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Using an Intratheater Regional Hub Heuristic in Iraq

An Exploratory Case Study

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Foreword

It is my great pleasure to present another of the *Wright Flyer Papers* series. In this series, Air Command and Staff College (ACSC) recognizes and publishes our best student research projects from the prior academic year. The ACSC research program encourages our students to move beyond the school's core curriculum in their own professional development and in "advancing air and space power." The series title reflects our desire to perpetuate the pioneering spirit embodied in earlier generations of Airmen. Projects selected for publication combine solid research, innovative thought, and lucid presentation in exploring war at the operational level. With this broad perspective, the *Wright Flyer Papers* engage an eclectic range of doctrinal, technological, organizational, and operational questions. Some of these studies provide new solutions to familiar problems. Others encourage us to leave the familiar behind in pursuing new possibilities. By making these research studies available in the *Wright Flyer Papers,* ACSC hopes to encourage critical examination of the findings and to stimulate further research in these areas.

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Abstract

Ongoing casualties inflicted on convoys transgressing dangerous roads highlighted airlift's important role in intratheater logistics operations within Iraq. While airlift can help decrease the number of convoys on the roads in combat zones, the finite number of airlifters must be managed effectively and efficiently to maximize its impact in supporting operations. This research proposes using a regional hub-and-spoke heuristic to design major-theater-war channel systems. The purpose of this research is to recommend a relaxation of the airlift operations' doctrinal definition of the hub-and-spoke concept to allow for inclusion of a regional hub in-theater.

To justify this recommendation, a case study methodology is used to compare performance of the intratheater airlift channel system as it existed in Iraq in February 2004 to a model channel system created using a regional hub heuristic. The two channel systems are compared using dependent variables designed to characterize efficiency, effectiveness, and adherence to the logistics principle of simplicity. The channel system created using a regional hub heuristic is more efficient by about 8 percent and more effective by 48 percent. Comparisons of adherence to the logistics principle of simplicity are inconclusive.

Using an Intratheater Regional Hub Heuristic in Iraq

An Exploratory Case Study

In November 2004, then chief of staff of the Air Force Gen John Jumper visited Iraq. Upon his return, he told a group of Washington writers that he "had a little fit" when he ascertained the lack of efforts to use intratheater airlift assets to their full potential to reduce ground convoys into Iraq.[1] General Jumper stated that he helped create better communication between the joint force air component commander (JFACC) and the land commanders.[2] Undoubtedly, he communicated his vision of an increased USAF role in transporting materiel by air, which would decrease the number of convoys and reduce the average of 100 casualties per month suffered by convoy personnel. A month later, General Jumper gladly reported that increased airlift operations to and within Iraq had decreased the number of convoys and taken 30 people per day off Iraq's most dangerous roads.[3]

In the above example, the increase in airlift operations was a direct result of squeezing additional sorties from the already taxed C-130 Hercules fleet, as well as using the C-17 Globemaster to transport Army cargo. Additionally, the AF started flying cargo bound for Army and Marine ground units in western Iraq directly to those airfields with C-17s.[4] The question then became, why, after almost three years of Operation Iraqi Freedom (OIF), was the USAF not leveraging every possible sortie it could muster to save lives by reducing ground convoys? More importantly, is there any way to further reduce ground convoys by more efficiently or effectively using airlift? Finally, are there any "lessons learned" to improve effectiveness, efficiency, or simplicity in using intratheater air in future campaigns?

Purpose of this Research

The purpose of this research is to recommend a change to air mobility doctrine. Current airlift doctrine confines the definition of hub-and-spoke. Air Force Doctrine Document (AFDD) 2-6, *Airlift Operations*, states,

> Intertheater airland operations normally offload personnel and materiel at a main operating location within the theater. Subsequently, intratheater airlift moves designated personnel and equipment to forward operating locations, an employment concept referred to as a hub-and-spoke operation.[5]

This research recommends a relaxed doctrinal definition of hub-and-spoke operations to adopt a more inclusive definition of the concept that allows for subordinate intratheater or regional hubs.

Statement of the Problem

Since the purpose of this research is to propose a change to existing doctrine, the objective addressed herein is to provide justification for this recommendation. This research therefore accomplishes an exploratory case study methodology comparing a snapshot (February 2004) of the channel airlift system servicing Iraq to a notional channel airlift routing system constructed using a regional hub heuristic. Dependent variables were compared using objective measures of efficiency and effectiveness and a subjective analysis of simplicity. The case study analysis seeks to justify this recommendation by demonstrating that the use of the regional hub-and-spoke heuristic to design a channel airlift system resulted in a more efficient, effective, and simple system.

Research Objectives

To accomplish the overall purpose of this research and justify the recommendation to relax the airlift doctrinal definition of hub-and-spoke operations, this effort was divided into logical steps, or research objectives.

Research Objective 1. The first portion of objective 1 was to understand the nature of US Central Command's (USCENTCOM) channel airlift system, the scheduled theater airlift routing system (STARS), during the period of study. This required an exhaustive analysis and decomposition of utilization rates down to individual legs during the month of February 2004. For example, a C-130 travels from Al Udeid, Qatar, to Tallil, Iraq, to Baghdad, Iraq, to Mosul, Iraq, and then back to Al Udeid. This single day's work of four legs represents one route. This route may be flown several times a week, so one way of measuring efficiency (utilization rates) would be to sum the utilizations of all the individual legs to arrive at aggregated route utilization. This would be helpful to airlift schedulers if they were thinking about cutting or increasing the frequency of an entire route. On the other hand, if airlift schedulers were redesigning routes, they would have to assess and manipulate individual leg utilizations rather than routes. To complete research objective 1, this research decomposed STARS routes into their component legs to present the frequency and utilization of each individual leg.

The next portion of research objective 1 was to use efficiency and effectiveness measures to set the baseline for systemwide STARS performance. First, leg utilization rates were aggregated as an efficiency measure for the entire STARS. Next, queue-days were calculated for each leg according to a constant, uniform demand assumption. Finally, individual leg queue-days were summed to measure and characterize STARS effectiveness.

Research Objective 2. The second objective was to design a new STARS adhering to a regional hub-and-spoke heuristic. The first challenge in designing the new STARS was to pick a regional hub within Iraq. Several assumptions were made about the utilization data; for example, that demand was constant and uniform. If a leg were flown from Baghdad to Mosul three times a week and the average utilization rate were seven people on each flight (21 people per week), then a constant, uniform demand assumption allows the researcher to conclude that three people need to travel from Baghdad to Mosul each day. The Methodology section of this work enumerates all assumptions made to design the new STARS. Of note, this research effort designed a new STARS by trial and error. In other words, the new STARS was developed without the aid of simulation or transportation network software, just as it would be done by in-theater airlift schedulers.

Research Objective 3. The next phase of the research was to apply historical demand data to the new STARS and measure efficiency (systemwide utilization) and effectiveness (total queue-days) of the new STARS. Historical (February 2004) data was used as a predictor of future demand.

Research Objective 4. The final phase of this research compared quantitative measures of effectiveness and efficiency between the CENTCOM's February 2004 STARS (old STARS) and a STARS built using a regional hub-and-spoke heuristic while conforming to joint movement center (JMC) business rules (new STARS). Additionally, each system was compared qualitatively for adherence to the logistics principle of simplicity.

Research Questions

Given a STARS designed using a regional hub-and-spoke heuristic, three research questions were proffered:

1. Is the new hub-and-spoke STARS more efficient (higher utilization rate of C-130s) than the old STARS?
2. Is the new STARS more effective (less queue-days) than the old STARS?
3. Does the new STARS better conform to the logistics principle of simplicity than the old STARS?

Scope

The scope of this research was defined by two primary factors: duration and type of airlift. First, the data gathered for this study measures STARS utilization rates for 28 days in February 2004. This data was used primarily because it was available to the researcher. Additionally, this time period marks a stable use of one STARS system; that is, the STARS was not changed during this period. This period of time should reflect a somewhat stable period of sustainment, as it began almost a year after cessation of the maneuver combat period of OIF.

As previously noted, this research limited its analysis of effectiveness, efficiency, and simplicity to only the STARS or channel type of airlift system. This was necessary because each type of airlift (channel and demand-triggered) uses separate and distinct scheduling processes. A combined analysis of both types becomes unwieldy and beyond the time and space constraints of this research effort. However, conclusions reached in this study do put forward the possibility that a more effective, efficient, simpler channel system (STARS) may increase use of channel airlift, thus supplanting requirements for demand-triggered airlift. Given a reliable, predictable STARS, customers may be more willing to use it for high-priority cargo rather than requesting special onetime (demand-triggered) missions.

Limitations

The greatest limitations to this exploratory case study involve assumptions made to design and measure the new STARS performance. While all research assumptions are enumerated under Methodology below, one merits emphasis because it severely limits the power of any conclusions made by this research: that is the assumption that past demand data was constant and uniform and that future demand will mirror past demand.

In essence, this study tests a new regional hub heuristic STARS with the same data used to design the new STARS. Simultaneously, it handicaps the old STARS by not allowing it to improve its performance, given February's data. A more realistic comparison would entail comparing the old STARS (updated with February's data) against the hub heuristic STARS during the month of March. However, March data was not available. Next, the lack of raw data necessitated making a constant, uniform assumption about future demand. The only data available for this research was the mean monthly demand for each leg. For example, given a weekly flight between Mosul and Kirkuk, the raw data would include the utilization rate each week. Instead, the data available for this research consisted of only the average of all four weeks. Access to the raw data would facilitate building a more robust simulation model to account for variance instead of using averages.

In summary, this research demonstrated the importance of efficiently using the intratheater airlift fleet and effectively meeting transportation requirements. Intratheater airlift in Iraq keeps convoys off the roads and saves lives. The following sections provide the background necessary to understand STARS (research objective 1), present efficiency and effectiveness measures of the old STARS to complete research objective 1, illustrate the methodology used to accomplish research objectives 2 and 3 by designing and applying data to a new STARS, present the results of research objective 3, and accomplish dependent variable comparisons to accomplish research objective 4. Finally, results, future implications, and recommendations for future research are discussed.

Background

This section is a review of literature and resources necessary to understanding the research problem and methodology used to answer the research questions. Major topics focus on the hub-and-spoke background, Iraq's channel airlift system (STARS), and a discussion of each of the dependent variables (efficiency, effectiveness, and simplicity).

Hub and Spoke

Research on hub networks abounds in academia and commercial sector literature. Utilizing one or more hubs within a distribution network allows consolidation of traffic flows for many types of transportation problems. Applications for the hub-and-spoke concept include movement of people, commodities, information, and energy. Research shows that effective utilization of hubs as transshipment points allows schedulers to bundle flows and reduce indirect connections to minimize systemwide costs and better utilize finite resources.[6]

Throughout the body of hub network literature, a great deal of research has attempted to optimize transportation network designs through operations management science techniques such as modeling, simulation, and enumeration. Each new journal article on this subject uses these techniques to find optimal or "near optimal" solutions to distribution problems. Successive research efforts build on previous ones by including one more heretofore non-included variable. New and complex algorithms are tailor-made to solve specific, unique business problems. This complex field of optimizing distribution networks was best described in a 1994 research effort by two widely published professors in the field who observed that "prospects for a comprehensive model for hub-network optimization are limited at the moment."[7] Currently, there exists no off-the-shelf equation or computer software flexible enough to account for all variables used in multiple military intratheater scheduling problems.

Without software or detailed techniques to help design intratheater transportation networks, military airlift schedulers use whatever knowledge they bring to the problem, to include past experience, lessons learned by their predecessors, and airlift doctrine guidance.[8] Instead of proactively designing an intratheater airlift network with systemwide optimization goals, schedulers may add routes as demanded and later optimize or tweak them reactively according to utilization data. This reactive process entails making effectiveness and efficiency trade-offs at the individual route or leg level rather than seeking a comprehensive systemwide optimization. As previously stated, this research seeks a change to airlift doctrine to provide future intratheater airlift schedulers with a simple hub heuristic to realize more efficient and effective large intratheater network designs.

Airlift operations doctrine defines the use of hub-and-spoke operations as one type of airland employment concept. The other employment concept is direct delivery. As noted, current airlift doctrine only recognizes the hub as the point where intertheater meets intratheater. Employment of the hub-and-spoke concept as written entails cargo and passengers originating in another theater, arriving at the theater hub, and crossloading onto intratheater airlift for onward movement to forward operating locations (FOL). Conversely, the direct-delivery option would involve movement directly from another theater to the FOL, thereby bypassing the theater hub.[9]

A review of an Air Force Institute of Technology (AFIT) thesis, "Integrating C-17 Direct Delivery Airlift into Traditional Airlift Doctrine," reveals that most theater airlift networks will most likely use a mixture of hub-and-spoke and direct-delivery employment concepts.[10] Since this research effort limited its focus to the intratheater channel system servicing Iraq, direct delivery from other theaters to FOLs in Iraq was not explored.

Channel Airlift Command and Control

Describing the Iraqi channel airlift system requires an explanation of the organizational structure which produces, monitors, and executes intratheater channel airlift. This section delineates the command and control structure for STARS and the responsibilities of stakeholders.

Title 10, as amended by the Defense Reorganization Act of 1986, states, "A geographic combatant commander has directive authority over logistics within his or her area of responsibility."[11] In this case study, the commander, USCENTCOM exercised the option to stand up a joint movement center (JMC) to satisfy those responsibilities. According to Joint Publication (JP) 4-01.3, *Joint Tactics, Techniques, and Procedures for Movement Control*, the JMC is the "primary advisor to the combatant commander in the transportation apportionment process."[12] The JMC, through the combatant commander's J-4 (joint logistics office) staff, acts as single coordination point for all theater movements, regardless of medium—air, land, or sea. Within the domain of air, the JMC validates requests for airlift and sets policy regarding STARS. The JMC works in coordination with the Air Mobility Division and director of mobility forces (DIRMOBFOR) on scheduling STARS to optimize efficiency and effectiveness.

While the JMC acts as a single source for oversight of all common-user transportation assets, planned movement requirements, and movement policy, the airlift assets themselves are usually under the operational control (OPCON) of the commander, Air Force forces (COMAFFOR). In CENTCOM, the COMAFFOR has OPCON of C-130s and is dual-hatted as the JFACC. Figure 1 depicts command relationships relating to airlift. While not pictured in the figure, an air movement designator (AMD) is responsible for assisting the JMC in developing a STARS schedule, ensuring the schedule is included in the air tasking order (ATO), and acting as a focal point for collecting utilization data for each STARS route. The AMD would fit in the same place in the figure as the air mobility operations control center (AMOCC), which accomplishes essentially the same function served by the AMD. The DIRMOBFOR oversees operations and planning and coordinates between the JMC, US Transportation Command, various CENTCOM staff agencies, and the JFACC.[13]

Channel Airlift

Airlift operations in Iraq are resource constrained by the number of intratheater C-130s available to accomplish force-sustainment logistics, deployment, and redeployment operations. During the period of this study (February 2004), CENTCOM had OPCON of 64 C-130s operating from four different locations. CENTCOM C-130s were dedicated to intratheater airlift operations in that area of responsibility

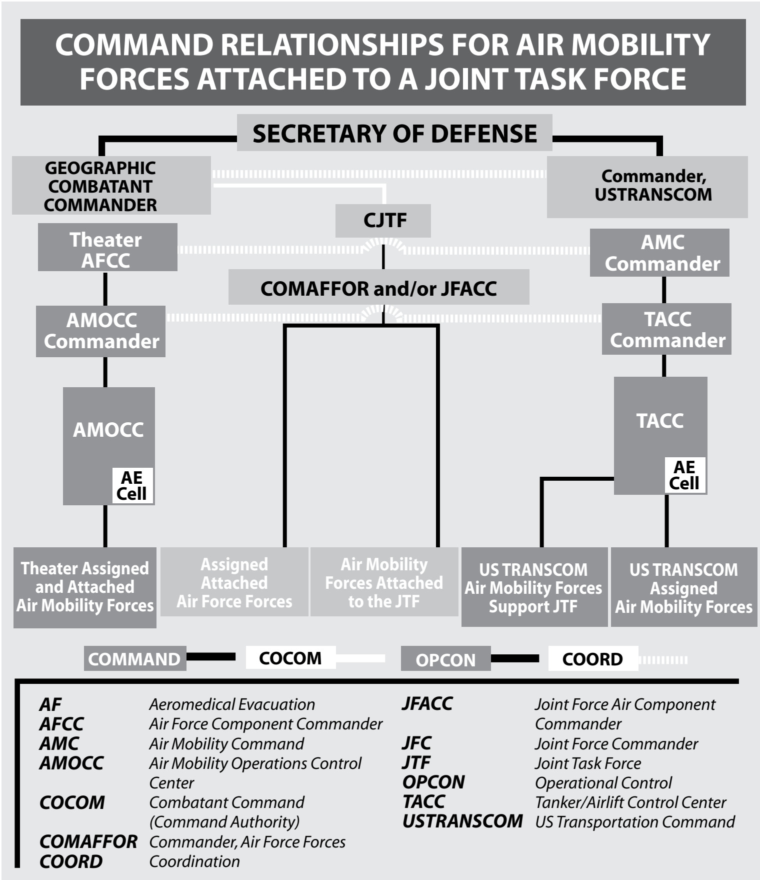

Figure 1. Notional command relationships for air mobility forces in a JTF. (Adapted from JP 3-17, *Joint Tactics, Techniques, and Procedures for Air Mobility Operations*, 14 August 2002, III-8.)

(AOR) supporting OIF in Iraq, Operation Enduring Freedom (OEF) in Afghanistan, and Horn of Africa (HOA) operations. C-130s supporting OIF were based at either Ali Al Saleem (AAS), Kuwait, or Al Udeid Air Base, Qatar.[14]

Given the sheer magnitude of logistically supporting these three separate operations, it is no wonder that intratheater airlift contributes only a small percentage of what actually moves in any given week. To illustrate, each day the US military in Iraq requires approximately 215 convoys consisting of 3,000 vehicles such as flatbed trucks, oil tankers, or heavy-equipment transports to sustain coalition forces. To put this in perspective, a C-130 can carry approximately two truckloads of cargo. This means it would take 1,500 C-130s dedicated solely to OIF operations to match surface logistics efforts there.[15]

Effectiveness. Airlift's niche in the force-sustainment mission is speed. The trade-off inherent in using airlift revolves around speed versus capacity. That is, airlift can transport high-priority items quicker than ground convoys, but the quantity of items is limited by available airlift. To reconcile this, the USCENTCOM, through the JMC, designated transportation priorities for cargo to move on airlift.[16] For instance, two supply classes, III (bulk fuel) and V (munitions), were designated low priorities for air movement. The large quantities of fuel and munitions needed for sustainment combined with the sheer bulk/weight of moving these supply classes make them a natural fit for ground convoy. Conversely, passengers and aircraft spare parts (class IX–air) were designated high priorities.

Given an accurate prioritization system, one can assume that the intratheater airlift system is moving the right things (cargo or passengers). Furthermore, it is reasonable to assume that once these high-priority items enter the airlift system, units in Iraq need them delivered as soon as possible. Therefore, airlift effectiveness as measured in this research effort deals with the ability to transport items quickly; that is, to reduce intransit and/or wait times. For example, if an Apache helicopter belonging to an attack regiment of the 101st Airborne Division in Mosul were not mission-capable for want of a part, the 101st would prefer the part travel by air from Kuwait for an in-transit/wait time of one day rather than travel four days by ground. However, if the 101st had to wait a week for a scheduled C-130 flight, the unit might choose to ground-ship the part. Thus, effectiveness emerges as the combination of waiting for transportation (queue-time) and in-transit time. Given the paucity of C-130s available to support OIF, it would seem the US military would utilize every C-130 bound for Iraq to its fullest allowable cabin load (ACL). Unfortunately, this was not the case during the period of this study, and thus the efficiency problem emerges.

Effectiveness versus Efficiency. In a letter of instruction (LOI) for intratheater airlift, CENTCOM, through the JMC, provided a "set of business rules to efficiently employ scarce airlift assets while providing a means to effectively meet the transportation needs of a variety of users throughout the AOR."[17] Throughout this LOI, CENTCOM's business rules recognized implicit trade-offs for seeking optimization of efficiency goals versus optimization of effectiveness goals. For instance, using the previous Apache part example, if a C-130 flew to Mosul loaded with only the Apache part, we can see that effectiveness from the perspective of the 101st Airborne (the war fighter) would be high while efficiency (ACL utilization) would be low. Conversely, if the C-130 were forced to wait four days until it had a full load of cargo bound for Mosul, the opposite would hold—high efficiency, low effectiveness. This omnipresent trade-off between effectiveness and efficiency is well documented by research efforts within airlift and logistics communities.

To realize better efficiency and maintain acceptable levels of effectiveness, airlift doctrine prescribes a mix of several different mission-tasking categories of airlift. The categories according to doctrine include: channel, special assignment airlift missions, special air missions, air mobility express, joint airborne/air transportability training, and exercise/contingency.[18] For the purposes of this research, these mission-tasking categories aggregate into two types of intratheater airlift—demand-triggered (onetime) and channel (recurring) airlift. To illustrate further, demand-triggered missions resemble calling a taxi, while the channel missions liken more to a regular bus schedule. The focus of this research is limited to channel-type airlift, more specifically the Iraqi STARS.

Several differences exist between demand-triggered and channel airlift. Channel airlift consists of a variety of routes, made up of one or more legs, flown on a scheduled basis to meet recurring, predictable demand on a requirements or frequency basis. Conversely, demand-triggered airlift consists of everything else—all nonrecurring transportation requirements. Demand-triggered missions may include deployments, redeployments, VIP movements, prisoners of war, aeromedical evacuations, high-visibility or backlogged cargo, and operational repositioning of troops and/or equipment.[19] At one level, each of these demand-triggered missions represents a onetime, unpredictable demand for transportation. At a higher level, even these seemingly unpredictable demands aggregate and start to represent predictable patterns of demand. As a channel system matures, it should effectively satisfy predictable demand, given a certain level of efficiency (e.g., 50 percent utilization). Finally, demand-triggered airlift complements the channel airlift system by satisfying any demand exceeding the channel system's capacity, or for assured effectiveness, call the taxi when the bus will not work.[20]

Demand-triggered missions increase system effectiveness by satisfying high-priority demand quicker than channel missions without regard to efficiency. For instance, assume a C-130 channel leg between Mosul and Kuwait that flies three times a week and averages 33 percent C-130 utilization each trip. Due to low utilization, airlift schedulers conclude this route does not meet the minimum 50 percent utilization threshold for continued service, per channel-airlift business rules. The business rules support a decision to cut the frequency of this channel leg from three times to twice per week, thereby increasing utilization (efficiency) to 50 percent. If we assume constant, uniform demand, cutting the channel-leg frequency increases queue-time for units (cargo or passengers) transported on this leg and thereby decreases effectiveness. In our example, the customers (war fighters) are not happy with the decrease in frequency, but grudgingly admit it meets their transportation needs most of the time. However, occasionally they require high-priority transportation that either exceeds the capacity of this channel leg or cannot wait days until the next service. On these occasions, they may request demand-triggered airlift through the JMC. As long as their requests meet CENTCOM's airlift request criteria, they will receive a onetime, demand-triggered air mission. This example illustrates use of channel airlift to meet a level of recurring demand at a given level of efficiency, augmented by demand-triggered airlift to achieve effectiveness.

Iraq STARS Background

Before OIF, the JMC evaluated STARS missions once or twice per month as they serviced demand for OEF. After hostilities commenced for OIF, JMC evaluated and changed STARS at least weekly.[21] As one might expect, the dynamic environment of maneuver operations led to the creation of an Iraqi STARS without the benefit of a known movement-demand history. To paraphrase one planner working in the JMC, many of the STARS built at this time were ad hoc, scheduled at the request of Army or Marine generals who were busy with immediate posthostility termination efforts. Requests for new STARS routes resulted in a schedule with 145 different STARS routes to service OEF, OIF, and HOA. As the air mobility division (AMD) schedulers assessed efficiency and cut inefficient routes, the number of STARS routes shrank from 145 in May 2003 to a total of 42 routes in February 2004.[22]

Efficiency. In October 2003 this process of tweaking to cut inefficient routes was formalized by CENTCOM's *Intratheater Airlift Letter of Instruction*. The LOI set minimum average requirements for C-130 utilization. Furthermore, the LOI provided a process whereby AMD could cut routes (with JMC approval) if they failed to meet these minimum average efficiency requirements. The only caveat to this was a "compelling minimum frequency requirement agreed to by both the JMC director and DIRMOBFOR."[23] As depicted in table 1, minimum averages equated one pallet position to 10 passengers, enabling planners to convert cargo or passengers into a common unit by multiplying pallet-equivalents by a factor of 10. Of note, JMC set two pallets or 20 passengers (20 units) as the minimum threshold utilization for STARS performance and 40 units as a utilization goal/target.[24]

Table 1. Minimum STARS route averages

Pallets or Equivalent Pallet Positions	*Passengers*	*Monthly Average to Keep STARS Route?*
2	0	Yes
1	And 10 or more	Yes
0	And 20 or more	Yes

Adapted from USCENTCOM, *Intratheater Airlift Letter of Instruction*, 15 October 2003, 9.

Both the JMC and AMD measured efficiency as a percentage of target rather than a percentage of the entire C-130 ACL. Therefore, the threshold of 20 units translates to 50 percent of target versus the actual 33 percent of C-130 ACL. Through the remainder of this paper, utilization rates are expressed as a percentage of the target rate; the reader should remember that 50 percent utilization really means 50 percent of the 66 percent target, or 33 percent of C-130 ACL. With these business rules in hand, AMD planners tweaked routes for efficiency gains from October 2003 every month leading up to the time of this research (February 2004). Efficiency gains came from cutting route frequency, changing routes, and even creating additional routes. While other efficiency measures (e.g., total air miles) are briefly discussed in the final section, this research effort used the same measure of efficiency as used by the JMC/AMD, C-130 target ACL utilization.

Simplicity. In addition to efficiency and effectiveness goals, channel airlift designs should also address ease of use by the customer. JP 4-0, *Doctrine for Logistics Support of Joint Operations*, designates simplicity as one of the principles of logistics. It states, "Simplicity reflects the need to reduce complexity and often fosters efficiency in both the planning and execution of national and theater logistics operations."[25] In other words, a channel-airlift system should adhere to the logistics principle of simplicity, at least in part because a simpler system may in turn make it easier for schedulers to make the system more efficient. Furthermore, from a war fighter's perspective, a simpler to understand and use STARS may increase the war fighter's propensity to use STARS versus demand-triggered airlift; that is, to use the bus instead of calling the taxi. Since no overarching quantitative variable exists for measuring simplicity, this research effort analyzed simplicity as a qualitative variable through subjective discussion. Final decisions as to whether the February 2004 STARS or the researcher-created new STARS was simpler are left for the reader to decide.

This section provided insight to understanding the research problem and the dependent variables presented in the research questions. Additionally it presented background information to provide a framework for understanding the STARS (research objective 1). The next section completes research objective 1 by describing the February 2004 STARS and measuring its performance against the dependent variables. It also describes the methodology used to design a new STARS (research objective 2) and measure its performance (research objective 3).

Methodology

This section revisits the research objectives and questions set forth earlier, then describes the methodology and results for research objective 1. Next, it lists the assumptions made to complete objective 2 and presents a complete methodology and results for completing that objective. Finally, it details the methodology for completing objective 3. Research objectives 3 and 4 results are presented in the next section.

Research objectives and questions are aligned with fulfilling the purpose of this research, as stated above. The overall problem emerges as whether using a regional hub-and-spoke heuristic to design a STARS results in a more efficient, effective, and simpler system, thereby justifying a less restrictive definition of the hub-and-spoke heuristic in airlift doctrine. To address this problem, four research objectives were created. Research objective 1 is to understand the old STARS. Next, research objective 2 is to design a new STARS adhering to the regional hub-and-spoke heuristic. Objective 3 tests the performance of the new STARS by applying the known demand data against the new schedule and measuring both effectiveness and efficiency. Finally, objective 4 compares results from research objectives 1 and 3 to assess effectiveness and efficiency and present a qualitative analysis of adherence to the logistics principle of simplicity.

Research Objective 1

All data and information regarding STARS routes during the month of February 2004 were provided by the AMD. At that time, the researcher was acting as the C-4 air transportation officer for Combined Joint Task Force Seven (CJTF 7) stationed at Camp Victory, Baghdad, Iraq. During that month, routes included service to five bases in Iraq. All Iraqi-bound STARS originated from either Al Udeid, Qatar, or Ali As Saleem, Kuwait. Another node serviced by the Iraq STARS was Kuwait City International Airport (KCIA), a mere 15 miles away from AAS. Al Udeid and KCIA acted as theater hubs, as the bulk of cargo and personnel supporting Iraq transited these traditional theater hubs. Once a week the Iraq STARS included service to Bahrain if cargo or passengers were awaiting transportation. If not, the C-130 on this route would overfly Bahrain on its way from Al Udeid to KCIA.

The nine bases (or nodes) included in the STARS throughout February 2004 were Baghdad, Mosul, Tallil, Kirkuk, Balad, AAS, KCIA, Al Udeid, and Bahrain. As of February 2004, nine different routes serviced these nodes. Table 2 depicts the nodes serviced (in order) by each of the different route packages. As illustrated, routes were flown a varying number of times each week, with one route operating four times per week and several routes only operating once per week. Each route represents one C-130 and crew flying each of the scheduled legs within one crew duty day. Twenty routes or 20 C-130 missions were dedicated to fly the Iraq STARS each week. For instance, referencing Day 1 of table 2, one would expect three C-130s to fly STARS routes in support of Iraq. The first C-130 (Route A) would takeoff from its base at AAS to reposition at KCIA, where it would download any personnel or cargo bound for that station and upload personnel and cargo bound for Balad (its next station). This process would repeat through Balad, KCIA, Baghdad International Airport (BIAP), KCIA, and then the C-130 would return to base at AAS.

Efficiency. To complete research objective 1, table 2 routes were decomposed into their component legs for measurement. Average leg-utilization rates were provided by the AMD. Table 3 depicts each of the legs flown by the STARS presented in table 2.

The first column of table 3 (leg frequency per week) presents the number of times each week a particular leg was flown. The second and third columns depict the origin and destination of each individual leg. The fourth column, provided by the AMD, presents the average percent of target utilization of each of the legs throughout the month of February. It was calculated by taking the actual number of units loaded on each leg and dividing by the target of 40 units. Recall that since 40 units only represents two-thirds of a C-130 ACL (60 units), then percent utilization may total more than 100 percent, as illustrated by the KCIA-to-Balad route. The fifth column was calculated by the researcher using the following formula:

40 units (percent of target) X (frequency per week) = weekly demand

Finally, the sixth column was calculated by dividing weekly demand by seven and rounding. Summing weekly demands gives the average number of units per week moved by the Iraq

Table 2. Old STARS schedule

	Route A	**Route B**	**Route C**		
Day 1	AAS KCIA Balad KCIA Baghdad KCIA AAS	Al Udeid (Bahrain) Kuwait Mosul Baghdad Balad Al Udeid	Al Udeid Tallil Balad Baghdad Al Udeid		
	Route D	**Route E**	**Route F**		
Day 2	AAS KCIA Tallil Mosul KCIA AAS	Al Udeid KCIA Mosul Kirkuk KCIA Al Udeid	Al Udeid KCIA Baghdad KCIA Al Udeid		
	Route A	**Route C**	**Route G**	**Route H**	
Day 3	AAS KCIA Balad KCIA Baghdad KCIA AAS	Al Udeid Tallil Balad Baghdad Al Udeid	Al Udeid KCIA Mosul Baghdad KCIA Al Udeid	Al Udeid KCIA Balad Kirkuk KCIA Al Udeid	
	Route D				
Day 4	AAS KCIA Tallil Mosul KCIA AAS				
	Route A	**Route C**	**Route F**	**Route H**	**Route I**
Day 5	AAS KCIA Balad KCIA Baghdad KCIA AAS	Al Udeid Tallil Balad Baghdad Al Udeid	Al Udeid KCIA Baghdad KCIA Al Udeid	Al Udeid KCIA Balad Kirkuk KCIA Al Udeid	Al Udeid KCIA Baghdad Mosul KCIA Al Udeid
	Route D	**Route E**	**Route G**		
Day 6	AAS KCIA Tallil Mosul KCIA AAS	Al Udeid KCIA Mosul Kirkuk KCIA Al Udeid	Al Udeid KCIA Mosul Baghdad KCIA Al Udeid		
	Route A				
Day 7	AAS KCIA Balad KCIA Baghdad KCIA AAS				

Table 3. February 2004 STARS leg frequencies and efficiency

Frequency Per Week	*Depart*	*Arrive*	*% of Target (40 units)*	*Weekly Demand*	*Daily Demand*
10	Al Udeid	KCIA	22.5	90	12.9
10	KCIA	Al Udeid	30.0	120	17.1
9	BIAP	KCIA	92.5	333	47.6
7	KCIA	AAS	7.5	21	3.0
7	AAS	KCIA	12.5	35	5.0
7	KCIA	BIAP	125.0	350	50.0
6	KCIA	Balad	122.5	294	42.0
5	KCIA	Mosul	105.0	210	30.0
4	Balad	KCIA	92.5	148	21.1
4	Mosul	KCIA	55.0	88	12.6
4	Kirkuk	KCIA	45.0	72	10.3
3	Tallil	Balad	47.5	57	8.1
3	Mosul	BIAP	22.5	27	3.9
3	Balad	BIAP	45.0	54	7.7
3	Tallil	Mosul	67.5	81	11.6
3	KCIA	Tallil	127.5	153	21.9
3	Al Udeid	Tallil	32.5	39	5.6
3	BIAP	Al Udeid	57.5	69	9.9
2	Mosul	Kirkuk	37.5	30	4.3
2	Balad	Kirkuk	25.0	20	2.9
1	BIAP	Mosul	87.5	35	5.0

STARS throughout the month of February 2004. This sum was 2,326 units. Recall that one pallet position or 10 passengers converts to 10 units. Therefore, Iraq's STARS moved 2,326 passengers per week or 232.6 pallet-equivalents per week, or some mixture of the two.

Due to the constant, uniform demand assumption, the efficiency for the entire February STARS was easily determined. Each "percent of target" utilization rate was multiplied by its corresponding "leg frequency per week," and then summed. This sum was divided by the total legs per week (99) to determine the overall STARS efficiency. The overall efficiency measure (percent of target utilization rate) for the February 2004 STARS was 58.74 percent; meaning that on average, any individual leg of the AMD's STARS utilized 58.74 percent of the 40-unit target. Put another way, any given C-130 carried an average of 23.5 passengers or 2.35 pallet-equivalents.

Effectiveness. Another portion of research objective 1 was to measure the effectiveness of the February 2004 STARS. Effectiveness equaled the total number of queue-days across the system in a state of equilibrium for one week. In-transit days were ignored, as all flights were completed in less than one day. Table 4 depicts the manual methodology used in this research to calculate total number of queue-days. The methodology consisted of applying the constant, uniform daily-demand rate (from table 3) to each of the legs. Given the STARS schedule presented in table 2, units of demand were either cleared (value = 0) each day or accumulated until a scheduled flight satisfied demand.

Table 4 provides a summary of effectiveness by depicting the number of units in each leg-queue by day. Columns 1, 2, and 3 should be familiar, as they mirror table 3. The units collected in each daily leg-queue represent a steady state; that is, the queue quantity measured in the second and all succeeding weeks. For instance, take the KCIA-to-Al Udeid leg (in table 4). Since no flight exists to service this leg on Day 1 (table 2), the daily-demand rate of 17.1 units (table 3) accumulates in Week 1. The model reaches equilibrium in Week 2 when the unsatisfied demand from Day 7 is added to the Day 1 demand for a total of 34.2 units awaiting transportation. Therefore, the STARS attains equilibrium in the second and all succeeding weeks.

Through-loading was allowed at the KCIA hub. In other words, unit demand to or from Al Udeid was satisfied by routes which took that demand through KCIA first. This assumption helped STARS effectiveness measures for leg-queue demand for Al Udeid to Tallil and BIAP to Al Udeid. To further illustrate, passengers/cargo bound for Tallil from Al Udeid could "deadhead" on flights from Al Udeid to Kuwait and then on to Tallil instead of waiting for direct flights from Al Udeid to Tallil. This assumption was consistent with KCIA operations as a theater hub.

Since the unsatisfied demand in each daily leg-queue was expressed in common units, the entire spreadsheet

Table 4. February 2004 STARS effectiveness

Depart	Arrive	Daily Demand	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Al Udeid	KCIA	12.9	—	—	—	12.9	—	—	12.9
KCIA	Al Udeid	17.1	34.2	—	—	17.1	—	—	17.1
BIAP	KCIA	47.6	—	—	—	47.6	—	—	—
KCIA	AAS	3.0	—	—	—	—	—	—	—
AAS	KCIA	5.0	—	—	—	—	—	—	—
KCIA	BIAP	50.0	—	—	—	50.0	—	50.0	40.0
KCIA	Balad	42.0	6.0	48.0	—	42.0	—	42.0	24.0
KCIA	Mosul	30.0	—	30.0	—	—	30.0	—	30.0
Balad	KCIA	21.1	—	21.1	—	21.1	—	21.1	—
Mosul	KCIA	12.6	25.2	—	12.6	—	—	—	12.6
Kirkuk	KCIA	10.3	20.6	—	—	10.3	—	—	10.3
Tallil	Balad	8.1	—	8.1	—	8.1	—	8.1	16.2
Mosul	BIAP	3.9	7.8	11.7	—	3.9	7.8	—	3.9
Balad	BIAP	7.7	—	7.7	—	7.7	—	7.7	15.4
Tallil	Mosul	11.6	23.2	—	11.6	—	11.6	—	11.6
KCIA	Tallil	21.9	43.8	5.7	27.6	—	21.9	—	21.9
Al Udeid	Tallil	5.6	—	—	—	5.6	—	—	5.6
BIAP	Al Udeid	9.9	—	9.9	—	9.9	—	—	9.9
Mosul	Kirkuk	4.3	4.3	—	4.3	8.6	12.9	—	4.3
Balad	Kirkuk	2.9	8.7	12.6	—	2.9	—	2.9	5.8
BIAP	Mosul	5.0	15.0	20.0	25.0	30.0	—	5.0	10.0

(table 4) was summed to arrive at a weekly expression of unsatisfied demand. This sum represents the number of passengers or pallet-equivalent (multiplied by 10) queue-days awaiting transportation; that is, the measure of effectiveness for this research. The sum for table 4 was 1,194.9 unit queue-days. Therefore, given the assumptions already made, we could expect 1,194.9 passenger queue-days or 119.49 pallet-equivalent queue-days. Another way to conceptualize this sum is to say that 100 passengers or 10 pallets awaited transportation for 11.949 days, while all other demand was satisfied within one day.

Research Objective 2

The second objective was to design a new STARS adhering to a regional hub-and-spoke heuristic. This section describes the methodology used to design the new STARS starting with several assumptions made to begin design.

Assumption 1: Constant, Uniform Demand. As previously mentioned, this assumption was necessary due to the lack of raw data; however, this assumption represents a limitation to this study. The constant portion assumes demand does not change due to the day of the week or even time of the year. The uniform portion of the assumption simplifies the calculations required to measure dependent variables but discounts the effects caused by variance in demand. Modeling the variability associated with demand would give schedulers the ability to simulate future demand against a schedule and thereby build better schedules.

Assumption 2: Future Demand Mirrors Past Demand. This acts as a simplifying assumption to complete a comparison of the two STARS. Not enough information exists to predict future STARS demand with anything other than past demand.

Assumption 3: Demand Would Transfer. This assumption was crucial to the creation of a regional hub in Iraq. This assumption means that when intra-Iraq legs were cancelled to adhere to a pure hub heuristic, there would be no change in demand. For example, when the Kirkuk-to-Mosul leg was cut, it was assumed that this leg-demand would transfer in total to the Kirkuk-to-Balad and Balad-to-Mosul legs.

Assumption 4: No Unknown Operational Limitations. This assumption encompasses all of the unknowns, which would not reveal themselves in the course of a research paper but would in practice. This includes problems with securing slot times at airfields, ability to execute the new schedule, and logistical constraints. Special care was taken to use no more C-130s per week from any one station (AAS or Al Udeid) than the February 2004 STARS. Furthermore, the new schedule stays within nautical mileage and number-of-legs limits represented by the February STARS. These limits were 1,603 nautical miles (nm) and a total of six legs for any one route.

Assumption 5: Right of Through-loading and Same-day Cross-loading at Hubs. This assumption was used to assess effectiveness of the February 2004 STARS as well. This assumption was expanded from the hub at KCIA to incorporate a regional hub within Iraq at Balad. Through-loading allows cargo/passengers to remain manifested on a C-130 as it arrives and departs a hub. Cross-loading consists of cargo/passengers deplaning at the hub and then boarding another flight, which is the reason hubs are called *hubs.* The same-day component of cross-loading simply means that cargo bound for Kirkuk can be unloaded at Balad from a C-130 which originated at KCIA and then put on a flight for Kirkuk that same day. This research effort did not complete a STARS schedule down to the hour, so this assumption acts as a simplifying assumption, which may in practice present new scheduling problems.

Assumption 6: Balad is Able to Act as a Regional Hub. As stated below in the first design step, Balad was selected as a regional hub. This assumption acted as a simplifying assumption to facilitate building the new STARS model. To actually make Balad a regional channel hub would consider many logistics issues such as throughput capacity, parking and loading constraints, availability of materiel-handling equipment, and manpower.

Design Step 1. The first step was picking a regional hub in Iraq. Balad was selected for three reasons. Both Balad and BIAP were considered due to their central location between the other Iraqi air bases and represent the first and second, respectively, greatest amount of weekly demand when compared to all other Iraqi bases. In fact, BIAP's demand (units originating from or destined for) exceeded Balad's by over 1,200 units. While BIAP could just as easily have been selected, the final decision was made due to practical considerations. In practice, Balad acts as a ground logistics hub for the Army in Iraq. This final factor led to the decision to use Balad as the hub for this study.

Design Step 2. The second step was to determine the total number of flights (legs) required to satisfy demand at each of the individual nodes. Of note, the data in table 3 was used to guide the entire new STARS design process. First, total weekly demand entering and departing each node was figured. For instance, weekly demand for Mosul totaled 336 units inbound and 145 units departing. Each of these totals was divided by the maximum C-130 ACL (60 units). Thus Mosul requires six C-130s to meet inbound demand and only three to satisfy outbound demand. Since all planes landing at Mosul must take off the same day, one can begin to see the inefficiency inherent in the imbalance between inbound and departing demands. Repeating this process for each airfield produced the minimum number of flights necessary to service each node.

Design Step 3. The third step in the design was to determine a new leg structure adhering to a pure regional hub-and-spoke heuristic. First, all non-Balad, intra-Iraq legs were eliminated. Then, daily demand from each of the eliminated legs was routed through Balad. So Mosul-to-BIAP demand would now be satisfied by two legs: first a Mosul-to-Balad leg and a same-day Balad-to-BIAP leg. This process was repeated and used to amend the number of required legs.

Design Step 4. Next, flights from KCIA and Al Udeid to each of the Iraq bases were assessed to determine if efficiencies could be gained by routing those legs through the regional hub (Balad) first. This resulted in routing KCIA-to-Mosul through Balad. Similarly, Al Udeid-to-Tallil and BIAP-to-Al Udeid demand was routed through KCIA to take advantage of through-loading at the KCIA hub. Finally, cuts were made to the Kirkuk-to-KCIA leg due to its inefficient performance and failure to meet JMC's 50 percent efficiency threshold. Inefficient positioning legs (i.e., AAS-to/from-KCIA and Al Udeid-to/from-KCIA) were not considered for cuts. These positioning legs were considered part of the cost of doing business, as they represent inefficiency caused by C-130 basing. Positioning from the C-130 base at AAS to the theater hub at KCIA was unavoidably inefficient from a utilization perspective but could not be helped unless C-130 basing was changed. Basing changes were beyond the scope of this research. The design process aimed to keep the number of legs in the new STARS (103) relatively close to the number of legs in the old STARS (99).

Design Step 5. After determining the number of required legs to service each node, the next step was to build a new weekly STARS schedule. The daily-demand rate served as a guide for spacing legs throughout the week. Route design was iteratively trial and error, using effectiveness and efficiency as feedback. The first iteration of scheduling resulted in a total of 16 missions with very high efficiency and effectiveness on par with the old STARS. This lower number of missions was expected since required legs had been figured using the full C-130 capacity (60 units). At this point, three

Table 5. New STARS schedule

	Route A				
Day 1	AAS KCIA BIAP KCIA Balad KCIA AAS				
	Route A	**Route B**	**Route C**		
Day 2	AAS KCIA BIAP KCIA Balad KCIA AAS	Al Udeid KCIA Tallil Balad KCIA Al Udeid	Al Udeid KCIA Balad Mosul KCIA Al Udeid		
	Route D	**Route E**			
Day 3	Al Udeid KCIA BIAP Balad BIAP KCIA Al Udeid	Al Udeid KCIA Balad Mosul Balad Al Udeid			
	Route A	**Route F**	**Route G**		
Day 4	AAS KCIA BIAP KCIA Balad KCIA AAS	AAS KCIA Tallil Balad Mosul KCIA AAS	Al Udeid KCIA Balad Kirkuk KCIA Al Udeid		
	Route H	**Route I**			
Day 5	Al Udeid KCIA Balad BIAP KCIA Al Udeid	Al Udeid KCIA Balad Mosul Balad Al Udeid			
	Route F	**Route I**	**Route J**		
Day 6	AAS KCIA Tallil Mosul KCIA AAS	Al Udeid KCIA Balad Mosul Balad Al Udeid	AAS KCIA BIAP KCIA BIAP KCIA AAS		
	Route F	**Route G**	**Route I**	**Route K**	**Route L**
Day 7	AAS KCIA Tallil Balad Mosul KCIA AAS	Al Udeid KCIA Balad Kirkuk KCIA Al Udeid	Al Udeid KCIA Balad Mosul Balad Al Udeid	Al Udeid KCIA BIAP Balad KCIA Al Udeid	Al Udeid Balad BIAP Balad KCIA Al Udeid

missions were added to gain effectiveness. Refer to table 5 to view the new STARS. A total of 12 routes was created, flying 19 C-130 missions (saving one C-130) and 103 legs (four more than the old STARS).

Research Objective 3 Methodology

The same methodology was used to calculate and measure efficiency and effectiveness for the new STARS as was used in objective 2 for the old STARS. The goal of objective 3 was to apply the demand data to the new STARS. This involved creating rationales according to the design assumptions as to what would happen to demand when some of the old STARS legs were cut. Table 6 details these rationales, which detail how the original demand data was applied to the new STARS legs. In sum, table 6 depicts the flow of cargo/passengers through the new STARS system, and it acted as an input to calculating new STARS efficiency and effectiveness. The next section presents efficiency and effectiveness measurements/results for the new STARS and compares these to the old STARS.

Results

This section presents the results for research objectives 3 and 4. It begins with a presentation of the efficiency of the new STARS and compares this to the old STARS. Next, it presents new STARS effectiveness results and compares those results to old STARS effectiveness. It concludes with an analysis of adherence to the principle of simplicity of both STARS.

Research Objectives 3 and 4 Results

Efficiency. As noted, calculating efficiency and effectiveness for the new STARS followed the same methodology as in research objective 1 for the old STARS. Table 7 depicts efficiency/utilization rates for both STARS legs. For legs in common to both STARS, efficiency/utilization increased for six of the new STARS legs, remained the same for three, and decreased for four. Not counting the positioning/depositioning legs, the old STARS had six underperforming (below 50 percent of target utilization) legs; the new STARS only one.

As in research objective 1, total system efficiency was calculated for the new STARS by weighting each of the leg

Table 6. Leg frequency/week comparison and demand rationale

Depart	*Arrive*	*Old frequency per week*	*New frequency per week*	*Rationale for demand/frequency changes*
Al Udeid	KCIA	10	11	Al Udeid-Tallil demand added to this leg
KCIA	Al Udeid	10	8	Added BIAP-Al Udeid demand to this leg
BIAP	KCIA	9	7	Days 1–6 BIAP-Al Udeid demand added to this leg. On day 7 BIAP-KCIA demand added to BIAP-Balad-KCIA routes
KCIA	AAS	7	7	No change
AAS	KCIA	7	7	No change
KCIA	BIAP	7	7	On day 7 KCIA-BIAP demand added KCIA-Balad-BIAP route
KCIA	Balad	6	11	KCIA-Mosul demand added to this leg
KCIA	Mosul	5	0	This leg cancelled. Demand added to KCIA-Balad and Balad-Mosul legs
Balad	KCIA	4	6	On day 7 BIAP-Al Udeid demand added to this leg
Mosul	KCIA	4	4	No change
Kirkuk	KCIA	4	2	Frequency decreased due to inefficient performance
Tallil	Balad	3	4	Tallil-Mosul demand added to this leg
Mosul	BIAP	3	0	This leg cancelled. Demand added to Mosul-Balad and Balad-BIAP legs
Balad	BIAP	3	3	Added Mosul-BIAP demand to this leg
Tallil	Mosul	3	0	This leg cancelled. Demand added to Tallil-Balad and Balad-Mosul legs
KCIA	Tallil	3	4	Al Udeid-Tallil demand added to this leg
Al Udeid	Tallil	3	0	This leg cancelled. Demand added to Al Udeid-KCIA leg
BIAP	Al Udeid	3	0	This leg cancelled. On days 2–6 demand through/cross loads on BIAP-KCIA-Al Udeid route. On day 7 demand added to BIAP-Balad-KCIA-Al Udeid route
Mosul	Kirkuk	2	0	This leg cancelled. Demand added to Mosul Balad and Balad-Kirkuk legs
Balad	Kirkuk	2	2	Mosul-Kirkuk demand added to this leg
BIAP	Mosul	1	0	This leg cancelled. Demand added to new BIAP-Balad and Balad-Mosul legs
BIAP	Balad	0	3	On day 7 added BIAP-KCIA and BIAP-Al Udeid demand. Added BIAP-Mosul demand to this new leg
Mosul	Balad	0	4	Added Mosul-Kirkuk and Mosul-BIAP demand to this new leg
Balad	Mosul	0	8	Added Tallil-Mosul, BIAP-Mosul, and KCIA-Mosul demand to this leg. Other added flights needed to balance flights out
Balad	Al Udeid	0	4	Added flights for depositioning
Al Udeid	Balad	0	1	Added flight for positioning

Table 7. Old and news STARS efficiency comparisons

Old Frequency per week	*New Frequency per week*	*Depart*	*Arrive*	*Old Daily Demand*	*Old Weekly Demand*	*New Daily Demand*	*New Weekly Demand*	*Old % of Targert*	*New % of Target*
10	11	Al Udeid	KCIA	12.9	90	18.4	129.0	22.5	29.3
10	8	KCIA	Al Udeid	17.1	120	27.0	189.0	30.0	53.0
9	7	BIAP	KCIA	47.6	333	49.3	344.8	92.5	119.6
7	7	KCIA	AAS	3.0	21	3.0	21.0	7.5	7.5
7	7	AAS	KCIA	5.0	35	5.0	35.0	12.5	12.5
7	7	KCIA	BIAP	50.0	350	42.9	300.0	125.0	107.1
6	11	KCIA	Balad	42.0	294	72.0	504.0	122.5	114.5
5	0	KCIA	Mosul	30.0	210	Route Cut		105.0	NA
4	6	Balad	KCIA	21.1	148	22.6	157.9	92.5	65.8
4	4	Mosul	KCIA	12.6	88	12.6	88.0	55.0	55.0
4	2	Kirkuk	KCIA	10.3	72	10.3	72.0	45.0	90.0
3	4	Tallil	Balad	8.1	57	19.7	138.0	47.5	86.3
3	0	Mosul	BIAP	3.9	27	Route Cut		22.5	NA
3	3	Balad	BIAP	7.7	54	11.6	81.0	45.0	67.5
3	0	Tallil	Mosul	11.6	81	Route Cut		67.5	NA
3	4	KCIA	Tallil	21.9	153	27.4	192.0	127.5	120.0
3	0	Al Udeid	Tallil	5.6	39	Route Cut		32.5	NA
3	0	BIAP	Al Udeid	9.9	69	Route Cut		57.5	NA
2	0	Mosul	Kirkuk	4.3	30	Route Cut		37.5	NA
2	2	Balad	Kirkuk	2.9	20	7.1	50.0	25.0	62.5
1	0	BIAP	Mosul	5.0	35	Route Cut		87.5	NA
0	3	BIAP	Balad	New Route		14.6	102.4	NA	85.3
0	4	Mosul	Balad	New Route		8.1	57.0	NA	35.6
0	8	Balad	Mosul	New Route		46.6	326.0	NA	101.9
0	4	Balad	Al Udeid	New Route Positioning		0.0	0	NA	0.0
0	1	Al Udeid	Balad	New Route Depositioning		0.0	0	NA	0.0

percent utilizations (multiplying by frequency) and then summing these. The sum was divided by total number of legs (103) to determine the system percentage of target utilization. The overall efficiency measure (percentage of target utilization rate) for the new STARS was 66.93 percent. This was 8.19 percent more efficient than the old STARS' 58.74 percent utilization rate. Additionally, the new STARS makes better use of the crew duty day by adding four legs to the total STARS, while simultaneously cutting one aircraft mission for a total of 19 missions versus the 20 routes flown by the old STARS. To further ensure validity, flight mileage for both STARS was compared; all distances were calculated using the baseops.net flight calculator. Execution of the new STARS entails flying a total of 25,816 nm versus the old STARS' 26,915 nm. Additionally, the longest route executed in the new STARS was 1,590 nm compared to 1,603 nm in the old STARS. There was only a 13 nm difference in average route length between the old STARS (1,346 nm) and the new STARS (1,359 nm).

Effectiveness. Effectiveness or total queue-days for the new STARS was calculated following the same methodology used to calculate effectiveness for the old STARS in research objective 1, Table 8 depicts the spreadsheet used to calculate unit queue-days for each leg. The new STARS schedule (table 5) was used in conjunction with the new projected daily-demand rates to manually calculate the queue-days for each grid in table 8. Again, demand was either cleared each day or accumulated, according to the new STARS schedule. Through- and cross-loading were allowed through the hubs (Al Udeid, KCIA, and now Balad). The new STARS reached equilibrium (steady state) in the first week, as all demand was cleared on Day 7. Unit queue-days were summed for the entire system. The sum of queue-days for new STARS in table 8 was 622.9 unit queue-days compared to the old STARS' 1,194.9. This represents a 48 percent reduction in unit queue-days. To conceptualize this, recall that 2,326 units traveled per week in the old STARS. If these were passengers, the effectiveness measure means that passengers using the new STARS would travel on the day they wanted to travel 73 percent of the time, thus waiting a day only 27 percent of the time. Comparatively, passengers would wait for transportation 51 percent of the time in the old STARS and only travel on the day they wanted to travel 49 percent of the time.

Simplicity. Research question 3 asked which STARS adheres more to the logistics principle of simplicity. Since no quantitative, definitive answer to this question exists, the question merits a simple qualitative comparison of the two STARS. As alluded to earlier, a simple STARS design is easier to use and execute and could result in increased use as the war fighter becomes more apt to take the bus than call a taxi. STARS simplicity (or lack of it) derives from the schedule and ultimately the heuristics behind the schedule.

If one simply compares the two schedules from tables 2 and 5, the new STARS appears just as complicated, if

Table 8. New STARS effectiveness

Depart	*Arrive*	*Daily Demand*	*Day 1*	*Day 2*	*Day 3*	*Day 4*	*Day 5*	*Day 6*	*Day 7*
Al Udeid	KCIA	18.4	18.4	—	—	—	—	18.4	—
KCIA	Al Udeid	27.0	27.0	—	—	—	—	27.0	—
BIAP	KCIA	49.3	—	—	—	—	—	—	—
KCIA	AAS	3.0	—	—	3.0	—	3.0	—	—
AAS	KCIA	5.0	—	—	3.0	—	3.0	—	—
KCIA	BIAP	42.9	—	—	—	—	—	—	—
KCIA	Balad	72.0	12.0	—	12.0	—	—	12.0	—
Balad	KCIA	22.6	—	—	22.6	—	22.6	45.2	—
Mosul	KCIA	12.6	12.6	—	12.6	—	12.6	—	—
Kirkuk	KCIA	10.3	10.3	20.6	30.9	—	10.3	20.6	—
Tallil	Balad	19.7	19.7	—	19.7	—	19.7	—	—
Balad	BIAP	11.6	11.6	23.2	—	11.6	—	11.6	—
KCIA	Tallil	27.4	27.4	—	27.4	—	27.4	—	—
Balad	Kirkuk	7.1	7.1	14.2	21.3	—	7.1	14.2	—
BIAP	Balad	14.6	14.6	29.2	—	14.6	29.2	43.8	—
Mosul	Balad	8.1	8.1	16.2	—	8.1	—	—	—
Balad	Mosul	46.6	46.6	33.2	19.8	6.4	—	—	—
Balad	Al Udeid	0.0	—	—	—	—	—	—	—
Al Udeid	Balad	0.0	—	—	—	—	—	—	—

not more so, than the old one. The new STARS uses more routes (11) than the old STARS (nine). Furthermore, if one looks at the schedules from the perspective of a passenger trying to get from point A to point B, both schedules appear complicated. However, armed with the knowledge of which locations act as hubs, thus allowing through-loading and cross-loading, passengers can quickly form a plan to get to their destination.

Seeing the schedule through an educated passenger's eyes demonstrates the flexibility and effectiveness of the new STARS over the old one. For example, a passenger needing to fly from Baghdad to Mosul could travel direct on the old STARS only on Day 6. If the passenger knew that KCIA and Al Udeid acted as hubs, the passenger could fly to the KCIA hub on any day except Day 4 and then travel from KCIA to Mosul on Days 2, 5, and 7. Under the new STARS, the same passenger could not travel direct; however, given the knowledge of the existence of hubs, the passenger could travel direct to Balad on Days 2 and 7 then on to Mosul; or to KCIA on any day except Day 7; KCIA to Balad on Days 2, 4, 5, and 7; and finally from Balad to Mosul on any day except Day 1. While not overtly simpler, the key to simplifying passengers' travel plans is to educate them on the existence of the hubs. Air transportation experts making passengers' reservations can advise them on the hubs and reserve the connections.

While the new STARS schedule may not appear overtly simpler, especially to passengers attempting to travel between Iraqi locations, the heuristic of a regional hub in Iraq creates a simpler cognitive map for those charged with executing STARS as a network. Figures 2 and 3 below illustrate the legs in the old and new STARS. Arrows indicate direction of travel; in many cases legs were one-way. The simplicity manifested by creating a Balad hub in the new STARS allows transportation personnel to adopt a transport strategy of "get it to Balad."

A qualitative assessment of the transportation networks illustrated by figures 2 and 3 reveals the new STARS as a simpler design. However, due to the complexity of the new STARS schedule, this research effort stops short of defini-

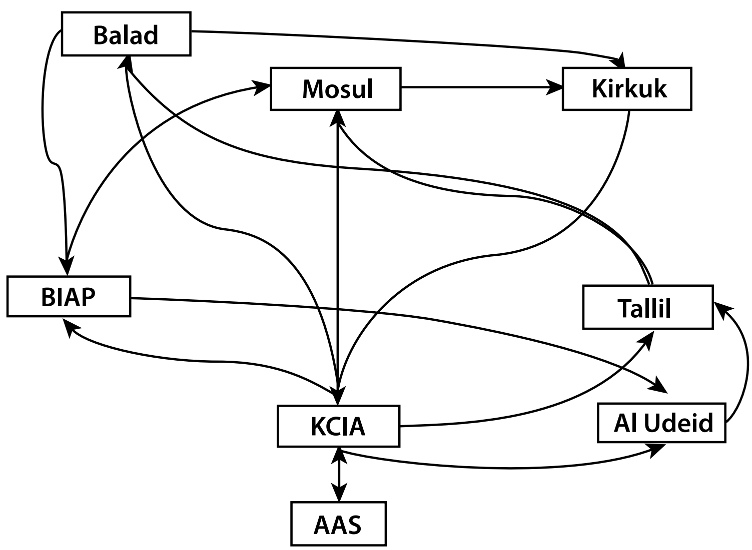

Figure 2. Old STARS

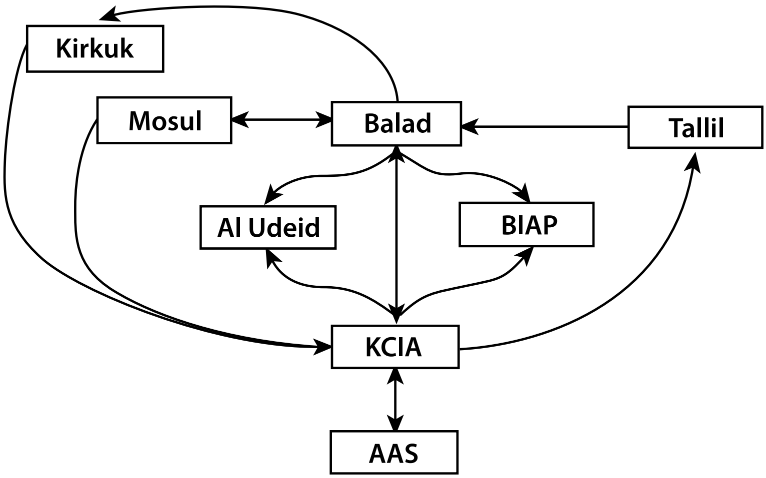

Figure 3. New STARS

tively stating which STARS more closely adheres to the logistics principle of simplicity. Therefore, the qualitative results for research question 3 were inconclusive. Instead, the research aims to put the question to the reader. As a passenger, a unit trying to ship cargo, a transportation specialist routing cargo throughout Iraq, or an AMD scheduler responsible for making monthly improvements to the STARS, which STARS design is preferable?

Summary

This section began by presenting utilization rates (efficiency) and total unit queue-days (effectiveness) as measured after applying historical demand data to the new STARS, which was designed using a regional-hub heuristic at Balad. Results revealed the new STARS as more efficient and significantly more effective than the old STARS. Next, it presented a qualitative analysis of both STARS' adherence to the logistics principle of simplicity. Results were inconclusive. Instead, the simplicity analysis presented adequate information to allow the reader to decide subjectively which STARS was simpler. The final section discusses the implications of these findings in relation to the purpose of this research and future efforts.

Conclusion

This section first discusses the implications of the results presented above. The individual research questions are restated and answered, the results adequately justify the recommendation to relax the USAF doctrinal definition of the hub-and-spoke concept to allow for the possibility of intratheater regional hubs, and recommendations are made to help guide future research.

Implications of Results

Due in large part to the limitations mentioned earlier, this exploratory case study falls well short of definitively proving that using a regional hub heuristic will always result in a more efficient, effective, and simpler channel-airlift system. Notwithstanding these limitations, caused by the constant/uniform demand assumption, the results for this individual case study present a compelling case for at least further exploring utilization of a regional hub for the STARS in Iraq. To illustrate this, revisit the research questions.

1. Is the hub-and-spoke (new) STARS more efficient (higher utilization rate of C-130s) than the old STARS?
2. Is the new STARS more effective (less queue-days) than the old STARS?
3. Does the new STARS better conform to the logistics principle of simplicity than the old STARS?

Within this case study, the answers to research questions 1 and 2 were yes, the STARS employing the hub heuristic was more efficient and more effective. Results from research question 3 were inconclusive—that is to say, picking the STARS which more closely conforms to the logistics principle of simplicity was subjective. Determining which STARS was simpler depends on the perspective of the person making the judgment. While an airlift scheduler might be inclined to think the new STARS was simpler, a potential STARS passenger desiring to travel to and from locations within Iraq might deem the old STARS schedule to be simpler. This passenger would notice that seven direct routes were cut in the new STARS schedule thereby necessitating additional travel through Balad.

Given the results of this case study, airlift schedulers would be remiss if they did not further explore the possible benefits of incorporating a hub heuristic into their STARS design. Furthermore, USAF doctrine should change to allow employing an intratheater, regional hub to sustain major regional conflicts like OIF. The doctrine should state that during major theater operations, if several forward operating locations exist within a geographical region separated by some distance from the theater hub, then schedulers should consider employing a subordinate regional hub for hub-and-spoke operations.

Although the power of the results presented in this case study was limited by the validity of the data, the research indicates a potential for STARS designs using a regional hub heuristic to result in gains in both effectiveness and efficiency. If an improved STARS design results in C-130 mission savings, as was the case for the new STARS, then those saved C-130 missions could help reduce ground convoys in Iraq and, according to General Jumper, save lives.

Recommendations to Future Researchers

Several topics emerged during the course of this research which beg for follow-on research. The first of these deals with overcoming the limitations inherent in the assumption of constant, uniform demand data. Secondly, review of similar industry regional-hub case studies reveals opportunities in repositioning resources (C-130s) and using optimization techniques to develop a process for determining the optimal location for a regional hub. Finally, the research process revealed a need to standardize and automate processes for schedule design and upkeep of an intratheater channel system.

Overcoming Limitations. A disciplined collection of STARS demand data would allow researchers to model STARS demand and run simulations to compare STARS design methodologies. Repeated simulations would lend validity to comparing STARS performance results. If demand were accurately modeled by individual leg distributions, researchers could simulate repeated runs of a STARS to accomplish sensitivity analysis on dependent variables like utilization (efficiency) and queue-time (effectiveness). Ideally, a simulation construct could be created to allow AMD schedulers to simply input data and test various iterations of proposed STARS schedules.

C-130 Basing and Hub Location. The second topic for future research entails more fully exploring opportunities to optimize resource (aircraft) and hub locations. Future researchers should explore effects on effectiveness and efficiency-dependent variables by manipulating independent variables: C-130 basing and hub location. For example, imagine the possible increases to effectiveness measures in this case study had several C-130s been stationed at Balad. This would have allowed more legs per mission within the Iraqi region, possibly increasing effectiveness, given the reduction in mileage. Coincidentally, near the end of the research process for this case study, CENTCOM changed C-130 basing; eight C-130s were based at Balad, Iraq. The CENTAF commander, Lt Gen Walter Buchanan, in a February 2006 interview, commented that due to the C-130 moves to Balad that it has become a "true hub and spoke system."[26] The new STARS schedule incorporating the new basing of C-130s at Balad was not available to include in this research. While it is likely that the new schedule does not follow a pure hub heuristic in Iraq (i.e., no intra-Iraq flights unless routed through Balad), putting C-130s at Balad combined with General Buchanan's comments lends credibility to the recommendation to relax airlift doctrine to allow for regional hubs.[27] Additionally, while this case study walked the reader through a decision process for picking the hub location (Balad) for the new STARS design, future research could formalize and improve on the decision process presented here.

Standardize and Automate STARS Design. Conversations with AMD and JMC personnel revealed a need to standardize STARS scheduling techniques and the benefits of developing software to make the airlift scheduler's task easier. While industry equivalents use proprietary management information systems to optimize transportation routing, the USAF lacks a system to perform intratheater channel airlift scheduling. Investment in research and development of such a system could allow the USAF to realize a return on investment if that system improved utilization and effectiveness of intratheater channel airlift systems in the future.

Summary

This exploratory case study fulfilled its purpose of testing the performance of a channel system designed with a regional hub heuristic to justify a recommendation for a change to airlift doctrine. The new STARS, designed using Balad as a regional hub, outperformed the old STARS in efficiency and effectiveness measures while simplicity results were inconclusive. However, assumptions made about the data used to compare STARS performance dilutes the validity of the results and detracts from the power of the conclusions. More research is required to improve validity of future STARS comparisons. This paper therefore made recommendations for future research to explore hub and resource location strategies, as well as standardizing scheduling processes through automation.

Notes

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2. Ibid.

3. TSgt Don Nelson, "Increased C-130, C-17 Flights Relieve Army Ground Convoys," *Air Force Print News*, 15 December 2004.

4. Ibid.

5. AFDD 2-6, *Air Mobility Operations*, 25 June 1999, 39.

6. M. E. O'Kelly and H. J. Miller, "The Hub Network Design Problem," *Journal of Transport Geography* 2, no.1, 1994: 31.

7. Ibid.

8. Maj Keith Justice (JMC air transportation officer, November 2003–April 2004), telephone and e-mail interviews by author, February–March 2006.

9. AFDD 2-6.1, *Airlift Operations*, 13 November 1999, 15–17.

10. Maj Creighton W. Cook, "Integrating C-17 Direct Delivery Airlift into Traditional Air Force Doctrine" (master's thesis, AFIT, Wright-Patterson AFB, OH, June 1998), 1–10.

11. JP 4-01.3, *Joint Tactics, Techniques, and Procedures for Movement Control*, 9 April 2002, 1-3.

12. Ibid., 3-1.

13. Ibid., 3-1–2; and JP 3-17, *Joint Tactics, Techniques, and Procedures for Air Mobility Operations*, 14 August 2002, 3.

14. Justice, interviews.

15. Tom Squitieri, "Air Force Boosts Number of Supply Flights," *USA Today*, 14 December 2004.

16. USCENTCOM, *Intratheater Airlift Letter of Instruction*, 15 October 2003.

17. Ibid.

18. AFDD 2-6, *Airlift Operations*, 25 June 1999, 19.

19. Ibid., 19–23.

20. USCENTCOM, *Letter of Instruction*; and JP 4-01.3, *Joint Tactics, Techniques, and Procedures*.

21. Maj Mark A. Brown, "The Joint Movement Center: Manager of Iraqi Freedom Theater Airlift" (masters thesis, AFIT, Wright-Patterson AFB, OH, May 2004), 60.

22. Justice, interviews; and information provided by Air Mobility Division personnel while the researcher was in-theater.

23. USCENTCOM, *Letter of Instruction*, 9.

24. Ibid.

25. JP 4-0, *Doctrine for Logistic Support of Joint Operations*, 6 April 2000, 2-1–2.

26. Bruce Rolfsen, "Demobilizations Spur War-Zone C-130 Reductions," *Air Force Times*, 6 March 2006, 18.

27. Bruce Rolfsen, "Numbers Soar for Close-air Sorties, Airlifts," *Air Force Times*, 3 April 2006, 12.

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