLP) that will utilize supply and demand as the decision variables. Additional factors included in calculating the objective function are equipment cost, demand priority, transportation cost and demand service levels. The MOLP methodology is well suited for this research as multiple constraints bound an optimal disposition/retrograde solution. Further, a MOLP allows the use of integer constraints to ensure optimal solutions yield whole number (item) solutions thereby eliminating a solution allocating percentages of one piece of equipment to multiple bases. Based upon the evolving constraints of this dynamic situation, MOLP programming methodology provides an excellent array of tools to determine optimal disposition for equipment.

## **Motivation**

The USAF needs a flexible equipment disposition decision tool that will close the loop between initial deployment and retrograde; one that will account for the factors affecting mission sustainment and drawdown operations while optimizing retrograde operations. Supply, demand, mission sustainment, base closure dates, transportation cost and equipment value must be considered before any equipment is moved. If undertaken correctly with dynamic management from applicable organizations, the retrograde of Class VII equipment will fit seamlessly into the comprehensive retrograde effort while supporting the continuing mission and national objectives.

## II. LITERATURE REVIEW

### **Chapter Overview**

The objective of this chapter is to provide an overview of the relevant literature necessary to complete this research. The chapter is broken down in to major subject areas; each written to narrow and refine the scope of the literature as it introduces the body of work most necessary to guide the formulation and usage of a USAF Class VII equipment disposition tool. Providing the general framework for all other subjects are the topics of SC and supply chain management (SCM). Nested within SC and SCM is RL – the functional process of moving items from point of use to origin. Building upon both SCM and RL, a review of CLSC literature is necessary to provide an understanding of the environment in which AF logisticians will operate the disposition tool. Finally, an overview of mathematical models in logistical research and how new and unique problems drive the need for consistently different models. A review of these subjects is critical to both understand the magnitude and complexity of the retrograde operation as well as the tool needed to improve USAF efforts.

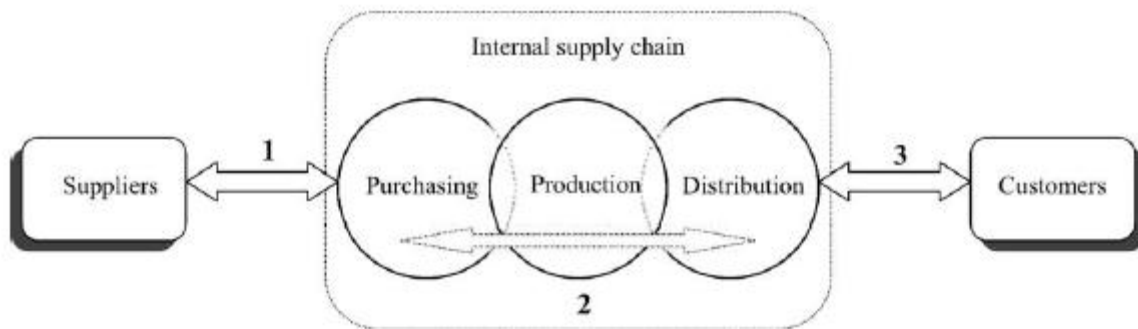
### **Supply Chains and Supply Chain Management**

Delivering products to customers requires extensive management of information and resources as well as control of numerous process flows across multiple internal divisions and corporate service providers. Many managers realized their disjointed and heavily siloed organizational structures were not sufficient to neither promote nor capture opportunities for efficiencies and increases in value to the customer (Lambert et al. 1998). Forrester (1958) theorized management was then on the verge of a breakthrough

in business understanding – company success depended on the interactions between the flows of information, materials, money, manpower and capital equipment. He stated further:

there will come general recognition of the advantage enjoyed by the pioneering management who have been the first to improve their understanding of the interrelationships between separate company functions and between the company and its markets, its industry, and the national economy (Forrester 1958:52)

The necessitation of differing logistical flows provided corporations a logical launching point to begin studying their own flows of information, materials, money, labor, and capital equipment. Hammer (2001) suggested the streamlining of processes that crossed corporate boundaries was an immediate area of opportunity to cut costs, enhance quality, and speed operations. “Victors of the productivity wars” (Hammer 2001:84) would be those companies that were able to adopt a new approach to business working closely with partners to improve both internal and mutual processes. Research was prevalent showing that more closely aligning one’s firm with suppliers and customers lead to enhanced operations (Hammer and Champy 1993; Womack and Jones 2003). However, many firms continued operating with an exclusively internal focus as illustrated by Figure 1. The day-to-day emphasis was on internal productivity, optimization, cost minimization, etc.



**Figure 1: Internal SC Operations (Chen and Paulraj 2003:120)**

A significant change in business management of the late 20<sup>th</sup> century was the realization individual businesses no longer competed as autonomous entities. Unless completely vertically integrated, firms operated within and competed as SCs. As detailed by Peck (2006:128) an SC is a “network of organizations, mutually and co-operatively working together to control, manage and improve the flow of material and information from suppliers to end users.” Increasing utilization of global sources of supply and a redefining of customer requirements (on-time delivery of defect-free product is expected) made SCs a logical transition from single firm process management. Like many decisions and functions of business, varied are the objectives of SCs: profit maximization (Manuj and Mentzer 2008; Hise 1995; Nelson and Gadi 1979), increase value to the customer (Christopher and Towill 2001); and competitive advantage (Mentzer et al. 2001, Monczka et al. 1998).

Supply chains, in practical application are not one to one interactions as the name suggests; rather most frequently they operate as complex networks of arcs and nodes. The ultimate success of a single firm will depend on whether its leaders can integrate its many business relationships into the SC (Lambert et al. 1998). Intuitively, all non-vertically integrated firms are participants in a SC – whether acknowledged or not.

Operating a single firm within the framework of an SC requires collaboration and synergy among partners. SCM is the philosophy and rubric designed to provide the broad framework for unifying individual firms into a single connected unit.

Defined, SCM is:

the systematic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole (Mentzer et al. 2001:18).

To its definition of SCM, the Council of Supply Chain Management Professionals (2013) adds coordination and collaboration among members and that it integrates supply and demand management within and across companies. SCM as a term is relatively new appearing first in literature in 1982 (Oliver and Weber 1982) and has since been described as a management philosophy (Ellram and Cooper 1990; Houlihan 1998), an implementation of a management philosophy (Bowersox and Closs 1996) and a set of management processes (Cooper et al. 1997; Davenport 1993). Whether viewed as a mindset or roadmap, the conceptual idea remains the same – firms acting in accord to achieve goals for singular and group benefit.

The Global Supply Chain Forum identified eight business processes that comprise the core of SCM: customer relationship management; customer service management; demand management; order fulfillment; manufacturing flow management; procurement, product development and commercialization; and returns (Cooper et al. 1997). For these functions to serve the SC they must stretch across traditional functional silos. Figure 2 provides a graphical representation of SCM implementation. When compared with management of traditional logistics flows, SCM is strategic, broader in scope and more

complex – intuitive as logistics is a functional silo through which information and products flow. For successfully SC management, firms must significantly increase the amount of planning and coordination before operations are initiated. Because the eight processes run the length of the SC and across traditional functional silos, care must be given to ensure the processes are managed at both the SC (strategic) as well as the firm (tactical) levels.

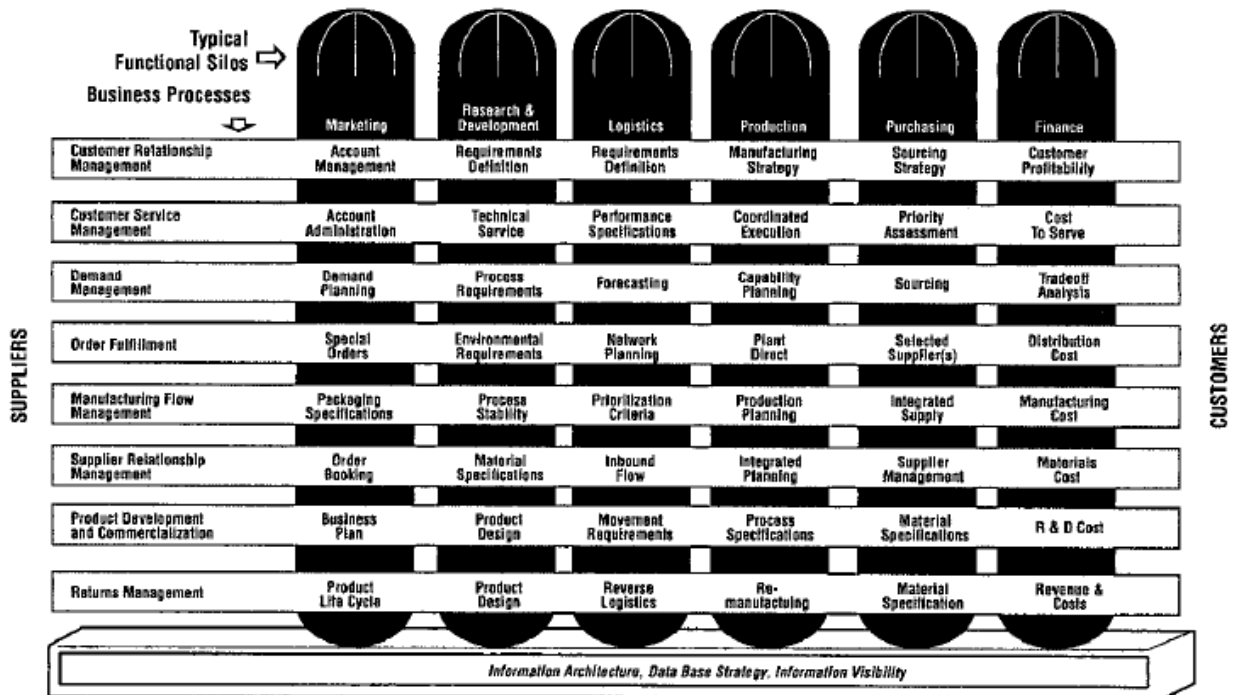


Figure 2: SC Management Implementation (Croxtan et al. 2001:31)

## Reverse Logistics

The subject of RL in the Air Force and business in general is limited; the topic in terms of academic research and literature dates to the late 20<sup>th</sup> century. However, the movement of materials and products from point of consumption to point of origin is not new. Almost universally, retail firms have dealt with product returns and more recently



the environmental movement and resulting social concerns necessitated many corporations initiate formalized recycling and waste reduction programs.

With these sometimes-new return requirements, managers quickly learned the success of their endeavors often hinged upon the firm and SCs' RL apparatus (Peterson 2005).

Guiltinan and Nwokoye (1975) offered one of the first examinations of the growing corporate emphasis on RL. Their work outlined a comparison of forward and RL as well as a framework for the unique requirements required of reverse distribution. Lambert and Stock (1981:19) authored the first formal definition of RL "going the wrong way down a one-way street because a great majority of product shipments flow in one direction."

Murphy and Poist (1989:177) added a similar definition – "movement of goods from a consumer towards a producer in a channel distribution." By 1992, a more encompassing definition was being used:

The term used to refer to the flow of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all relating to logistics activities carried out in source reduction recycling, substitution, reuse of materials and disposal. (Stock 1992:2)

In 1998, RL definitions and focus were beginning to have an environmental focus; one article stated RL is a process whereby companies can become more environmentally efficient through recycling, reusing, and reducing the amount of materials used (Carter and Ellram 1998). This definition is a continuation of previous definitions as well as a scoping of the concept; RL encompassed more than the firm, its products and customers.

By early 1999, the conceptual idea of RL was changing from one based solely in environmental concern to a more holistic idea that included environmental concern, returns management, functional logistics and business incentive.

Rogers and Tibben-Lembke (2001:129) provided a definition more fitting of the broader holistic concept:

the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal.

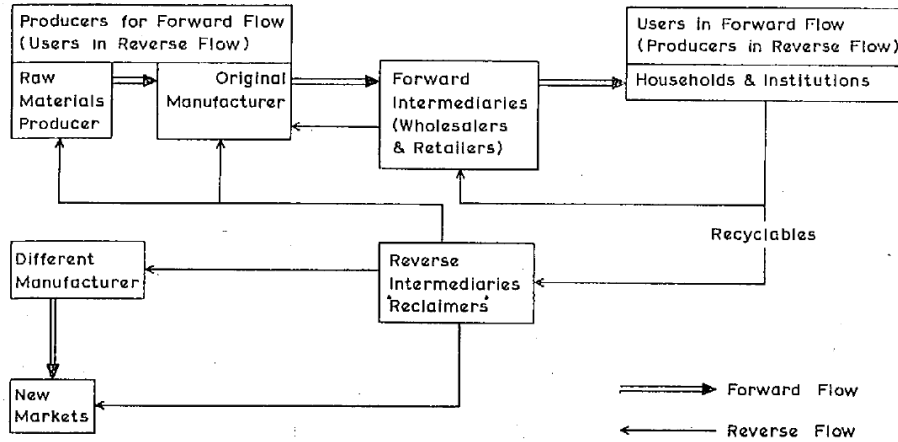
As definitions in previous research did by adding emphasis to environmental concern, this definition added “recapturing” or “creating value” as a parameter of consideration when firms establish RL programs.

Utilizing definitions alone it is easy to see RL is closely tied to environmental considerations. Much of the foundational work associated with the topic as well as the later literature regarding model optimization and application cite environmental regulation and concern as the primary driver (Dowlatshahi 2000; Veerakamolmal and Gupta 2001; Guide and Van Wassenhove 2002; Krumwiede and Sheu 2002; Daugherty et al. 2002; Kocabasoglu et al. 2007). Going forward, RL will be viewed using the 2001 Rogers Tibben-Lembke definition of asset recovery; however, the conceptual basis for the literature cited is often environmentally focused.

In 1988 the Council of Supply Chain Management Professionals began publishing an annual *State of the Logistics Union* report outlining dollar amounts spent on logistics operations. While the *State of the Logistics Union* does not specifically capture totals spent on RL, Rogers and Tibben-Lembke (2001:134) estimate 4% of the total outlay is dedicated to RL. The 2013 *State of the Logistics Union* reported \$1.331 trillion or 8.5% of the United States gross domestic product was spent on logistics during calendar year 2012 (Gilmore 2013). While the total number is significant, firms require personalized

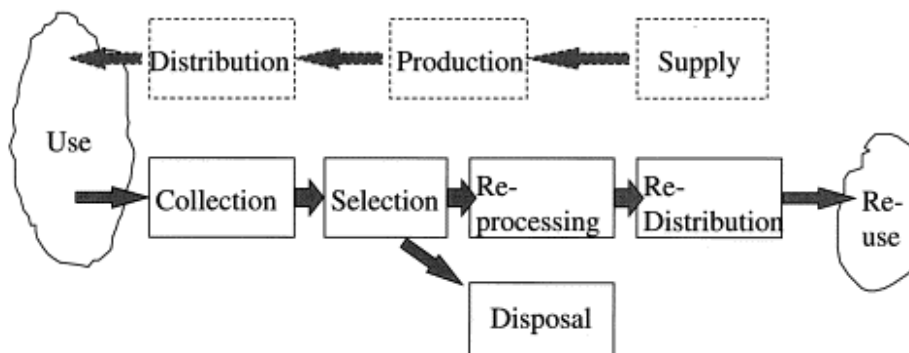
incentive to initiate RL practices. In businesses where returned merchandise significantly reduces the overall percentage of sold merchandise – catalog companies, book publishers, and consumer electronics – controlling RL costs can significantly impact overall firm profits. Book publishers expect 20 to 30% returns, catalog retailers 35% and greeting card companies 20 to 30% (Zieger 2003). The Automotive Parts Remanufacturing Association (2013) estimates the end items and raw materials they move through RL channels would annually fill 155,000 railroad cars creating a train 1,110 miles long. Upon initiation of their telephone switching equipment RL program, AT&T saved nearly \$100 million in 19 months (Carter and Ellram 1998).

When faced with new RL requirements, the question is not when to begin, but rather where; consistently emphasized as the starting point for any RL effort is to map the new flow (Gooley 1998; Zieger 2003). The literature is varied on what constitutes RL– the framework and map consistently depend upon the literature area of emphasis. The Guiltinan and Nwokoye (1975) process map shown in Figure 3 describes the RL of recyclables. Their fundamental RL process steps included: collection and storing; storage and transportation; contact and communication with buyers.



**Figure 3: Forward and Reverse Distribution Channels (Gultinan and Nwokoye 1975:29)**

Approaching RL structures from a business perspective with focus on product recovery Fleischmann et al. (2000), as shown in Figure 4, outlined different yet similar fundamental process steps: collection; inspection and separation; reprocessing; disposal; and redistribution. An interesting distinction of their analysis is their consideration transportation and storage as links between major function steps vice distinct activities and are therefore not included in their below recovery chain.



**Figure 4: The Recovery Chain (Fleischmann et al. 2000:657)**

An analysis of third-party RL providers and requirements for their entry into the field utilized three distinct phases: retrieval; transportation; and disposition (Krumwiede and Sheu 2002). Nested within each phase are the steps necessary for the service provider to connect their portion of the product flow with the next. This process flow is logical; many firms are neither able nor structured to handle the complex networking required of an encompassing RL program and therefore rely upon third-party providers.

While specific steps vary by case, many RL structures are consistent. Beyond formulation of the steps, Tibben-Lembke and Rogers (2002) show in Table 1 the conceptual differences between forward and RL. The table shows the assumptions and decisions driving forward logistics (FL) are different from RL.

**Table 1: Differences in Forward and Reverse Logistics (Tibben-Lembke and Rogers 2002:276)**

Forward	Reverse
Forecasting relatively straightforward	Forecasting more difficult
One to many transportation	Many to one transportation
Product quality uniform	Product quality not uniform
Product packaging uniform	Product packaging often damaged
Destination/routing clear	Destination/routing unclear
Standardized channel	Exception driven
Disposition options clear	Disposition not clear
Pricing relatively uniform	Pricing dependent on many factors
Importance of speed recognized	Speed often not considered a priority
Forward distribution costs closely monitored by accounting systems	Reverse costs less directly visible
Inventory management consistent	Inventory management not consistent
Product lifecycle manageable	Product lifecycle issues more complex
Negotiation between parties straightforward	Negotiation complicated by additional considerations
Marketing methods well-known	Marketing complicated by several factors
Real-time information readily available to track product	Visibility of process less transparent

Provided a firm's RL structure is not its exact forward flow in reverse, RL requirements can place new and sometimes significant strain on organizational resources. The differing nature of many functions often necessitates both resource (information technology systems) and personnel (quality inspection) specialization. The unique requirements of the flows often necessitated by RL can lead to significant increase resource utilization.

Table 2 offers a brief comparison of the costs of RL with traditional forward flow logistics:

**Table 2: Reverse Logistics Costs (Tibben-Lembke and Rogers 2002:278)**

<b>Cost</b>	<b>Comparison with forward logistics</b>
Transportation	Greater
Inventory holding cost	Lower
Shrinkage (theft)	Much lower
Obsolescence	May be higher
Collection	Much higher – less standardized
Sorting, quality diagnosis	Much greater
Handling	Much higher
Refurbishment/repackaging	Significant for RL, non-existent for forward
Change from book value	Significant for RL, non-existent for forward

The Tibben-Lembke and Rogers table above is not all inclusive of RL costs and the new outlays will vary given the firm’s resources, experience, requirements, location, service providers, etc. Variability in incentives, requirements, firm size, capability, locations, timelines, etc. logically eliminates the possibility of an off the shelf universal fit RL program. Gooley (2008:49-54) provides five steps to successful RL. The logic behind the steps is simple and robust; Gooley states firms should:

1. Analyze your reasons for starting a RL program.
2. Decide how and what to communicate with customers.
3. Plan the mechanics of your RL operation.
4. Develop information systems to gather necessary data.
5. Know the tax, finance and credit implications.

Whether formed to comply with regulations or capture economic value, firms must devote the necessary time, attention and resources to engender success from their internal

and SC RL processes. However, RL should not be a standalone structure; a process of its magnitude and importance should be part of the overall logistics strategy. Coupling forward and RL represents a fundamental transition from piecemeal logistics to CLSCs.

### **Closed Loop Supply Chains**

As described earlier, the addition of reverse product and materials movement to forward flows significantly changed the scope and managerial requirements of a firm's logistical apparatus. As business incentives and regulations drove necessity to formalize these new reverse logistical flows within the business plan, managers and academics determined a new conceptual model and decision logic was required – SCs and SCM. The eight business process that comprise the core of SCM (Cooper et al. 1997) includes returns providing a basis and nesting point for RL and an extension of the single direction SCs to CLSCs. In forward focused SCs product delivery to the customer is most often the end of the process. Unless the product is defective, there is no expectation of the product reentering the SC. Alternatively, CLSCs include forward flows for product delivery and reverse flows for the expectation of the product returning to the SC.

The primary focus and intent of CLSCs is receiving products from the customer or point of sale for the purpose of recovering value by reusing the entire product, and/or some of its modules, components, and parts (Guide and Van Wassenhove 2009).



Capturing the SCM holistic philosophy, CLSCs include:

- product retrieval from the point of sale or end-user
- RL to move the products through the SC
- product analysis to determine the product's condition and most economically beneficial second use option
- Refurbishing to enable desired second use option
- Remarketing to exploit economic benefit of product (Guide et al. 2003)

Because CLSCs focus squarely on product returns and secondary value creation, CLSC management will be significantly different from the more simple individual logistic flows and forward SCM. Guide and Van Wassenhove (2006:5) define CLSC management as “the design, control and operation of a system to maximize value creation over the entire life-cycle of a product with dynamic recovery of value from different types and volumes of returns over time.” This management definition is significantly different from that of SCM (product vice firm and SC focus) and far more encompassing than RL (emphasized reverse movement and by extension traditional logistics functions). The recovery network necessary to retrieve products from end users forms a link between two distinct markets – the disposer and reuse markets. In the disposer market, end users avail their products for reentry to the SC; and the reuse market provides demand for the recovered products. Formation of a CLSC occurs when the markets coincide and the product returns to its original SC. The typical steps enabling transfer between markets and the capturing of secondary value include collection, inspection and separation, reprocessing, redistribution, and disposal (Fleischmann et al. 2001).

In the United States companies became increasingly interested in CLSC for economic reasons and European countries for legislative reasons (Guide et al. 2003; Schultmann et al. 2005; Forta Neto et al. 2010). Irrespective of motivation, CLSCs and their associated product recovery and reuse networks do serve as the foundation for the development of industrial systems that are both economically and environmentally sustainable (Guide and Van Wassenhove 2009; Bell et al. 2013). Research of the Xerox Corporation's introduction of a second use copier line (Thierry et al. 1995) provided a foundational look at how CLSCs can blend environmental requirements with economic incentives.

The successful new second-use product line affected business functions corporate wide leading to eight managerial implications of recovery networks:

1. There were significant problems in obtaining the required managerial decision making because information was scattered among many groups, if available.
2. The selection of the most profitable option depended on technological feasibility, sufficient sources of used products, markets for recovered goods, and legislation.
3. The use of specific material reuse targets is beneficial to focus managerial attention.
4. Product redesign is most often necessary.
5. More cooperation is required among different supply chain actors.
6. There are opportunities to cooperate with competitors in developing reverse supply chains.
7. Companies wanting to develop capabilities in product recovery must be able to manage the supply of used products (product acquisition) and develop markets for recovered products (remarketing).
8. Product recovery activities will have a profound influence on production, operations and logistics management (Atasu et al. 2008:484).

The work of Thierry et al. (1995) and Guide et al. (2003) clearly show in addition to product returns, some level of refurbishing, remanufacturing, or component retrieval is necessary to achieve the system's intended goal of dynamic value recovery.

Within CLSCs, remanufacturing is a central tenant therefore managers give significant care to understand the type of product return, not product type, reentering the SC.

Guide and Wassenhove (2009) and Krikke et al. (2004) distinguish four primary types of product returns:

1. Commercial Returns: products returned within 30, 60 or 90 days after purchase. These returns are largely a function of liberal return policies.
2. End-of-use Returns: these returns occur when a functional product is replaced with a new or technologically updated product.
3. End-of-life Returns: these products are technologically obsolete, are no longer supported by a manufacturer, or no longer provide utility to the owner.
4. Repair and Warranty Returns: products the end-user expects to be returned in the originally purchased condition.

Because end-of-life returns on average will be significantly different from commercial returns, CLSCs must consider both the type of return as well the products' most economically beneficial end point. Guide and Van Wassenhove (2009) propose CLSCs be viewed from two different perspectives – type of returns or activities yielding natural return-recovery pairs: consumer returns and repair; end-of-use returns and remanufacturing or refurbishing; and end-of-life returns and (component) recycle.

Through the basic CLSC steps of collection, inspection and separation, some returns will need vectoring toward different value recovery activities.

A comparison of the different recovery options is provided in Table 3:

**Table 3: Comparison of Product Recovery Options (Thierry et al. 1995:120)**

	Level of Disassembly	Quality Requirements	Resulting Product
Repair	To product level	Restore product to working order	Some parts fixed or replaced by spares
Refurbishing	To module level	Inspect all critical modules and upgrade to specified quality level	Some modules repaired/ replaced; potential upgrade
Remanufacturing	To part level	Inspect all modules and parts and upgrade to as new quality	Used and new modules/parts combined into new product; potential upgrade
Cannibalization	Selective retrieval of parts	Depends on process in which parts are reused	Some parts reused; remaining product recycled/disposed
Recycling	To material level	High for production of original parts; less for other parts	Materials reused to produce new parts

While pairings of return type and recovery options are in most cases intuitive, each additional requirement within the SC adds additional complexity. Because current business trends promote expanding product varieties with shorter life cycles, global sourcing, and rapid technological improvement, management of a CLSC is highly complex. When viewing return recovery pairs and the intermediate steps to move the products between markets, the requirement for multiple unique paths through the SC and increased complexity quickly becomes apparent. Adding to this complexity, the availability of used products for recovery is vastly different from input resources in a traditional SC (Fleischmann et al. 2001).

Regardless of the motivation, scope or complexity, CLSC are most often uncontrollable at the supply side resulting in uncertainty across three dimensions: quality and composition; quantity; and timing (Krapp et al. 2013). Timing uncertainty in returns is natural – the rate at which consumers use products will vary by both product and user. Even in situations such as automobile component core charges where the price for a new product is significantly higher without the used product, users are often not compelled to return their products immediately following replacement or obsolescence. Krapp et al. (2013) note that even if it was possible to guarantee the return of every product sold, the firm could still not definitively project timing.

Combining timing uncertainty with questions on the quantity and quality of returns exacerbates already difficult operational environments. Irrespective of the inherent uncertainties, actual and projected returns are input data for subsequent CLSC planning activities – both at the tactical and strategic levels. Because returns can and will drive capacity planning, inventory levels, and production schedules, firms have need of precise information on backflows. Krapp et al. (2013) stated forecasting and the development of tools and techniques to manage the quantity and timing of return flows is a critical CLSC research area. Until the mechanisms are in place to precisely track returns, supply uncertainty will be inherent and therefore a major characteristic of recovery networks (Fleischmann et al. 2001). While waiting for improved quantitative tools and forecasting tools, Guide et al. (2006) advocate preponment – early determination on the condition of the returned product; this an effort to vector products to the most economically beneficial second use option.

According to Guide et al. (2003) and Atasu et al. (2008) companies often passively accept returns or worse view them as a nuisance, not actively managing the process like they do their forward SCs thereby missing opportunities for value creation. Like the concepts of RL and SCM, CLSCs operate within their own dynamic environments with unique objectives, strategies, and performance measurement systems (Ozkar and Basligil 2012). The strategic level incorporation of the reverse flow of products distinguishes the CLSC from the simple application of RL to the traditional forward SC (Bell et al. 2013). Increased global competition, product proliferation, reduced product life cycles, increased environmental governance, and the increasing leniency of return policies will necessitate the formalization of value capturing return structures.

Studying CLSCs as they relate to natural resource scarcity, Bell et al. (2013) state in the face of scarce resources (generalized usage of the term resources), proactively capturing and managing products in a CLSC offers significant opportunity for firms to gain long-term competitive advantage. Efficiencies and competitive advantage lead firms to the realization there is a definite need for a life-cycle approach to products. The optimal life-cycle approach integrates all four types of product returns into the business model (Guide et al. 2003). This life-cycle management approach is beyond the scope and capabilities of forward SCs.

In today's business environment, interesting problems are appearing at the strategic business level to which Guide et al (2003:3) state:

The world is changing very rapidly, and companies, in cooperation with academics, must quickly develop supply chains that can handle coordinated forward and reverse materials. First and perhaps foremost, they must develop methods of showing managers the benefits to be obtained by developing reverse supply chains. If manager cannot quantify the potential financial (and nonfinancial) benefits, they are unlikely to consider return flows as anything other than a nuisance, for which they must minimize losses. Second they must adopt new business models that show top managers how to release the enormous value that is currently unrecognized and unappreciated. Finally they must adopt new operational models to help them manage the day-to-day tactical elements so they can realize their business objectives.

### **Logistical Operations and Mathematical Models**

Led by the desire to have standard units of measurement and quantitative answers for the broad spectrum of logistics problems, managers consistently turn to the fields of operations research (OR) and industrial engineering (IE) for mathematical solutions. Atasu et al. (2008) stated CLSC research often naturally falls into one of four major foundational streams: industrial engineering/operations research; design; strategic; and behavioral. Flowing from traditional IE/OR positions, the first stream deals with such topics as forecasting return rates, inventory control and RL network design. Stream 2, design, builds upon stream one and seeks to uncover profitability drivers. Stream 3 further builds and considers strategic level competition within a CLSC context. While different in nature and scope, the three streams of literature offer problems perfectly suited for mathematical model answers.

Two decades ago when business opportunities and environmental requirements were necessitating the formalization of RL structures beyond simple product returns, one



of the first subjects to be jointly researched by logisticians and IE/OR was modeling and designing the new reverse flows (Fleischmann et al. 1997; Jayaraman et al. 2003). As it relates to matters of strategic importance, SC network design is one of the most important decisions in SCM (Pishvae et al. 2010). Quantity of locations and placement, facility capacity and the flows amongst form the conceptual basis for network design decisions (Amiri 2004). Yucesan (2007) argued the primary goal of a firm should be sustainable creation of shareholder described value and that this goal implicitly provides a mechanism to strike the correct balance between the conflicting objectives of the various stakeholders. Formed across multiple firms, SCs often yield differing objectives at the functional task and firm partnership levels. Given their nature, managers should expect strategic decisions to be in place for a considerable duration. Considering their large investments and compromises on a firm's individual objectives, stability with respect to SC network design is a highly desired (Melo et al. 2009). Mathematical models provide non-subjective answers to problems born from the uniqueness, needs and performance of the SC.

Literature covering reverse SC network designs show the mixed-integer programming (MIP) model is the most commonly used mathematical model (Pishavee et al. 2010). Formulated in an attempt to provide situation specific answers and information, MIP models as tools for decision analysis range in complexity from simple location only models to multi-time period multi-commodity remanufacturing models.

Fleischman et al. (1997) provided one of the first encompassing looks at mathematical models in RL. Dimensions of RL, reverse distribution, inventory control in systems with return flows, deterministic inventory models, stochastic inventory models,

and production planning with reuse of parts and materials were some of the topics presented. Their paper aggregated the broad spectrum of research and presented a comprehensive review on the then current application of mathematical models in RL management. Melo et al. (2009) completed an exhaustive review of SCM facility location literature and mathematical models. In addition to facility location, the authors found six additional topics prominent in logistics mathematical models: capacity, inventory, procurement, production, routing and transportation modes. Pishvae et al. (2010) provided a broad-spectrum look at reverse SC network and CLSC network designs; referenced articles were categorized using the matrix in Table 4:

**Table 4: Article Classification Matrix (Pishvae et al. 2010)**

Supply	Network Structure	Modeling
Push	Opened-Loop	Mixed Integer Linear Program
Pull	Closed-Loop	Mixed Integer Non-Linear Program
		Stochastic Mixed Integer Program
		Mixed Integer Goal Program
		Robust Mixed Integer Program

Including the authors’ model a push/pull open/closed-loop robust mixed integer program, 17 total models yielding 15 unique combinations of the above categories formed the model review.

There is a growing stream of research and model development dedicated to integrating the strategic, tactical, and operational levels of SC planning and management. The increasing scope and complexity of SCs are driving the need for new and more comprehensive models that have the ability to simultaneously capture aspects relevant to firm encountered problems. Therefore, there is still great opportunity for the

development of new models for helping the decision-making process of integrated SCs and SC planning. (Melo et al. 2009)

### III. METHODOLOGY

#### **Chapter Overview**

The purpose of this chapter is to describe the multiple objective linear programming (MOLP) methodology, its utilization and the significant factors influencing this research. Like previous chapters, main subject areas are addressed individually providing conceptual information and decision logic for inclusion herein. Covered first will be the research question and a brief relating of it to the reviewed literature. After the research question, the MOLP methodology is covered showing why it is an appropriate choice for this research. Following the initial review of the research methodology, the model assumptions that shape and constrain the research, are presented. Tying all the subjects together is an outline of the analytical basis for this research, the two linear programs (LP) and MOLP model designed to optimize the disposition and retrograde of USAF Class VII equipment. The chapter ends with a review of the data, its origins, and utilization.

#### **Research Question**

The intent of this research is to determine whether a multi-objective decision analysis tool that considers factors affecting the alignment of supply with demand and the cost of moving equipment improves the USAF Class VII equipment disposition and retrograde process. The USAF supply chain is massive, moving end items, components and resources throughout the world; the disposition and retrograde of Class VII equipment is but an aspect of that supply chain. Returning equipment after its utilization at non-permanent locations is very similar to the returns situations faced by managers of

closed-loop supply chains. Upon deployment or procurement to support deployed operations, USAF managers, like their civilian peers, know a significant percentage of the equipment will reenter the supply chain and require disposition and reverse movement. The mathematical models used to optimize these and similar processes are situation specific. Therefore, beyond a conceptual basis or shared approach, models are often not applicable to differing sets of factors and assumptions. The USAF model used to return non-mission capable resources to stateside and deployed maintenance locations would not provide optimal solutions for returning Class VII equipment, even though the assets are departing the same locations en route to bases with known demand. The USAF disposition and retrograde effort is unique and its implementation requires its own assumptions and optimization.

### **Multiple Objective Linear Program Methodology**

The ultimate goal of a prescriptive LP or MOLP model is to provide managers with information necessary for good decision-making (Ragsdale 2004). LPs can have only one objective function, the maximization or minimization of some function of the data; possibly leaving vital information unconsidered. Such is the case when firms optimize based solely on cost, delivery speed, delivery mode, geographic region, etc.; strategic situational perspective required by managers is lost in single solution answers. Unlike standard LPs, MOLP models provide the advantage of accurately representing the real multi-criteria nature of certain situations, among them transportation: minimization of transportation costs, maximization of delivery speed, maximization of goods delivered (Benayoun et al. 1970). Considering the previous transportation example, when the

objective functions are plotted, no one single point simultaneously optimizes all three of the objective functions. Each function is optimized at a unique plotted location; therefore, multiple objective optimization models offer the decision maker an opportunity to analyze the tradeoffs between the different and often competing objectives (Ragsdale 2004).

MOLP problems require managers establish target values for each of the different problem objectives. Establishing target values can be completed one of two ways: user defined (e.g. minimum amount allowed by regulation, maximum amount budgeted, etc.) or optimally solving for the value through its LP. Because the optimal solution to a LP always occurs at an extreme corner point of the feasible region, a new objective function is required to explore the points on the edge of the model's feasible region – those points representing a best-fit solution given the firm's various target values. (Ragsdale 2004).

The MINIMAX objective is necessary when decision makers desire to minimize the maximum deviation from any target value. Utilizing the MINIMAX objective function requires the establishment of deviational variables and their mutual constraint. Formed using the calculated value from the MOLP and the target value, the deviational variable for minimization objectives is presented below:

$$\frac{\text{actual value} - \text{target value}}{\text{target value}} \quad (1)$$

Equation 1 when multiplied by a corresponding importance value (weight) provides the objective's weighted deviation from the target value. Of particular importance in the formula is the placement of the numerator's target value. For minimization problems, intuitively, the target value is the smallest value the objective will take. Therefore, the

subtraction of the target value from the calculated actual value yields a positive percentage deviation.

Formed similarly to the deviational variable for minimization LPs, a maximization problem's variable is:

$$\frac{\text{target value-actual value}}{\text{target value}} \quad (2)$$

Using the same logic, the target value for maximization problems is the optimal solution; any subsequent solution will naturally be less than or equal to it. This equation yields a positive deviation from the target value as well.

The MINIMAX variable  $Q$  is the constraint designed to minimize the deviations presented in Equations 1 and 2.

$$\begin{aligned} \frac{\text{actual value-target value}}{\text{target value}} &\leq Q \\ \frac{\text{target value-actual value}}{\text{target value}} &\leq Q \end{aligned} \quad (3)$$

With the establishment of deviational variables and a third variable to minimize the magnitude of those deviations, the objective function of MOLP models is given by:

$$\text{MIN: } Q \quad (4)$$

The MOLP methodology, like minimization LPs, is intended to determine the point corresponding to the smallest objective function value. To achieve an optimal minimized solution, the variable  $Q$  will always be greater than or equal to all deviational variables.

The MINIMAX variable name is derived from the objective function's intent – minimize the maximum deviation (Ragsdale 2004).

The MOLP methodology provides an excellent array of tools the USAF can utilize to manage its disposition and retrograde process. Inherently this process is rife with alternative objectives – minimize transportation cost, maximize the amount of equipment returned, minimize transportation delays, fill demand evenly, ship only minimum required, etc. Further MOLPs are scalable including as many individual models as necessitated by the situation; the scope of the model is determined at the discretion of managers and process owners. The MOLP designed for this research is a single item model intended to provide the USAF disposition decision logic for its retrograde equipment. To do this there are three individual models with objective functions:

1. Minimize Transportation Cost
2. Maximize Average Fill
3. Multiple Objective Model

The Minimize Transportation Cost model considers the cost of moving the selected piece of equipment to its various demand locations and calculates an optimal solution based the lowest total transportation costs. Relying solely upon the Minimize Transportation Cost model to align supply with demand, while producing a cost efficient solution, does not ensure available equipment is spread evenly or correctly across the demand. To ensure bases beyond those with the lowest associated cost of movement receive available supply, the Maximize Average Fill model runs parallel to the Minimize Transportation Cost model. This model's objective function maximizes demand bases' average fill until supply is exhausted; it therefore provides a higher total transportation cost.



Minimizing the deviations from the calculated target values of the cost and fill models, the MOLP model provides the USAF with disposition instructions for the available supply. It aligns supply with demand based upon the smallest deviation from target cost and fill values. As with all LPs, the above models calculate their solutions bound by situation and model specific constraints; those constraints will be addressed in subsequent paragraphs.

Microsoft Excel was utilized to build the above three models; Ragsdale (2004) outlined four guidelines for mathematical models built within spreadsheets: communication; reliability; auditability; and modifiability. Communication is the spreadsheet's primary function – deliver information to decision makers. For this guideline to be fulfilled, the spreadsheet should present the information in an easy to understand manner communicating relevant information in a clear and intuitive manner. Reliability ensures the model output is correct and consistent. Auditability allows decision makers to retrace the steps followed to generate the objective solution(s). Minimizing required labor, auditability allows the decision maker to understand the model without significant design involvement. Modifiability is achieved when the model can be changed and adapted to a changing scenario – a particularly important trait as the modeled scenario evolves. These four guidelines provided the rubric upon which the model and data analysis presented in Chapter 4 are based.

### **Model Assumptions**

In order to eliminate uncontrollable variability, decision makers rely upon assumptions and exclusions to model stochastic events as deterministic processes.

There are four key assumptions necessary to both the computation and usability of this MOLP model:

1. Surface transportation is the sole source of movement from supply to demand base.
2. All ocean movements originate from the port of Karachi, Pakistan.
3. All United States bound cargo will be delivered to the seaport at Charleston, South Carolina.
4. Equipment destined for demand bases outside the continental United States will utilize one country specific seaport.

Movement from Bagram or Kandahar Air Base to a demand base is a function of myriad factors. The conduct of operations, political negotiations with host and surrounding countries, weather, time of year, drawdown timeline, availability of transportation resources and many other factors will affect retrograde operations. With strategic interest in mind, theater logistics planners will utilize their movement prioritization and optimization strategies to egress cargo from the country in the most efficient manner. Sometimes, opportune movement is available and cargo will be transported on a different mode at differing speeds and costs. All cargo movements, irrespective of mode, are subject to delays, diversions and reprioritizations. Because cargo theoretically can arrive at a demand base utilizing almost infinite combinations of routes and modes, this study relies upon universal mode selection and country specific routes to calculate transportation delivery costs.

The second assumption necessary for this research is the establishment of a single port of embarkation. Transportation rate specialists assigned to the U.S. Transportation Command Enterprise Readiness Center's Business Management Branch stated all

Afghanistan supporting reverse surface movements heretofore have originated from the seaport in Karachi, Pakistan. This second assumption continues the logic of the first by providing a standard ocean movement starting point.

Assumption 3 is the natural extension of the first two. Given the majority of demand for retrograded equipment is at bases within the continental United States, a common port of debarkation was necessary. The seaport at Charleston, South Carolina, will be the transition point from ocean to linehaul transportation.

Assumption 4, like number 3, provides for cost continuity for demand bases in foreign countries by ensuring only delivery distances account for the difference in transportation pricing.

### **Minimize Transportation Cost Model**

Given the fiscal environment currently constraining Air Force resources, the minimize cost model provides a logical starting point for the disposition and retrograde process. The sole purpose of this model is to align supply with demand at the lowest possible transportation cost until supply is exhausted or all demand is filled.

Objective Function:

$$\text{Min: } \sum_{i,j} H_{ij} * X_{ij} \quad (4)$$

Indices:

- $i$  = 1,2 Supply Locations
- $j$  = 1,2,...,n Demand Locations
- $k$  = 1,2,3 Equipment Priorities

Parameters:

$A$	=	Supply
$B$	=	Total Demand
$C_k$	=	Priority Demand
$D_{jk}$	=	USAF Equipment System Demand
$H_{ij}$	=	Cost of Transportation Between $i$ and $j$
$L$	=	Item Value
$N$	=	$\min\{H_{1j}, H_{2j}\}$
$y$	$\in$	$\{0,1\}$
$g_w$	=	The Family of Functions $\{g_w\}_{w \in [0,1]}$

The objective function of the Minimize Transportation Cost Model is subject to the below pre-process constraints and variables used for their calculation:

$$X_{ijk} = \text{Item Shipped from } i \text{ to } j \text{ in priority } k, \in \{1,2, \dots\} \quad (5)$$

$$g_w(A) = wA, \text{ Maximum supply} \quad (6)$$

$$v(k) = \text{Weight of the } k^{\text{th}} \text{ priority} > 0 \quad (7)$$

$$f(y) = (1 - y)(N - v(k)L) + y(-N + v(k)L) \leq 0 \quad (8)$$

$$E_{jk} = D_{jk}(1 - y) \text{ Base model demand} \quad (9)$$

$$G = \sum_{jk} E_{jk} \text{ Sum of base model demands} \quad (10)$$

$$f(y) = (1 - y)(H_{ij} - w(k)L) + y(-H_{ij} + w(k)L) \leq 0 \quad (11)$$

$$\sum_{i,j,k} X_{ijk} \leq (1 - y)E_{jk} \quad (12)$$

$$M = \min\{g_w(A), G\} \text{ Optimization quantity} \quad (13)$$

$$z_k = M - \sum_{r=1}^k C_r \quad (14)$$

$$F_k = \sum_{i,j} X_{ijk} = \begin{cases} C_k, & C_k \leq z_{k-1} \\ z_{k-1}, & C_k > z_{k-1} \end{cases} \text{ Priority Fill (15)}$$

$$f_k(M) = F_k \quad (16)$$

Model Constraints:

$$\sum_{j,k} X_{ijk} \leq A_i \quad \text{Supply Constraint (17)}$$

$$\sum_i X_{ijk} \leq E_{jk} \quad \forall j, k \quad \text{Demand Constraint (18)}$$

Equations (5) through (18) build upon each other providing the necessary framework to ensure USAF retrograde guidance is followed. These variables and constraints are required to establish the quantity of supply and demand and cost considerations before the model calculates the optimal solution.

Equation (5) is an item shipped from a supply to demand base under the  $k^{th}$  equipment priority. Each respective ( $X_{ijk}$ ) value is an integer greater than or equal to zero.

Equation (6) allows a decision maker to establish a maximum amount of supply to be considered by the model. This equation is necessary if decision makers desire to retrograde an amount of supply less than what is available e.g. retrograde of a particular item will be capped at 75% of its supply.

Equation (7) provides the weighted value of the  $k^{th}$  equipment priority which is necessary to calculate a base model demand ( $E_{jk}$ ). Equations (7), (8) and (9) work together to ensure the model does not consider bases where the cost of transportation ( $H_{ij}$ ) is more than the weighted value of the item ( $v(k)L$ ). Some USAF equipment is plentiful

and easily replaced allowing for transfer or disposal in the deployed theater. Other equipment is sensitive, scarce or not easily or economical feasible to replace necessitating retrograde irrespective of the cost. Equations (8) and (9) are binary functions allowing a base model demand ( $E_{jk}$ ) to equal USAF equipment system demand ( $D_{jk}$ ) when the minimum transportation cost ( $N$ ) is less than the weighted value of the item ( $v(k)L$ ). When  $y$  equals 0, a base model demand ( $E_{jk}$ ) equals its USAF equipment system demand ( $D_{jk}$ ) and minimum transportation cost ( $N$ ) is less than or equal to the weighted value of the item ( $v(k)L$ ). When  $y$  equals 1, a base model demand ( $E_{jk}$ ) equals 0 and the minimum transportation cost ( $N$ ) is greater than the weighted value of the item ( $v(k)L$ ) ensuring the model does not consider that base as a possible destination for available supply.

The practical application of Equations (7), (8) and (9) is the determination of whether it is cost efficient to transport an item to a demand base – in this case cost efficiency is determined by the ratio of item value to item transportation cost. Cost inefficiency at one supply base does not mean the base’s demand will not be considered in the model analysis. Rather the set of equations allow the demand base to be considered when one supply base combination provides for cost efficient transportation. In Excel, Equations (8), (9), and (10) are formed using if/then statements:

$$if(\min\{H_{ij}\} \leq v(k)L, D_{jk} = E_{jk}, 0) \quad (19)$$

The excel function found in Equation (17) is formed by three components. Coming first is the logic query:  $if(\min\{H_{ij}\} \leq v(k)L$ . The logic query stated in words – is the minimum transportation cost ( $N$ ) less than or equal to the weighted value of the item?

The second portion is the value if the logic query is true -  $D_{jk} = E_{jk}$  , the USAF

Equipment System Demand equals Base Model Demand ( $E_{jk}$ ). Coming last is the value if false: zero; transportation from both supply bases is not cost efficient.

Equation (10) shows the total model demand for an item. As equations (7), (8) and (9) show, a USAF Equipment System Demand ( $D_{jk}$ ) does not alone provide necessary justification for inclusion in model calculations. Equation (10) sums all base model demands ( $E_{jk}$ ) yielding the sum of base model demands ( $G$ ) which is considered in Equation (13).

Equations (11) and (12) are another set binary switches working in conjunction with Equations (8) and (9). The latter two equations establish whether at least one supply and demand base pair provides for cost efficient allocation of supply. Equations (11) and (12) ensure equipment is not sent between supply base  $i$  and demand base  $j$  ( $X_{ij}$ ) when it is not cost efficient. When  $y$  equals one, the price of transportation is greater than the weighted value of the item and Equation (12) requires the sum of all equipment items sent between supply base  $i$  and demand base  $j$  under priority  $k$  ( $X_{ijk}$ ) to be less than or equal to zero. When  $y$  equals zero, the price of transportation is less than or equal to the weighted value of the item and Equation (12) limits the sum of all equipment items sent between supply base  $i$  and demand base  $j$  under priority  $k$  ( $X_{ijk}$ ) to be less than or equal to the base's model demand ( $E_{jkl}$ ).

The instances of the maximum supply ( $g_w(A)$ ) equaling the sum of base model demands ( $G$ ) will likely be minimal which necessitates Equation (13). This function is critical as it selects the amount of supply to be considered by the model. In cases where supply exceeds demand, optimization quantity ( $M$ ) will be the sum of base model demands ( $G$ ). Alternatively, when demand exceeds supply, Optimization Quantity ( $M$ )

will equal maximum supply ( $g_w(A)$ ). Optimization quantity ( $M$ ) does not mean there won't be remaining supply or demand; rather the minimum value selected is equal to 100% of the supply capable of being allocated by the model. In Excel this value is achieved by using the minimum function:

$$\min\{g_w(A), G\} \quad (20)$$

The minimum function in Excel provides an answer by selecting the lowest value in the provided range. Optimization Quantity ( $M$ ) is the critical component of the equation allocating supply to demand priorities.

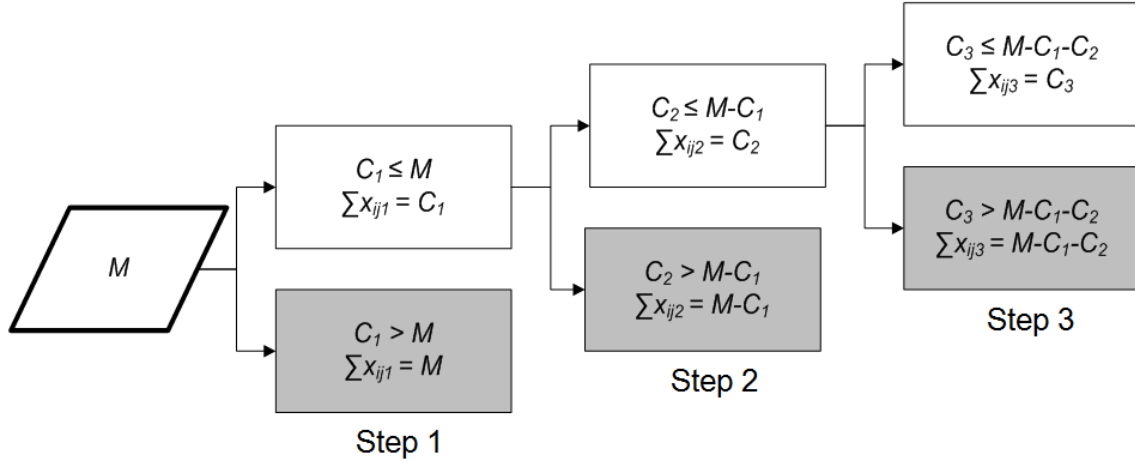
Equation (16) is activated only after the optimization quantity ( $M$ ) has been established. Equations (14) and (15) provide the decision logic to ensure the highest equipment priority is filled before lower priorities are considered. Equation (14) is an iterative function based on index  $k$  that considers the optimization quantity ( $M$ ) and the sum values of priority demand ( $C_k$ ). Each value Equation (14) takes is provided below:

$$\begin{aligned} z_0 &= M \\ z_1 &= M - C_1 \\ z_2 &= M - C_1 - C_2 \end{aligned}$$

Equation (15) is a piecewise function that acts as the decision node determining what value priority fill  $k$  ( $F_k$ ) will take.



Figure 5 provides a graphical representation of the decision logic of Equations (15) and (16):



**Figure 5: Equipment Priority Fill Allocation**

Decision Step 1: When priority 1 demand ( $C_1$ ) is less than or equal to  $z_0$ , priority fill 1 ( $F_1$ ) equals priority 1 demand ( $C_1$ ) either consuming all supply or leaving a quantity to fill some portion of priority 2 demand ( $C_2$ ). When priority 1 demand ( $C_1$ ) is greater than  $z_0$ , priority fill 1 ( $F_1$ ) equals  $z_0$ , in this case optimization quantity ( $M$ ). If priority 1 demand ( $C_1$ ) is less than or equal to  $z_0$ , Decision Step 2 is necessary.

Decision Step 2: When priority 2 demand ( $C_2$ ) is less than or equal to  $z_1$ , priority fill 2 ( $F_2$ ) equals priority 2 demand ( $C_2$ ) either consuming all remaining supply or leaving some quantity to fill priority 3 demand ( $C_3$ ). When priority 2 demand ( $C_2$ ) is greater than  $z_1$ , priority fill 2 ( $F_2$ ) equals  $z_1$ , in this case optimization quantity ( $M$ ) minus priority fill 1 ( $F_1$ ). If priority 2 demand ( $C_2$ ) is less than or equal to  $z_1$ , Decision Step 3 is necessary.

Decision Step 3: When priority 3 demand ( $C_3$ ) is less than or equal to  $z_2$ , priority fill 3 ( $F_3$ ) equals priority 3 demand ( $C_3$ ) consuming all remaining supply. When priority 3 demand ( $C_3$ ) is greater than  $z_2$ , priority fill 3 ( $F_3$ ) equals  $z_2$  or all remaining supply.

Equation (16) acts as a binding constraint ensuring the highest equipment priority is filled before lower priorities.

Conceptually, Equations (14), (15), and (16) work together iteratively to determine the amount of supply available then how to allocate it with respect to the three equipment priorities. These functions are established easily in Excel using if/then statements:

$$if(C_1 \leq M, F_1 = 100\%, 0) \quad (21)$$

Once again, the first portion of Equation (21) is the logic query: is priority 1 demand less than the optimization quantity. The result if the logic test being true is the establishment of a constraint forcing the model to fill 100 percent of the demand. The value if false directs the model to exhaust supply filling priority 1 demand. The logic for these constraints continues for Priority 2 Demand ( $C_2$ ); however, equipment priorities 2 and 3 necessitate both a greater than and less than constraint.

Priority 2 demand ( $C_2$ ):

$$if((C_1 + C_2) \leq M, F_2 \geq 100\%, 0) \quad (22)$$

$$if(C_1 \leq M, F_2 \leq 100\%, 0) \quad (23)$$

Priority 3 Demand ( $C_3$ ):

$$if((C_1 + C_2 + C_3) \leq M, F_3 \geq 100\%, 0) \quad (24)$$

$$if((C_1 + C_2) \leq M, F_3 \leq 100\%, 0) \quad (25)$$

Equations (22) and (24) are greater than constraints and Equations (23) and (25) less than constraints; the logic queries for each test are the same as that of Equation (21).

Equation (17) ensures the total quantity of items allocated by a supply base is less than or equal to the bases' available supply ( $A_i$ ). The USAF cannot fill demand with supply it does not have nor fill beyond the threshold established by Equation (6); these facts necessitate a constraint to eliminate fallacious optimal solutions. Establishing this constraint in the Excel model is intuitive, the cells assigned the function of totaling the supply base's allocation of items to demand bases ( $X_{ij}$ ) is constrained by an adjacent cell listing the amount of available supply ( $A_i$ ).

Equation (18) is the corollary to Equation (17), just as a supply base cannot allocate more than its available supply, demand bases cannot receive more than their demand. Equation (18) limits the total amount sent between a supply and demand base under Priority  $k$  to the base's model demand ( $E_{jk}$ ). The Excel implementation of these constraints is the same as that described for Equation (17).

### **Maximize Average Fill Model**

The Minimize Transportation Cost Model yielded an optimal solution to align supply with demand at the lowest possible transportation cost; however, that does not ensure supply is allocated to maximally fill existing demand. The objective of the Maximize Average Fill Model is to allocate demand so the overall average fill percentage of all considered demand bases is as high as possible.

Objective Function:

$$Max: \frac{\sum \left( \frac{\sum_i X_{ijk}}{E_{jk}} \right)}{P} \quad \forall j, k \quad (26)$$

Indices:

- $i$  = 1,2 Supply Locations
- $j$  = 1,2,...,n Demand Locations
- $k$  = 1,2,3 Equipment Priorities

Parameters:

- $A$  = Supply
- $B$  = Total Demand
- $C_k$  = Priority Demand
- $D_{jk}$  = USAF Equipment System Demand
- $H_{ij}$  = Cost of Transportation Between  $i$  and  $j$
- $L$  = Item Value
- $N$  =  $\min\{H_{1j}, H_{2j}\}$
- $P$  = Number of Bases Considered by Model
- $y$   $\in$   $\{0,1\}$
- $g_w$  = The Family of Functions  $\{g_w\}_{w \in [0,1]}$

The objective function of the Maximize Average Fill Model is subject to the below pre-process constraints and variables used for their calculation:

$$X_{ijk} = \text{Item Shipped for } i \text{ to } j \text{ in priority } k, \in \{1,2, \dots\} \quad (5)$$

$$g_w(A) = wA, \text{ Maximum supply} \quad (6)$$

$$v(k) = \text{Weight of the } k^{\text{th}} \text{ priority} > 0 \quad (7)$$

$$f(y) = (1 - y)(N - v(k)L) + y(-N + v(k)L) \leq 0 \quad (8)$$

$$E_{jk} = D_{jk}(1 - y) \text{ Base model demand} \quad (9)$$

$$G = \sum_{jk} E_{jk} \text{ Sum of base model demands} \quad (10)$$

$$f(y) = (1 - y)(H_{ij} - w(k)L) + y(-H_{ij} + w(k)L) \leq 0 \quad (11)$$

$$\sum_{i,j,k} X_{ijk} \leq (1 - y)E_{jk} \quad (12)$$

$$M = \min\{g_w(A), G\} \text{ Optimization quantity (13)}$$

$$z_k = M - \sum_{r=1}^k C_r \quad (14)$$

$$F_k = \sum_{i,j} X_{ijk} = \begin{cases} C_k, & C_k \leq z_{k-1} \\ z_{k-1}, & C_k > z_{k-1} \end{cases} \text{ Priority Fill (15)}$$

$$f_k(M) = F_k \quad (16)$$

Model Constraints:

$$\sum_{j,k} X_{ijk} \leq A_i \text{ Supply Constraint (17)}$$

$$\sum_i X_{ijk} \leq E_{jk} \quad \forall j, k \text{ Demand Constraint (18)}$$

The interpretation and implementation of the above indices, parameters, variables and constraints are the same for this model as the Minimize Transportation Cost Model.

Establishing the same constraint set was necessary to ensure nothing changed between the two models, thus allowing the objective functions to account for the only change in item disposition. Intuitively, this model has a higher total transportation cost as well as higher average fill.

### Multiple Objective Model

The Minimize Transportation Cost and Maximize Average Fill Models yielded two distinct optimal solutions and sets of disposition instructions.

The function of the MOLP model is utilize the two optimal solutions as target values and produce an answer that minimizes the largest deviation from the established target values.

Objective Function:

$$\text{Min: } Q \quad (27)$$

Indices:

$$\begin{aligned} i &= 1,2 \text{ Supply Locations} \\ j &= 1,2,\dots,n \text{ Demand Locations} \\ k &= 1,2,3 \text{ Equipment Priorities} \end{aligned}$$

Parameters:

$$\begin{aligned} A &= \text{Supply} \\ B &= \text{Total Demand} \\ C_k &= \text{Priority Demand} \\ D_{jk} &= \text{USAF Equipment System Demand} \\ H_{ij} &= \text{Cost of Transportation Between } i \text{ and } j \\ L &= \text{Item Value} \\ N &= \min\{H_{1j}, H_{2j}\} \\ P &= \text{Number of Bases Considered by Model} \\ y &\in \{0,1\} \\ g_w &= \text{The Family of Functions } \{g_w\}_{w \in [0,1]} \end{aligned}$$

The objective function of the Multiple Objective model is subject to the below pre-process constraints and variables used for their calculation:

$$X_{ijk} = \text{Item Shipped for } i \text{ to } j \text{ in priority } k, \in \{1,2, \dots\} \quad (5)$$

$$g_w(A) = wA, \text{ Maximum supply} \quad (6)$$

$$v(k) = \text{Weight of the } k^{\text{th}} \text{ priority} > 0 \quad (7)$$

$$f(y) = (1 - y)(N - v(k)L) + y(-N + v(k)L) \leq 0 \quad (8)$$

$$E_{jk} = D_{jk}(1 - y) \text{ Base model demand} \quad (9)$$

$$G = \sum_{jk} E_{jk} \text{ Sum of base model demands (10)}$$

$$f(y) = (1 - y)(H_{ij} - w(k)L) + y(-H_{ij} + w(k)L) \leq 0 \quad (11)$$

$$\sum_{i,j,k} X_{ijk} \leq (1 - y)E_{jk} \quad (12)$$

$$M = \min\{g_w(A), G\} \text{ Optimization quantity (13)}$$

$$z_k = M - \sum_{r=1}^k C_r \quad (14)$$

$$F_k = \sum_{i,j} X_{ijk} = \begin{cases} C_k, & C_k \leq z_{k-1} \\ z_{k-1}, & C_k > z_{k-1} \end{cases} \text{ Priority Fill (15)}$$

$$f_k(M) = F_k \quad (16)$$

Model Constraints:

$$\sum_{j,k} X_{ijk} \leq A_i \text{ Supply Constraint (17)}$$

$$\sum_i X_{ijk} \leq E_{jk} \quad \forall j, k \text{ Demand Constraint (18)}$$

$$\frac{(\sum_{i,j} H_{ij} * X_{ij} - \text{Min Transportation Cost Model Optimal Solution})}{\text{Min Transportation Cost Model Optimal Solution}} \leq Q \quad (28)$$

$$\frac{\left( \text{Max Average Fill Model Optimal Solution} - \frac{\sum \left( \frac{\sum_i X_{ijk}}{E_{jk}} \right)}{P} \right)}{\text{Max Average Fill Model Optimal Solution}} \leq Q \quad \forall j, k \quad (29)$$

In addition to the variable, pre-process and model constraints that framed the calculations and optimal solutions of the previous two models, the MOLP relies upon an objective function that changes as optimal solutions are tested, discarded and established.

Equations (28) and (29) minimize the maximum deviation ( $Q$ ) from the cost and fill model optimal solutions. As discussed previously,  $Q$  will always be greater than or equal to the largest deviation. Producing Equations (28) and (29) in the Excel model requires carrying forward the cost and fill model optimal solutions, and then using cell calculations to establish the deviational variables according to Equations (1) through (4), (28) and (29). Once established those cells are set less than or equal to the objective function variable  $Q$ .

### **Minimum Fill Level Constraint**

Linear programs and MOLP models calculate optimal solutions based upon the objective function and limiting constraints. The Minimize Transportation Cost Model and Maximize Average Fill Model serve a unique purpose – establish target values for the MOLP. However, there will be times when the calculated optimal solutions, while correct, do not meet the intent of USAF decision makers. The Minimum Fill Level Constraint allows decision makers the opportunity to recommend a specific amount of supply for all demand bases. Intuitively, the USAF cannot fill demand for which there is insufficient supply; however, it can ensure distribution of supply is as uniform as possible. Equation (31) acts as a constraint to require the decision maker's recommended minimum supply level be considered before the three models calculate their optimal solutions.



The usage of recommended minimum supply level vice mandatory minimum fill level is necessary for two distinct reasons:

1. Given the quantities of supply and demand, the decision maker's recommended minimum fill level might be infeasible. There is insufficient supply to provide the level of fill across all demand bases.
2. The recommended minimum fill level would allocate more supply than required by the demand base.

Equation (31) accounts for the above two supply and demand discrepancies before establishing its pre-process constraint value. The constraint is established using the following:

Indices:

- $i$  = 1,2 Supply Locations
- $j$  = 1,2,...,n Demand Locations
- $k$  = 1,2,3 Equipment Priorities

Parameters:

- $A$  = Supply
- $C$  = Priority Demand
- $D$  = USAF Equipment System Demand
- $R$  = Recommended Minimum Fill Level
- $S$  = Number of Priority  $k$  Bases
- $y$   $\in$  {0,1}
- $g_w$  = The Family of Functions  $\{g_w\}_{w \in [0,1]}$

Equations:

$$X_{ijk} = \text{Item Shipped for } i \text{ to } j \text{ in priority } k, \in \{1,2, \dots\} \quad (5)$$

$$g_w(A) = wA, \text{ Maximum Supply} \quad (6)$$

$$E_{jk} = D_{jk}(1 - y) \text{ Base model demand} \quad (9)$$

$$G = \sum_{jk} E_{jk} \text{ Sum of base model demands (10)}$$

$$M = \min\{g_w(A), G\} \text{ Optimization quantity (11)}$$

$$T_i = \left\lfloor \frac{M - \sum_{i=1}^{k-1} C_i}{S_k} \right\rfloor \text{ Uniform Supply Allocation (30)}$$

$$\text{Minimum Fill Level} = \text{minimum}\{R, T, E_{jk}\} \text{ (31)}$$

There are three components of the Minimum Fill Level constraint Equation (31) – the recommended minimum fill level ( $R$ ), the uniform supply distribution value ( $T$ ) Equation (30) and the base model demand ( $E_{jk}$ ). The first portion is a subjective value declared when item attribute, supply, demand, and location information is logged into the model. Uniform supply allocation ( $T$ ) Equation (30) is second; it is a floor function that returns the largest possible integer when the optimization quantity ( $M$ ) is divided by the number of priority  $k$  bases ( $S_k$ ). This value represents the highest amount of supply that can be spread evenly across all demand bases. When the quotient is less than one, the floor function returns zero. Coming last, the Base Model Demand value ( $E_{jk}$ ). When combined with the constraints governing priority fill and supply and demand allocation, Equation (31) returns the only value that will yield a feasible solution.

The decision maker's recommended minimum supply level ( $R$ ) is returned when both of the following are met:

1. The uniform supply allocation ( $T_k$ ) value is greater than the recommend minimum supply level ( $R$ ).
2. The Base model demand ( $E_{jk}$ ) is greater than or equal to the recommended minimum supply level ( $R$ ).

The uniform supply allocation ( $T_k$ ) value is returned when the following are met:

1. The optimization quantity ( $M$ ) is not sufficient to satisfy the recommended minimum supply level ( $R$ ).
2. The Base Model Demand ( $E_{jk}$ ) is greater than the uniform supply distribution ( $T_k$ ) value.

The Base model demand ( $E_{jk}$ ) value is returned when it is less than both the recommended minimum supply level ( $R$ ) and the uniform supply allocation ( $T_k$ ) value.

The Excel implementation of this constraint is quite simple; it builds upon previously used equations, requires one new calculation, and one new variable. The mathematical and Excel annotation are the same for each priority demand ( $C_k$ ); however, the individual values will be different for each demand base ( $j$ ) within priority  $k$ . The recommended minimum supply level ( $R$ ) is static to the item.

The uniform supply allocation value Equation (30); however, changes with each demand priority ( $C_k$ ), the respective priority equations are listed below:

$$\text{Priority 1: } T_1 = \frac{M}{S_1}$$

$$\text{Priority 2: } T_2 = \frac{M - C_1}{S_2}$$

$$\text{Priority 3: } T_3 = \frac{M - C_1 - C_2}{S_3}$$

As discussed and defined earlier in Equations (9) and (10), the base model demand ( $E_{jk}$ ) is unique representing the upper bound on the base  $j$  priority  $k$  supply allocation.

Conceptually, this constraint sets a lower bound on supply allocation; therefore, in Excel it is applied as a greater than or equal to constraint.

Implementation of the Minimum Fill Level constraint will significantly alter the optimal solutions of all three models; it requires a certain allocation of supply that does not align with minimizing transportation costs or maximizing average fill. This is in intuitive – the bases with the highest transportation costs will be allocated supply. Further, bases with significant demand requirements will be allocated supply at the expense of bases that are more easily filled to higher percentages. Because of this altering affect, the Minimum Fill Level constraint was designed to be turned on and off allowing a comparison of optimal solutions both and without its activation. The selective application of this constraint is necessary; the requirements for items vary given their unique attributes, importance to bases, missions, capabilities, cost, etc.

### **Data Origins and Preparation**

Provided by contractors assigned to the 404 Supply Chain Management Squadron, Material Support Flight, Robbins Air Force Base, Georgia, the data used to build and test the presented models is a minor sampling of both the available supply at Bagram and Kandahar airfields and the demand for equipment across the Air Force. Dated, 01 December 2013, the supply and demand listings come from the actual data used by the USAF's Retrograde Management Planning Team (RMPT) and 440<sup>th</sup> Supply Chain Operations Squadron for ongoing disposition and retrograde efforts.

Generated from the Air Force Equipment Management System (AFEMS) and Equipment Requirements System (ERS), the complete demand listing outlines all open Class VII equipment requirements.

The report contains the following information for each individual demand:

- Demand Priority
- Unique Requirement Number
- National Stock Number (NSN)
- National Item Identification Number
- Stock Record Accounting Number (SRAN)
- Base Name
- Air Force Major Command
- Quantity Required by Requirement Number

Because the demand listing is exhaustive covering all Class VII demand requirements across the USAF, data from the above categories was often missing. If an item selected for inclusion in this research was missing demand priority, base name and SRAN, or quantity required that individual line was deleted from the analysis. Also deleted from the analysis was any occurrence of Bagram or Kandahar Air Base showing demand.

Like demand, the supply data is a report generated from AFEMS and ERS providing the same general information. This report; however, alternatively provides quantities on hand and owning organizations. The 01 December 13 demand report listed 1557 unique items requiring disposition instructions.

Utilizing database management techniques, items were aggregated at both supply and demand bases. The primary consideration for an item's inclusion in this research was supply being less than demand; this is important to the research as it necessitates an optimal solution given the decision logic and constraints of the models. In an attempt to select a representative sample of USAF equipment requiring disposition and retrograde,

over 100 NSNs were reviewed and considered. To gather name, cost, dimensions, and weight information, each item was queried using the Defense Logistics Agency NSN search website. Table 5 contains the relevant information of the nine items selected for inclusion in this research.

**Table 5: Equipment Specific Information and Details**

Number	NSN	Item name	Cost	Dimension (in <sup>3</sup> )	Weight (lbs.)
1	5820014939675	Radio Set (AN/PRC-112)	\$22,134	68.84	2.13
2	6665015522704	Joint Chemical Agent Detector (M4A1)	\$3,853	44.00	2.20
3	5820014994473	Radio Set (An/PRQ-7)	\$8,988	39.94	2.19
4	5810015302811	Encryption-Decryption Equipment (KIV-7M)	\$8,000	115.50	2.42
5	4520014828571	Heater, Duct Type, Portable	\$18,959	193577.50	550.00
6	4210010441429	Wheeled Halon 1211 Fire Extinguisher (Model 600K)	\$914	79048.20	165.00
7	5855014320524	Monocular Night Vision Device (AN/PVS-14)	\$3,607	21.19	0.95
8	5820015268808	Aircraft Survival Radio Set (AN/PRC-112G)	\$6,600	68.84	2.13
9	42400134334433	Gas-Particulate Filter Unit(MBU-19/P)	\$644	1728.00	3.30

**Item Dimension, Weight, and Shipping Cost**

The range in type of items requiring disposition and retrograde is large necessitating a standard units of measure across all equipment. A fixed standard ensures, space and cost allocations are uniform across all items. The Defense Logistics Agency NSN search provides size data for the individual NSNs. To allocate shipping space and

generate transportation costs representative of actual movement, each item’s dimension and weight was increased by a factor of 10 percent. This increase is designed to simulate necessary transportation packaging.

In accordance with the first assumption of this research, all NSN movement is conducted via surface transportation. This assumption allows for the utilization of the standard 20-foot shipping container as the single unit of measure from supply to demand base. The interior dimensions of a 20-foot shipping container are: length 232 inches; width 92 inches; and height 94 inches. The dimensions yield 2,006,336 cubic inches of shipping space with a maximum allowable cargo weight of 32,000 pounds. Equations (32) and (33) provide the logic for calculating transportation costs:

$$\text{Container Utilization} = \min \left\{ \begin{array}{l} \text{Weight} \quad \frac{\text{Allowable Cargo Weight}}{\text{Item Weight}} \\ \text{Dimension} \quad \frac{\text{Container Dimension}}{\text{Item Dimensions}} \end{array} \right. \quad (32)$$

$$\text{Transportation Cost Calculation} = \frac{\text{Container Transportation Cost}}{\text{Minimum Value}} \quad (33)$$

Equation (32) provides the answer to whether the shipping container will reach its weight or dimensional limitation first. The minimum of those two values establishes the maximum quantity of items the shipping container can hold. As shown in Equation (33), the container transportation cost is then divided by the minimum value thereby providing the item’s landed cost used in this research.

Rate information for all transportation components was taken from the U.S. Transportation Command’s August 2013 schedule of transportation rates. Contained in the schedule were drayage, linehaul, mileage, ocean container, ocean break-bulk, and

single service rates for every country in which the U.S. Transportation Command conducts operations. When rate options for a 20-foot container were not available, rates for containers under 40-feet were utilized. The rate schedule contained multiple rates for each transportation segment, to glean the most representative cost; an average of available rates was taken and used for each cost component. The calculation of transportation costs fell into one of the three scenarios described below:

1. Demand bases within the continental United States: The ocean rate was calculated from Karachi, Pakistan, to Charleston, South Carolina using the Eastern United States delivery rate. The over-the-road portions were taken from individual mileage range rates. An internet mapping tool was utilized to calculate the mileage distance between Charleston, South Carolina, and the demand base. That appropriate mileage range was determined and the average rate was then multiplied by the calculated mileage producing the total cost to deliver one 20-foot shipping container. Equations (32) and (33) were applied to get the item specific cost of transportation.
2. United States Demand bases within 250 miles of their respective seaport: The rate schedule's mileage ranges started at 250 miles; bases within that range required usage of drayage rates for delivery from the servicing port. Drayage was calculated using the average flat delivery rate. Equations (32) and (33) were then applied for individual item cost.



3. Demand Bases outside the United States: In foreign countries with multiple USAF bases such as Korea, England, Germany, etc. a single port of debarkation was selected for all bases. Because exact mileage between foreign ports and USAF bases was unknown, actual linehaul rates were utilized for bases under this scenario. These linehaul rates; however, were calculated with the base/general area as the originating location and seaport as the terminating location. Actual rates between two exact locations were selected over mileage estimation; however, that decision could lead to erroneous transportation costs for the linehaul portion of delivery to USAF bases in foreign countries. Equations (32) and (33) were then applied for individual item cost.

## IV. ANALYSIS AND RESULTS

### **Chapter Overview**

This chapter summarizes the results of this research effort and provides responses to the investigative questions outlined in Chapter 1. Investigative questions are addressed individually with the responses building upon each other to form a basis for the conclusions and recommendations found in Chapter 5. When applicable, a representative sampling of raw data, model optimal solutions and disposition instructions are presented to amplify investigative question responses and demonstrate model performance.

### **Investigative Question 1**

Investigative question 1 was posed to serve as a guide during research and model formulation. The determination of the objective functions that will feed the multiple objective model is critical to both data collection and model implementation. Like all military operations, the USAF retrograde of Class VII equipment, in practical application, will be a function of myriad factors, some drastically more important than others.

The units of measure necessitating minimization or maximization vary and are combined in MOLPs for specific reasons under situational specific parameters. Research utilizing this and other optimization methodologies has incorporated multiple factors, to include the minimization of transportation cost (Hafich 2013, Rappoport et al. 1994), transportation time (Skipper 2002), travel distances (Dantzig et al. 1959, Rink et al. 1999), and optimal travel routes (Dantzig and Ramser 1959). Also abundant is research covering maximization linear programs; Rosenthal et al. (1997) developed a linear programming model to maximize on-time throughput of both aircraft cargo and

passengers. Lawrence and Burbridge (1976) utilized linear programming to maximize coordinated production and logistics planning. The retrograde of Class VII equipment provides a logical home for many of the above variables of interest.

Unlike the initial stages of armed conflict or humanitarian responses where time is of the utmost importance, retrograde operations are not inherently time sensitive. In this research, there is an element of time sensitivity to remove the equipment before the drawdown date; however, delivery to the demand base does not require urgent delivery. In matters of logistics and movement, speed and price are positively and significantly correlated (Corbett et al. 2009). Because there was no need to actively minimize an item's time spent in transit, time was not included as a variable requiring optimization in this study.

Relating significantly to time as a variable requiring optimization is distance traveled. When the USAF provides for the movement of equipment, minimizing distance traveled is of prime importance; estimated times of arrival, fuel consumption and aircrew availability are just a few of the factors influenced by distance traveled. However, retrograde equipment is not time sensitive nor perishable, as such optimization based on minimizing total miles is neither necessary nor logical.

Throughput is another variable of significant interest to USAF planners; it as a measurement can fundamentally alter how militaries proceed to a destination. If, for example, an airfield does not have the parking, fuel, or service capacity to process and sustain a defined number of aircraft missions, other airfields will be utilized alternatively or in conjunction. For this research, assumptions were made that all retrograde equipment would be moved via surface transportation. These surface transportation

channels are beyond the scope of direct USAF control and were therefore not included in this research.

The most logical and necessary variables of interest in this research were transportation cost and average fill. The current fiscal environment necessitates the USAF be as efficient as possible and the Minimize Transportation Cost Model is designed to meet that end. Equally important is ensuring the plan to align supply with demand is logical and consistent. The Maximize Average Fill Model is designed to spread available supply uniformly – to fill demand in a way that achieves the highest percentage of demand closure. The selected LPs and the multiple objective model they feed provide the USAF optimal solutions and guidance on two critically important variables of interest for the retrograde of excess Class VII equipment.

### **Investigative Question 2**

As outlined in Chapter 3, the raw item data, supply and demand bases, transportation costs, user defined inputs and constraints each play a role in determining the solutions produced by the three models. The items presented below form a representative sample of the model outputs and varying solutions; each selected to highlight a particular model attribute. Further provided is information and supporting details intended to convey the decision logic of the models and associated constraints. The presented model output in the tables below represents variables of interest and notional disposition instructions the USAF could utilize to align supply with demand.

**Table 6: Item 1 Supply and Demand Information**

<b>Aircraft Survival Radio Set (AN/PRC-112G)</b>			
<b>NSN</b>	<b>Cost</b>	<b>Dimensions (in<sup>3</sup>)</b>	<b>Weight (lbs.)</b>
5820015268808	\$6,600	68.84	2.13
<b>Supply</b>			
Bagram AB:	59		
Kandahar AB:	37		
<b>Demand</b>			
<b>Bases</b>	<b>Priority 1</b>	<b>Priority 2</b>	<b>Priority 3</b>
Baltimore ANG			20
Ellsworth			2
Fairchild			27
Fairchild ANG			1
Hill			22
Kadena			25
Madison ANG			8
Moody			9
Patrick			4
Reno ANG			7
Robins ANG			1
Tinker			6
Westfield ANG			18

The aircraft survival radio example presented in Table 6 has a total demand of 150 units across 13 bases and a supply 96. The USAF does not have retrograde specific priority codes for equipment. In an effort to delineate importance of demand, this research utilized guidance on original equipment purchase provided by the 404<sup>th</sup> Supply Chain Management Squadron (SCMS). Within the Equipment Requirements System, USAF equipment managers apply a criticality assessment to all equipment requirements. This assessment is used in the development of the Air Force Requirements Planning List and other strategic level budget documents (404 SCMS 2013).

Three priority codes are housed under the ERS criticality assessment. Each is described below:

1. Critical:
  - a. Work stoppage has or will occur with no work-around
  - b. Safety of flight/safety of troops affected.
  - c. Joint Chiefs of Staff project coded surge requirement.
2. Important:
  - a. Current asset condition may cause work stoppage.
  - b. Improved safety and saved resources through technology advances.
3. Routine:
  - a. ERS default for all requirements.

The original purchase criticality assessment provided a logical basis upon which to categorize returning equipment. If the requirement was so critical as to necessitate purchase by the USAF; it follows, that requirement should be filled by retrograde equipment before others.

Item 1 outlined in Table 6 above has only Priority 3 demand, therefore there will be no additional constraints mandating equipment be allocated to one base over another. The resulting disposition instructions will be purely a function of the three models. Presented in Table 7 are the optimal solutions for the Minimize Transportation Cost and Maximize Average Fill Models. These optimal solutions were not constrained by the minimum fill constraint. The differences in calculated values and supply allocation are purely a function of the model objective.

**Table 7: Item 1 Transportation Cost and Average Fill Optimal Solutions**

Item 1 Optimal Solutions					
Minimize Transportation Cost			Maximize Average Fill		
Objective Function:	\$59.20		Objective Function:	83.69%	
Fill Rate:	70% (-17%)		Transportation Cost:	\$66.32 (+12%)	
Allocation			Allocation		
Base:	Net Flow:	Demand:	Base:	Net Flow:	Demand:
Baltimore ANG	20	20	Baltimore ANG	20	20
Ellsworth	2	2	Ellsworth	2	2
Hill	3	22	Fairchild ANG	1	1
Kadena	25	25	Hill	20	22
Madison ANG	8	8	Madison ANG	8	8
Moody	9	9	Moody	9	9
Patrick	4	4	Patrick	4	4
Robins ANG	1	1	Reno ANG	7	7
Tinker	6	6	Robins ANG	1	1
Westfield ANG	18	18	Tinker	6	6
			Westfield ANG	18	18

**\*Note: The positive and negative values within parentheses are the deviations from the optimal solution. From above a 70% fill rate is 17% less than the optimal solution of 83.69%**

As shown in Table 7, the two models produced similar yet slightly different results. The Minimize Transportation Cost model produced an optimal solution that allocated supply to 10 total bases, including Kadena Air Base (AB), Japan, which had the second highest demand, but one of the lowest shipping costs. The Maximize Average Fill model allocated supply to 11 bases; however, it did not allocate supply to Kadena AB. This is intuitive as Kadena’s demand of 25 necessitated a significant portion (26 percent) of the total supply. The Maximize Average fill model exhausted supply filling demand at Hill AFB, leaving Kadena AB and Fairchild Air Force Base (AFB) as the only bases not to receive supply. The model allocated supply according to its intended purpose filling 100 percent of the demand at 10 bases. The change in supply allocation did produce a

transportation cost of \$66.23 which is 12 percent higher than the Minimize Transportation Cost model.

Equally important is the allocation of supply between Bagram and Kandahar Air Bases. Table 8 presents how the two models dispersed supply.

**Table 8: Item 1 Supply Allocation**

Item 1 Supply Allocation							
Minimize Transportation Cost				Maximize Average Fill			
Bagram AB		Kandahar AB		Bagram AB		Kandahar AB	
Kadena	25	Baltimore ANG	20	Fairchild ANG	1	Baltimore ANG	20
Madison ANG	8	Ellsworth	2	Hill	20	Ellsworth	2
Moody	9	Hill	3	Madison ANG	8	Westfield ANG	15
Tinker	6	Patrick	4	Moody	9		
Westfield ANG	11	Robins ANG	1	Patrick	4		
		Westfield ANG	7	Reno ANG	7		
				Robins ANG	1		
				Tinker	6		
				Westfield ANG	3		

As intended, the models exhausted all supply. Both model solutions had Kandahar AB filling 100 percent of the demand for Baltimore ANG, Ellsworth AFB, and Westfield ANG. Patrick AFB, Robins ANG, and Hill AFB had their demands filled by a different supply base during the respective model runs. Of significant note is the manner in which supply was exhausted; in the Minimize Transportation Cost model, Bagram AB filled demand of just five bases and then nine bases in the Maximize Average Fill model. The opposite happened for Kandahar AB, it filled six bases in the transportation cost model but only three in the average fill model. While individual and comparative inspection of the two LPs are important to ensure they are producing logical results; the model intended to deliver disposition instructions to the RMPT and USAF decision makers is the Multiple Objective model.



Without user interface, the Multiple Objective model calculates solutions automatically pulling in the needed target values from the transportation and average fill models. Table 9 presents notional disposition instructions for Item 1 including the total transportation cost, average fill and receiving bases categorized by supplier.

**Table 9: Item 1 Multiple Objective Model Optimal Solution**

Item 1 Multiple Objective Model						
Objective Function: 0.0145 (1.45%)						
Minimize Transportation Cost			Maximize Average Fill			
\$59.57 (+1.2%)			82.69 (-1.5%)			
Demand			Supply			
Base	Net Flow	Demand	Bagram AB		Kandahar AB	
Baltimore ANG	15	20	Baltimore ANG	15	Ellsworth	2
Ellsworth	2	2	Kadena	9	Fairchild ANG	1
Fairchild ANG	1	1	Madison ANG	3	Kadena	16
Kadena	25	25	Moody	9	Madison ANG	5
Madison ANG	8	8	Tinker	6	Patrick	4
Moody	9	9	Westfield ANG	17	Reno ANG	7
Patrick	4	4			Robins ANG	1
Reno ANG	7	7			Westfield ANG	1
Robins ANG	1	1				
Tinker	6	6				
Westfield ANG	18	18				

The optimal solution is not significantly different from solutions provided by the transportation cost and average fill models. The deviational variable  $Q$  was minimized to below 2 percent with the average fill variable accounting for largest deviation. The alignment of supply and demand bases stayed consistent into this model. The two bases with the highest demand and highest transportation costs Hill and Fairchild AFBs were not allocated supply; a result to be expected after inspection results in Table 7. The total transportation cost of the Multiple Objective model increased slightly (1.2 percent/ 37 cents) to \$59.57. The two supply bases saw similar results; both bases provided supply to

large and small demand bases. However, bases with larger demands consistently received no or limited supply. With the stated purpose of the Maximize Average Fill model, bases receiving no or limited supply is to expected, but drawbacks such as this are overcome with the application of the minimum fill constraint.

As discussed in Chapter 3, the recommended minimum fill level can be set and minimum fill constraint activated when USAF decision makers desire. This on/off feature allows analysis of multiple optimal solutions both with and without the constraint and with different fill values. Table 10 presents the optimal solution and disposition instructions for Item 1 with a recommended minimum fill level of three.

**Table 10: Item 1 Multiple Objective Model with Minimum Fill Constraint**

Item 1 Multiple Objective Model with Minimum Fill Constraint						
Objective Function: 0.0158 (1.58%)						
Minimize Transportation Cost			Maximize Average Fill			
\$60.79 (+1.2%)			82.24 (-1.5%)			
Demand			Supply			
Base	Net Flow	Demand	Bagram AB		Kandahar AB	
Baltimore ANG	10	20	Baltimore ANG	6	Baltimore ANG	4
Ellsworth	2	2	Ellsworth	2	Fairchild	3
Fairchild	3	27	Fairchild ANG	1	Madison ANG	8
Fairchild ANG	1	1	Hill	3	Moody	9
Hill	3	22	Kadena	25	Patrick	3
Kadena	25	25	Patrick	1	Westfield ANG	10
Madison ANG	8	8	Reno ANG	7		
Moody	9	9	Robins ANG	1		
Patrick	4	4	Tinker	6		
Reno ANG	7	7	Westfield ANG	7		
Robins ANG	1	1				
Tinker	6	6				
Westfield ANG	17	18				

A first and obvious difference between optimal solutions presented in Table 9 and Table 10 is Hill and Fairchild AFBs were allocated sufficient supply to meet the

recommended minimum fill level. The necessary supply to provide Hill and Fairchild AFBs with the recommended minimum supply amount came from Baltimore ANG (-5) and Westfield ANG (-1). A clear take away from this solution is it is far more cost effective to fill the large demand at Kadena than to fill large demands at state side bases. The total transportation cost increased again (\$1.59/2.69 percent) from the Minimize Transportation Cost model optimal solution. A marginal analysis of Item 1 Multiple Objective model solutions with recommended minimum fill levels of 5 and 7 revealed the average fill across all bases did not drop below 81 percent; Table 11 captures those results:

**Table 11: Item 1 Multiple Objective Model Minimum Fill Constraint Analysis**

<b>Item 1 Multiple Objective Model Minimum Fill Constrain Analysis</b>			
<b>Recommended Minimum Fill = 5</b>		<b>Recommended Minimum Fill = 7</b>	
Objective Function = 0.016 (1.6%)		Objective Function = 0.015 (1.5%)	
Transportation Cost	Average Fill	Transportation Cost	Average Fill
\$61.40 (+1.4%)	82.019 (-1.6%)	\$62.28 (+1.3%)	81.852 (-1.5%)

The uniform supply allocation ( $T$ ) becomes the default value for the minimum fill constraint when a decision maker recommends an integer greater than 7. At this value, Kadena is no longer allocated 100% of supply and the average fill reaches its lowest point. An inspection of the fill rates of all models presented thus far shows the Maximize Average Fill model with no minimum fill constraint as having the highest fill rate at 83.91 percent. Each subsequent model whether multiple objective or constrained by a recommended minimum fill deviates from that value. While each base is seeing an increasing amount of supply, the total transportation cost is also increasing. A recommended minimum fill level of five increases transportation cost to \$61.40 a 3.72

percent increase over the baseline cost amount. A recommended minimum fill level of seven increases that cost 5.20 percent to \$62.28. While necessary in situations determined by USAF decision makers, increasing the amount of supply each base receives increases the total transportation cost; a trade-off that must be considered.

When there is a single equipment priority, the model decision logic necessary to fill equipment demand is quite simple. As was the case for Item 1, the constraints and user-defined inputs are easily applied;. Requiring both pre-process and model constraints are pieces of equipment that have demand across multiple equipment priorities.

Presented below in Table 12 is Item 2, its demand requirements fall under two priorities.

**Table 12: Item 2 Supply and Demand Information**

<b>Filter Unit, Gas-Particulate (MBU-19/P)</b>			
<b>NSN</b>	<b>Cost</b>	<b>Dimensions (in<sup>3</sup>)</b>	<b>Weight (lbs.)</b>
4240013433443	\$644	1728.00	3.30
<b>Supply</b>			
Bagram AB:	60		
Kandahar AB:			
<b>Demand</b>			
<b>Bases</b>	<b>Priority 1</b>	<b>Priority 2</b>	<b>Priority 3</b>
Andrews		1	
Dover		2	
Grissom ARB		3	
Mildenhall	50		
Minn-St Paul ARS		4	
Nellis		15	
Pittsburgh ARS		2	
Tinker		6	
Wright Patterson		2	

Item 1 demonstrated the performance of the three models and minimum fill constraint. The constraints required to distribute Item 2 supply, while present in the models for Item 1 were not specifically impacting of the optimal solutions. For Item 2,

the function and pre-processing constraint found in Equations (15) and (16) respectively allocate supply to priority demand ( $C_k$ ) and ensure the highest priority demand is filled before optimizing the remaining supply. As shown in Table 12, Mildenhall AB has a demand of 50; for the model to function correctly, 50 of the 60 pieces of supply will flow to Mildenhall AB in each individual model and every model run.

**Table 13: Item 2 Multiple Objective Model Optimal Solution**

Item 2 Multiple Objective Model				
Objective Function: 0.0145				
Minimize Transportation Cost			Maximize Average Fill	
\$381.36			66.7%	
Demand			Supply	
Base	Net Flow	Demand	Bagram AB	
Andrews	1	1	Andrews	1
Dover	2	2	Dover	2
Grissom ARB	3	3	Grissom ARB	3
Mildenhall	50	50	Mildenhall	50
Pittsburgh ARS	2	2	Pittsburgh ARS	2
Wright Patterson	2	2	Wright Patterson	2

As expected, the Multiple Objective model allocated the necessary 50 units of supply to Mildenhall AFB. The model then optimized the remaining 10 pieces of supply to fill five demand bases to 100%; this supply alignment left three bases without any supply. The total transportation cost necessary for this disposition of is \$381.36. Given priority 1 demand ( $C_1$ ) will be filled to 100%, the uniform supply allocation ( $T$ ) will equal one.

The results of Item 2's Multiple Objective Model with minimum fill constraint activated are presented in Table 14:

**Table 14: Multiple Objective Model with Minimum Fill Constraint**

Item 2 Multiple Objective Model with Minimum Fill Constraint				
Objective Function: 6.15E-10				
Minimize Transportation Cost			Maximize Average Fill	
\$383.85			59.07%	
Demand			Supply	
Base	Net Flow	Demand	Bagram AB	
Andrews	1	1	Andrews	1
Dover	2	2	Dover	2
Grissom ARB	1	3	Grissom ARB	1
Mildenhall	50	50	Mildenhall	50
Minn-St Paul ARS	1	4	Minn-St Paul ARS	1
Nellis	1	15	Nellis	1
Pittsburgh ARS	2	2	Pittsburgh ARS	2
Tinker	1	6	Tinker	1
Wright Patterson	1	2	Wright Patterson	1

From the Multiple Objective model results in Table 13, the minimum fill constraint increased total transportation cost a negligible 0.6 percent to \$383.85. Average fill; however, was impacted significantly falling 11.4 percent from 66.7 to 59.07 percent. The model again allocated all necessary supply to priority 1 demand ( $C_1$ ), filled each individual base's requirement and optimized the remaining two pieces of supply. Item 2 provides an additional opportunity to functional check the priority fill constraint and its impact on optimal solutions.

Instances of USAF decision makers placing a limit on the maximum amount of retrograde supply do not interfere with the application of model constraints. A notional example of this is to establish a maximum amount of Item 2 at 80 percent of supply; this establishes the model optimization quantity ( $M$ ) at 48. For the model to function

correctly, applying the minimum fill constraint with a recommended minimum fill level of one should have zero effect on the model optimal solution and disposition instructions. All supply should be allocated to Mildenhall AB and its Priority 1 demand ( $C_1$ ) of 50.

**Table 15: Multiple Objective Model with Maximum Supply**

Item 2 Multiple Objective Model with Maximum Supply				
Objective Function: 0				
Minimize Transportation Cost			Maximize Average Fill	
\$292.03			96%	
Demand			Supply	
Base	Net Flow	Demand	Bagram AB	
Mildenhall	48	50	Mildenhall	48

With only one priority 1 demand base and insufficient supply to satisfy demand, the Minimize Transportation Cost, Maximize Average Fill, and Multiple Objective models each returned the same optimal solutions. As shown in Table 15 the model and constraints functioned as described, limiting the available supply to 48 and allocating it all to the only priority 1 base.

The solutions and disposition instructions presented above demonstrate the decision logic and effectiveness of the model constraints. Functionality was further tested with a user-defined input limiting supply to less than its total available quantity. Recalling Equation (3) from Chapter 3, assigning importance values to deviational variables in multiple objective models leads to differing optimal solutions. Establishing a value increasing the importance of one variable of interest over another requires the model find an optimal solution that minimizes a now larger deviational variable. Changing importance values is another user-defined input that works in-conjunction with the model constraints and other user-defined inputs.

**Table 16: Item 3 Supply and Demand Information**

<b>Wheeled Halon 1211 Fire Extinguisher (Model 600K)</b>			
<b>NSN</b>	<b>Cost</b>	<b>Dimensions (in<sup>3</sup>)</b>	<b>Weight (lbs.)</b>
4210010441429	\$914	79048	165
<b>Supply</b>			
Bagram AB:			
Kandahar AB:	42		
<b>Demand</b>			
<b>Bases</b>	<b>Priority 1</b>	<b>Priority 2</b>	<b>Priority 3</b>
Kadena	16		
Keesler	44		
Luke	138		
Peterson	25		
Ramstein	87		
Sheppard	50		

Item 3 as shown in Table 16 has a total demand of 360 units and a supply of 42 at Kandahar AB. Comparing Item 3 to the previous, it is must larger in both dimension and weight and will therefore generate significantly higher shipping costs. Further, each base demand is significant; the available supply will only completely satisfy two base demands. Combining limited supply and large base demands will logically engender very different optimal solutions between the three models. Those differing optimal solutions will be amplified when one variable of interest is considered more important than the other. Table 17 presents the optimal solutions of the Minimize Transportation Cost and Maximize Average fill models.



**Table 17: Item 3 Cost and Fill Models Optimal Solutions**

<b>Item 3 Optimal Solutions</b>					
<b>Minimize Transportation Cost</b>			<b>Maximize Average Fill</b>		
Objective Function:	\$14605.66		Objective Function:	33.71%	
Fill Rate:	21.65% (-36%)		Transportation Cost:	\$18,151.67 (+24%)	
<b>Allocation</b>			<b>Allocation</b>		
Base:	Net Flow:	Demand:	Base:	Net Flow:	Demand:
Kadena	16	16	Kadena	16	16
Ramstein	26	87	Keesler	1	44
			Peterson	25	25

As expected, the two models produced different results, though not to the level expected.

Save allocation to Kadena AB by both models (a function of low demand and low shipping costs) there are no other commonalities. The deviations in transportation cost and average fill between the two models are significant with the average fill rate of the Minimize Transportation Cost model being 35 percent less than the optimal solution of the Maximize Average Fill Mode. The transportation cost deviation between the two models is significant too at 24 percent.

The Multiple Objective model for Item 3 must derive a solution limiting the deviations from two very different optimal solutions.

**Table 18: Item 3 Multiple Objective Model Optimal Solution**

<b>Item 3 Multiple Objective Model</b>					
Objective Function: .152 (15.2%)					
<b>Minimize Transportation Cost</b>			<b>Maximize Average Fill</b>		
\$16,829.99 (+15.2%)			29.25% (-13.2%)		
<b>Demand</b>			<b>Supply</b>		
Base	Net Flow	Demand	Bagram AB		
Kadena	16	16	Kadena	16	
Peterson	16	25	Peterson	16	
Ramstein	10	87	Ramstein	10	

Outlined in Table 18 the Multiple Objective model optimal solution with equal importance values is as expected – Kadena AB, Peterson AFB, and Ramstein AB were the only three bases to receive supply. Keesler AFB is the lone base appearing in Table 17 that was not included in the multiple objective solution; however, it was originally allotted only one unit of supply in the Maximize Average Fill model. At 15.2% the MINMAX variable (*Q*) is the largest of the three items presented. Transportation cost accounted for this deviation moving from an optimal solution of \$14,605.66 to \$16,829.99.

Elevating one variable of interest over another, like previous user-defined inputs, is situation specific. There will be individual pieces of equipment, budgetary situations, and equipment allocation scenarios that drive transportation cost to be more important than average fill and still others average fill will be more important. The Multiple Objective model establishing transportation cost twice as important as average fill is presented in Table 19 below:

**Table 19: Item 3 Multiple Objective Model with Weighted Transportation Cost**

Item 3 Multiple Objective Model with Weighted Transportation Cost				
Objective Function: .217 (21.7%)				
Minimize Transportation Cost			Maximize Average Fill	
\$15995.86 (+19.0%)			26.40% (-21.7%)	
Demand			Supply	
Base	Net Flow	Demand	Bagram AB	
Kadena	16	16	Kadena	16
Peterson	10	25	Peterson	10
Ramstein	16	87	Ramstein	16

Affixing transportation cost with an importance value of two created an optimal solution similar to the original equal weight multiple objective model. The differences in supply

alignment did not affect selected bases; rather the allocation between Peterson AFB and Ramstein AB switched between the two models. Doubling the importance value of transportation cost produced a deviation of 19.0 percent; however, this is not intuitive when reviewing only the deviations. This model produced an optimal solution with transportation cost of \$15995.86, which is less than the optimal solution of \$16,829.99 found in Table 18. The original Multiple Objective model solution of \$16,829.99 deviated from the Minimize Transportation Cost model best solution by 15.2 percent. A transportation cost importance value equaling two times the importance of average fill forced the model to find a solution whose deviation when multiplied by 2 remains less than or equal the largest deviation. Weighting transportation cost lead to an optimal solution where transportation cost deviated only 9 percent from the Minimize Transportation Cost model; however, the result produced a 21.7 percent deviation from the Maximize Average Fill model.

Valuing demand bases' average fill – situations where equipment specific considerations reduce the importance of transportation cost – should produce optimal solutions exactly opposite from the previous multiple objective model. In this new case, the average fill should increase leading to an increase in transportation costs as the model looks to fill as much demand as possible irrespective of shipping costs.

**Table 20: Item 3 Multiple Objective Model with Weighted Average Fill**

Item 3 Multiple Objective Model with Weighted Average Fill				
Objective Function: .181 (18.1%)				
Minimize Transportation Cost			Maximize Average Fill	
\$17,247.05 (+18.1%)			31.0% (-18.0%)	
Demand			Supply	
Base	Net Flow	Demand	Bagram AB	
Kadena	16	16	Kadena	16
Peterson	19	25	Peterson	19
Ramstein	17	87	Ramstein	7

The increased importance placed upon average fill, like predicted, increased average fill and transportation cost. Average fill increased from both the equal weight model and weighted transportation cost models, but naturally is less than the Maximize Average Fill model. An observed deviation 9.52 percent is similar in value to the deviation of the weighted transportation cost model. Total transportation cost increased 18.1 percent to \$17,247, leaving only the Maximize Average Fill model with a higher total transportation cost. Establishing the importance of one variable of interest over another allows decision makers further opportunities to investigate alternate optimal solutions.

The equipment disposition examples above showed the functionality and utility of three user-defined inputs. Establishing the importance of one variable over another, setting a maximum amount of supply or recommended minimum fill level constitute user-defined inputs applicable to every piece of equipment and model run. However, other user inputs are applicable only to certain equipment and situations. Equipment price relative to transportation cost highlights a decision logic and set of user inputs critical to decision makers.

Further still are inputs that affect how the model runs. Table 21 captures each user-defined input and provides an explanation of its use:

**Table 21: User-Defined Inputs**

User-Defined Model Inputs	
Input Name	Input Description
Maximum Supply	Value between 0 and 1 the decision maker multiples by the amount supply returning the maximum amount of supply to be considered by the model. Used to establish an amount less than what is available i.e. retrograde capped at 75% of available supply
Recommended Minimum Fill Level	Minimum amount of supply to be allocated to each demand base. Input is nested within the minimum fill level constraint Equation (31)
Variable Prioritization	Establishes transportation cost or average fill as the variable interest in a multiple objective optimal solution. Deviation variable when multiplied by some integer must be less than or equal to the other variable's deviation
Priority 1 Transportation Cost Factor	An integer multiplied by the price of the equipment to determine whether it is cost effective to ship the item. The price of shipping between the supply and demand base pair must be less than or equal to this value or the model will not consider the base pair. If none of the base pairs is cost effective, the model will not allocate any supply
Priority 2 Transportation Cost Factor	A unique integer applied to Priority 2 equipment demand that is utilized in the same manner as Priority 1 Transportation Cost Factor
Priority 3 Transportation Cost Factor	A unique integer applied to Priority 3 equipment demand that is utilized in the same manner as the Priority 1 and 2 Transportation Cost Factors
Include Item in Analysis	Yes/No switch allowing user to select which items will have solutions and disposition instructions produced
Use Minimum Fill Constraint	Yes/No switch allowing user to decide whether or not minimum fill constraint is applied to the solutions
Model Run Time	Maximum time in seconds Excel's Solver will spend calculating model solution. If maximum time is reached model terminates calculations and moves to next model or piece of equipment

Investigate Question 2 sought to determine and highlight the effect constraints and user-defined inputs have on optimal solutions. As shown above, the Minimize Transportation Cost and Maximize Average Fill models will always provide the optimal solutions for their respective variables of interest; every subsequent model irrespective of

form will deviate from those optimal solutions. Further deviation occurs when decision makers constrain the model with user-defined inputs like maximum supply ( $g_w(A)$ ) and importance values.

Gleaning actionable information necessary for retrograde operations is the intent of this model and its solutions. Retrograde scenarios will evolve – each possibly requiring a different combination of constraints and user-inputs. Test running the model with different constraint user-input combinations allows decision makers to compare produced results and select the best option. Table 22 is a notional decision matrix the RMPT could use to compare and evaluate model results before deciding on a set of disposition instructions. Table 22 provides the results of the Minimize Transportation Cost, Maximize Average Fill, and Multiple Objective models over two different scenarios, one with no user-defined inputs and another with a recommended minimum fill level of three. The variables of analysis are transportation cost, average fill and bases receiving. Concise presentations necessitated the utilization of the following acronyms and abbreviations:

- MTC: Minimize Transportation Cost
- MAF: Maximize Average Fill
- MO: Multiple Objective
- w/Min: with Minimum Fill Level Constraint

**Table 22: Disposition Decision Matrix**

Disposition Decision Matrix							
	Item	Model					
		MTC	MAF	MO	MTC w/Min	MAF w/Min	MO w/Min
Transportation Cost	1	\$59.20	\$66.32	\$59.97	\$59.84	\$65.49	\$60.83
	2	\$381.36	\$381.36	\$381.36	\$383.85	\$384.08	\$383.85
	3	\$14,605.66	\$18,151.67	\$16,829.99	\$15,987.31	\$17516.54	\$17,099.48
Average Fill	1	70%	84%	83%	74%	84%	82%
	2	67%	67%	67%	59%	59%	59%
	3	22%	29%	29%	24%	29%	28%
Bases Receiving	1	10	11	11	13	13	13
	2	6	6	6	9	9	9
	3	3	2	3	6	6	6

The results above demonstrate the act of combining constraints and user-defined inputs provides decision makers the opportunity to, when necessary, influence optimal solutions. Acting up and implementing the information gleaned from the Disposition Decision Matrix found in Table 22 provides the genesis for Investigative Question 3.

**Investigative Question 3**

The USAF is a large organization with myriad different functions and objectives all requiring time and attention by a finite number of able decision makers. Increasing opportunities to utilize proven decision logic, management systems, tools, etc. alleviates decision makers from having to become more involved than their leadership position necessitates. The USAF retrograde process is another function requiring dynamic

management; it affects combat operations in Afghanistan, equipment levels at in-garrison bases and the USAF budget. Conducting the operations without relying upon proven CLSC concepts eliminates opportunities for the Air Force to implement concepts and efficiencies previously refined by both the civilian sector and U.S. military.

The Multiple Objective model and the solutions it provides the RMPT and other decision makers the opportunity to begin implementing supply chain concepts. Guide and Van Wassenhove (2009) state the primary focus and intent of CLSCs is receiving products from the customer or point of sale for the purpose of recovering value by reusing the entire product, some of its modules, components and parts. This is exactly the purpose of retrograde operations – retain equipment valuable to the USAF. However, merely retaining the equipment does not mean the retrograde process is successful.

Closed loop supply chains build upon the holistic philosophy of SCM, they include:

- Product retrieval from the point of sale or end-user
- RL to move the products through the SC
- Product analysis to determine the product's condition and most economically beneficial second use option. (Guide et al. 2003)

The above operations are well beyond the scope of simplistic logistics operations of equipment storage or transportation. CLSC operations require a methodology, decision logic, and tool to ensure consistency throughout the process. The Multiple Objective model with its constraints and user-defined inputs is a tool that can help the USAF utilize CLSC concepts in its Class VII equipment disposition and retrograde process.



## V. CONCLUSIONS AND RECOMMENDATIONS

### **Chapter Overview**

This chapter will provide additional fidelity on the investigative and research questions and summarize the conclusions from this research. Limitations to the research and multiple objective model will be presented and discussed. Recommendations for action and future research follow the presentation of limitations. This chapter provides closure to the research effort.

### **Conclusions of Research**

This research was initiated without specific guidance from the sponsoring office; there were no clearly defined parameters to include nor end state to which the research and resulting multiple objective model had to point. Formulation of the multiple objective model and the notional disposition instructions it produces centered on input from academic advisors and many subject matter experts. To produce original unanchored thought and research, the methodology, decision logic, and supply alignment tool currently utilized by the RMPT and USAF was specifically not referenced.

As discussed in Chapter 2, the definition and concepts both applied to and born from CLSCs apply to the USAF's Class VII equipment retrograde process. The USAF is in a position where it knows it must remove its equipment from Afghanistan. Civilian firms find themselves in similar positions knowing the end of a product's life necessitates its return to the supply chain for second-use or end of life processing. Much is required of successful a CLSC; simply taking products or equipment back from the point of use does not constitute a successfully employed or managed CLSC. Determining returning

equipment's logical destination – or as stated by Guide (2003) Guide and Van Wassenhove (2009) determining its most economically logical second use option – is critical to the USAF its operations and budget.

Over the coming months, the USAF will disposition thousands of pieces of equipment for return to in-garrison bases, transfer to other U.S. government agencies, transfer to foreign governments, or disposal. Excluding the guidance to bring every piece of equipment home or leave every piece of equipment in Afghanistan – both illogical – there is no one size fits all solution for each piece of equipment. As demonstrated in Chapter 4, the solutions produced by the model were dependent upon the piece of equipment, supply, demand and transportation cost. Including user-defined values to the model's established variables only increases the number of possible solutions and sets of disposition instructions.

The ability to produce multiple solutions is undoubtedly a benefit of the MOLP methodology and this multiple objective model. The retrograde process and its priorities will evolve and the solutions/disposition instructions produced for one moment in time might be completely illogical for another. The utilization of AFEMS and ERS in conjunction with the multiple objective model provides the Air Force with the ability to continually test run optimal solutions. Assuming AFEMS and ERS demand information is correct, the RMPT could without input or delay test scenarios for equipment still in use. From Chapter 2, CLSC's operate under three supply uncertainties: quality and composition; quantity; and timing (Krapp et al. 2013). In-country equipment manager inspections easily eliminate equipment quality and composition questions. Combining AFEMS and ERS with on-ground confirmation greatly reduces questions of equipment

quantity; some percentage of misplaced, pilfered or found equipment is to be expected. Timing remains as the variable of uncertainty; but early and continual course of action analysis can significantly reduce the effects of timing on operations. Guide et al. (2006) advocate preponment – the early determination of the condition of the resource in preparation for its eventual return to the supply chain. Acting within the framework of current strategic guidance, the USAF has the information, tool and resources necessary to initiate equipment preponement. This multiple objective model and the decision maker's ability to influence the quantities of supply and subsequent allocation provide the USAF the ability to implement CLSC concepts and methodologies.

### **Limitations**

Excel, as a platform, was the logical choice on which to base this research. The program is available on all standard operating system USAF computers allowing utilization from any workstation. For all the benefits and flexibility Excel allows, it by itself is a limitation to this research and future research. The implementation and utilization of the three models relies heavily upon Visual Basic for Applications (VBA) coding. VBA code houses the decision logic that activates constraints, applies user-defined inputs, and activates Excel's optimization software add-in Solver.

Many of the calculations performed by the three models are conditional based. For example, holding cells static for calculations leads to erroneous results e.g. calculating average fill based on all demand bases when supply is not sufficient to fill even priority 1. To overcome this and similar problems conditional logic must be employed to ensure accurate statistics are produced. However, when used in the right

side of equations (calculable portion being solved for and constrained) conditional logic such as if/then statements cause Excel based optimization problems to become non-linear. Moving from linear to non-linear optimization creates a problem significantly more difficult to solve (Chinneck 2012). The desire to keep the model and its calculations linear and therefore easier for Excel to solve necessitated the use of VBA code. With the conditional logic established in the VBA code, the model runs automatically, setting the information it needs to provide solutions for each piece of equipment. However, without a skilled VBA code writer significantly altering the models is not possible.

Excel's optimization software Solver while robust does have some significant limitations. The upper limit on decision variables (the individual allocation of supply from one supply base to one demand base) is limited to 200. When the demand bases are limited, the model can provide solutions for each piece of equipment in a matter of seconds. As the number of decision variable approaches its upper limit, the longer the model takes to solve. Further, the software limits the number of constraints to 100. Significant expansion of the model to include other variables of interest such as time, an increased number of supply bases and multiple modes requires transition from Excel to software specifically designed for optimization. It is at this point the model and the flexibility it provides in global use is lost.

Beyond software selection, the methodology is limited to the utilization of surface transportation. As discussed in Chapter 3, irrespective of planning, the exact mode and route combination used to deliver a piece of equipment from supply to demand base is uncontrollable. There are too many factors that can affect wartime logistical movement

to guarantee an exact mode and route combination. Aircraft will undoubtedly move some percentage of Class VII equipment and this model does not capture those costs.

### **Recommendations for Action**

This research centered upon a multiple objective model designed to provide disposition instructions for single pieces of equipment; therefore, besides utilizing the model, there is no one specific recommendation. The optimal solutions are unique to the piece of equipment and the decision maker establishing the user defined inputs.

Utilizing the three models for marginal and course of action analysis covering as many combinations of constraints and user-defined inputs possible provides the decision flexibility necessary for dynamic situations. Based on strategic guidance and local operations, USAF retrograde operations are and will continue to be dynamic – the USAF can ill afford to tie itself to one single solution.

In earnest the USAF should begin reviewing and planning the disposition of in-use equipment. The opportunity to select the best-conditioned equipment improves when the USAF delineates what equipment it intends to retain for retrograde. Lead-time in the decision making process is a variable whose value cannot be understated. Pre-planning retrograde operations allows the RMPT to act deliberately vice reactionary; it also eases the process of disposing or transferring unneeded equipment.

The utilization of standard operating software is a significant benefit of this model; however, the inherent flexibility contained therein can lead to program implementation problems. The utilization of AFEMS and ERS as sole source systems for supply and demand information leads to opportunities for multiple allocations of the

same equipment. The selection of disposition instructions from this model and their subsequent implementation does not automatically lead to updates of AFEMS and ERS. Because the two systems do not interface, updates to AFEMS and ERS supply and demand quantities occur upon equipment receipt and processing at demand bases. As the drawdown date approaches, the USAF will disposition and move increasing volumes of equipment. Implementing individual or organization specific disposition instructions is a danger presented by a global use decision and analysis tool. Centrally approving disposition and tracking equipment during shipment reduces the opportunity for multiple allocations of supply. The publication and coordination of multiple sets of disposition instructions will lead to suboptimal utilization of personnel and the over scheduling of transportation thereby costing the USAF both time and resources. Central management is a necessary check on flexibility and global use.

### **Recommendations for Future Research**

There is much to be gained by further research in both CLSCs and military optimization. A more robust model producing disposition instructions for multiple products simultaneously is a logical first step to advance this research. Given this model relies upon original requisition criticality codes, further research on the categorization and prioritization of retrograde military equipment is justified. Much of today's CLSC research is environment or remanufacturing focused. Warranted and useful is research delineating the differences between functional asset recovery and legislated end-of-life product recovery.

Improvements to the model itself such as the user interface and the aggregation of supply and demand information would benefit model users. Creating a more dynamic user interface that allows data input and solution receipt from one single screen would vastly increase the ease with which users employ the model.

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<b>14. ABSTRACT</b> To meet the President's established OPERATION ENDURING FREEDOM drawdown date of 31 December 2014, the United States Air Force, while continuing to conduct and support combat operations, must begin to plan disposition and execute retrograde its Class VII equipment. Calling upon concepts utilized in the management of closed-loop supply chains and optimization, this research proposes a multiple objective linear program to optimize the alignment of Bagram and Kandahar Air Base positioned equipment with in-garrison demand. Closed-loop supply chains provide planning process guidelines necessary for second use value creation and efficient reverse logistical flows. Optimization concepts provide the methodology for model development and output. The proposed multiple objective model provides solutions and equipment disposition instructions that minimize the deviations from the lowest total surface transportation cost and maximum average demand satisfaction values. To ensure compliance with Air Force guidance on equipment prioritization, cost-efficient transportation and maximum amounts of supply, multiple pre-process and model constraints limit the allocation of supply to demand bases. Combining situational specific user input values and constraints provides United States Air Force equipment managers the ability to test multiple courses of action for both real-time and future equipment movements.					
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