DOCUMENTED BRIEFING

RAND

Should C-17s Be Used to Carry In-Theater Cargo During Major Deployments?

Paul S. Killingsworth, Laura Melody

Project AIR FORCE
National Defense Research Institute

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Prepared for the
United States Air Force
Office of the Secretary of Defense

Project AIR FORCE
National Defense Research Institute

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PREFACE

In 1995, RAND was asked to support a study, called the C-17 Tactical Utility Analysis, to examine possible roles for the C-17 as an in-theater airlifter. The study, conducted by the Office of the Secretary of Defense, Program Analysis and Evaluation (OSD[PA&E]), with the support of the Services, found a need for up to a squadron of C-17s operating in-theater during major regional contingencies. The work described in this Documented Briefing used the same assumptions as those in the Tactical Utility Analysis, but a different analytic approach, thereby helping to validate the findings. RAND had two objectives in its support of the TUA: one to estimate the capacity of airfields to support air mobility operations and the other to evaluate possible concepts of operation for in-theater C-17 operations. The first objective is addressed in James P. Stucker, Ruth T. Berg, et al., *Understanding Airfield Capacity for Airlift Operations*, Santa Monica, CA: RAND, MR-700-AF/OSD (forthcoming). This Documented Briefing addresses the second objective.

This work was jointly sponsored by the Projection Forces Division, OSD(PA&E), and the Mobility Forces Division, Headquarters, Air Force (HQ AF/XOFM). Within RAND, the work was performed under the auspices of the Forces and Resources Policy Center of the National Defense Research Institute (NDRI), and the Resource Management and System Acquisition Program of Project AIR FORCE. NDRI is a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, and the defense agencies. Project AIR FORCE is a federally funded research and development center sponsored by the United States Air Force.

The study results should be of interest to those involved in the analysis and employment of in-theater and strategic mobility forces.

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SUMMARY

Past analyses of the roles and missions of the C-17 have centered chiefly on its effectiveness in moving military equipment over intercontinental distances, i.e., as a strategic airlifter. In contrast, the C-17 Tactical Utility Analysis (TUA) provided an in-theater perspective on C-17 operations. RAND had two objectives in its support of the TUA: one to estimate the capacity of airfields to support air mobility operations and the other to evaluate possible concepts of operation for in-theater C-17 operations. The first objective is addressed in James P. Stucker, Ruth T. Berg, et al., *Understanding Airfield Capacity for Airlift Operations*, Santa Monica, CA: RAND, MR-700-AF/OSD (forthcoming). This Documented Briefing addresses the second objective.

To understand how and why C-17s might be used as theater airlifters, we applied a large-scale linear optimization model of the air mobility system, a model called CONOP, which had been under development for two years. CONOP models the routes, bases, aerial-refueling points (not used in this analysis), cargo types, and delivery timelines of actual military deployment operations. The model chooses the routes and aircraft needed to achieve a targeted schedule for delivering cargo and passengers to an overseas theater of operations, and identifies all bottlenecks to the flow. In addition to accounting for such aspects of the air mobility system as aerial-refueling operations and crew staging, the model can also represent tactical airlifts by transshipping cargo at aerial ports of debarkation (APODs) for further movement to forward operating bases (FOBs) within a theater of operations. This unique capability enables the model to address both the strategic and in-theater (so-called tactical) air movement requirements simultaneously. For this analysis, we allowed CONOP to select the mixes of C-130s and C-17s to most efficiently deliver the in-theater cargo, while also requiring that the strategic cargo be efficiently

delivered. This combination identified the best C-17 roles, since the airplane has capabilities in both the strategic and in-theater modes.

The scenario used for the analysis was the two nearly simultaneous major regional conflicts (MRCs) described by the Defense Planning Guidance.[1] The first conflict, MRC-West, takes place on the Korean peninsula. The second, MRC-East, follows MRC-West and takes place in Southwest Asia, on the Arabian peninsula. The air cargo movement requirements to support this scenario were the same as those used in other portions of the Tactical Utility Analysis. We did not analyze alternative in-theater transportation modes, such as line-haul by truck.[2] Our results are affected by the quantity and mix of cargo identified for in-theater movement by air, as our sensitivity analyses of these factors demonstrate.

For the two-MRC scenario, massive amounts of cargo and passengers must be transported strategically, from the continental United States (CONUS), European, and Pacific aerial ports of embarkation (APOEs) to APODs in each theater. In addition, cargo must be transshipped at APODs and transported to FOBs. For the movement of in-theater cargo, the model would deploy C-130s and C-17s to the theater to fly shuttles from the APODs to FOBs. In most cases, we assumed that these deployments of aircraft would remain unchanged throughout each contingency. We also required that in-theater movement requirements be met on time, but we allowed the strategic cargo to lag by up to a week, assuming that the in-theater deliveries would be more important for ongoing military operations. Generally, we closely matched the assumptions and requirements of the broader Tactical Utility Analysis.

After establishing the requirements and setting up the scenarios in CONOP, we examined how the need for the C-17 in theater operations changed as we varied several parameters:

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[1]The Defense Planning Guidance is the Secretary of Defense's guidance to the Services and defense agencies for the development of their budgets. See U.S. Department of Defense, Secretary of Defense, *DoD Instruction 7045.7*, Washington, D.C., May 24, 1994.

[2]Additional transportation modes should be considered in future analyses.

- Amount of outsized cargo[3]
- Allowable lateness[4]
- Capacity of beddown bases
- Total number of C-17s available.

We started from the same set of baseline values in each case. The baseline in-theater outsized cargo movement requirements were about 17,000 short tons for MRC-West and 9,500 short tons for MRC-East over a 120-day period. We varied the allowable lateness in a range from a baseline of "on time" to five days late. The baseline capacity of the in-theater beddown bases was derived from the maximum numbers of C-130s that were assumed to be available in each theater for the Tactical Utility Analysis.[5] Finally, the number of available C-17s was varied from 40 to 120, and 86 was used as the baseline (86 C-17s was the "middle" case for the TUA). The number of C-130s and C-17s the model would deploy to each theater for the baseline values of the parameters are shown below:

	MRC-West	**MRC-East**
C-130s	**102**	**166**
C-17s	**13**	**10**

[3]*Outsized cargo* generally requires either a C-5 or C-17 aircraft to be moved by air. Examples are helicopters and M-1 tanks.

[4]*Allowable lateness* is the amount the model could slip the delivery in order to reduce overall lift requirements. Past that point, if the cargo was not delivered, the model would stop trying to deliver it.

[5]The ability of a theater to accommodate, or bed down, the aircraft and crews is always severely constrained. Beddown capacity for the C-130 was an input to the analysis from the sponsor's work on TUA. Since we were trading off the C-17 against the C-130, it made sense to use that constraint for the C-17s as well. We assumed a 1.5:1 parking-space ratio of C-17s to C-130s.

At the baseline, approximately a squadron of C-17s is recommended for theater operations. Although these numbers varied according to the values given to the parameters we investigated, some level of C-17 presence in-theater is usually indicated. However, whenever the opportunity existed to deliver a requirement directly from a CONUS APOE to an FOB, this concept--direct delivery by C-17s--was usually the preferred option. Direct delivery avoids the necessity both to deploy airlifters to the theater and to transship cargo. Nevertheless, in a major conflict, short-notice requirements would most often be met with in-theater transportation assets. As did the TUA, we assumed that most theater cargo movements would originate within the theater itself, limiting the opportunities to employ direct delivery.[6]

The need for C-17s in-theater is sensitive to the requirement to move outsized cargo, but this requirement does not dictate the entire need for the aircraft.[7] Even when there is no outsized cargo at all, the model still preferred dedicating a few C-17s to perform in-theater shuttles. Specifically, with no outsized cargo to haul, the model deployed nine C-17s for MRC-West and seven for MRC-East, because of the total amount of cargo of all types that needed delivery, as well as the demanding timelines for its delivery.

Similarly, the total cargo requirement, combined with the outsized requirement, still pointed toward a C-17 presence as we relaxed the on-time requirement to an allowable five days late: four C-17s were still used in MRC-West, and nine in MRC-East.

The C-17 is especially effective when beddown-base capacity is limited, as is often the case in contingencies. The mix of deployed C-17s and C-130s

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[6]Direct delivery is given short shrift in our analysis because we assumed that most theater cargo originates within the theater, as prepositioned equipment and supplies. Cargo in the Time-Phased Force and Deployment Database (TPFDD) for delivery from an APOE to an FOB probably would be direct-delivered.

[7]Although outsized cargo, as exemplified by the M-1 Main Battle Tank, can be carried on either C-5 or C-17 aircraft, we allowed only the C-17 to carry this type of cargo for in-theater operations.

increasingly favors the C-17 as beddown capacity becomes more constrained, because the C-17 makes the best use of limited parking space per ton of cargo delivered. In MRC-West the number of deployed C-17s increased to 24 when beddown capacity was cut in half, and for MRC-East the number increased to 15.

The number of C-17s the model would deploy to meet in-theater demand was not particularly sensitive to the total number of C-17s that we assumed were available. As we varied the number of C-17s from 40 to 120, the numbers deployed to the theater dropped only at the lowest availability, or 40 C-17s: to six for MRC-West and to four for MRC-East. Evidently, in-theater operation of this aircraft is a preferred role, especially if priority is placed on the in-theater movement requirements.

Finally, we examined two alternatives to the deployment of C-17s to the theater for the entire duration of a contingency. In the first alternative, the "stratshuttle" concept, C-17s flying strategic cargo into APODs would perform one day of in-theater shuttles before returning to the strategic flow. We investigated this concept by varying its efficiency relative to that of deployed C-17s. Our analysis showed that stratshuttles could be quite effective in decreasing the number of C-17s permanently assigned to the theater, particularly for MRC-East. The second alternative, the "extended shuttle" concept, relied on civil-derived airlifters to deliver bulk and oversized cargo to large, high-capacity bases somewhere near the theater of operation, and transshipping to C-17s for further movement to the theater. The delay for the transshipment operation made this concept relatively inefficient. Only as the in-theater capacity to accommodate airlifters became extremely constrained did the model tend to shift to this concept.

In general, our analysis supports a robust role for C-17s operating in-theater during major regional contingencies, as much as a squadron of about 12 aircraft in each theater. The number of deployed aircraft probably could be reduced substantially using concepts of operation such as the "stratshuttle." A limitation of the analysis is its use of fixed air-

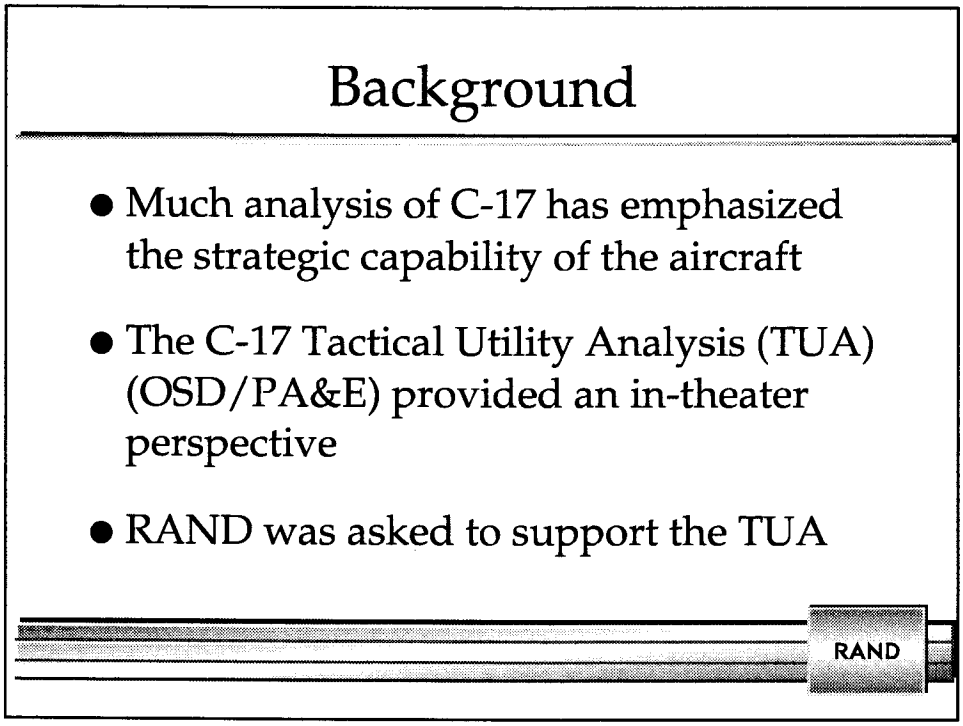
movement requirements and in-theater requirements that were insensitive to the availability of alternative transportation modes. The addition of such alternatives as line-haul by truck would be a worthwhile direction to take in future research. Even so, our results suggest that the Air Force should plan for a substantial level of C-17 operations in-theater during major regional contingencies.

ABBREVIATIONS AND ACRONYMS

AB	Air base
AC	Aircraft
ACE	Airfield Capacity Estimator
AFB	Air Force Base
APOE	Aerial port of embarkation
APOD	Aerial port of debarkation
AR	Aerial refueling
ARP	Aerial-refueling point
C-Day	Delivery day
CHOP	Change of operational control
CONOP	Concept of Operation model
CONUS	Continental United States
FOB	Forward operating base
MHE	Materiel-handling equipment
MIDAS	Model for Intertheater Deployment by Air and Sea
MOG	Maximum [number of aircraft] on the ground
MRC	Major regional conflict
NPS	Naval Post-Graduate School
NRMO	NPS-RAND Mobility Optimization model, an extension of the CONOP model
RDD	Required delivery date
SUMMITS	Scenario Unrestricted Mobility Model for Intratheater Simulation

TPFDD	Time-Phased Force and Deployment Data
TUA	Tactical Utility Analysis
UTE rate	Utilization rate

1. INTRODUCTION

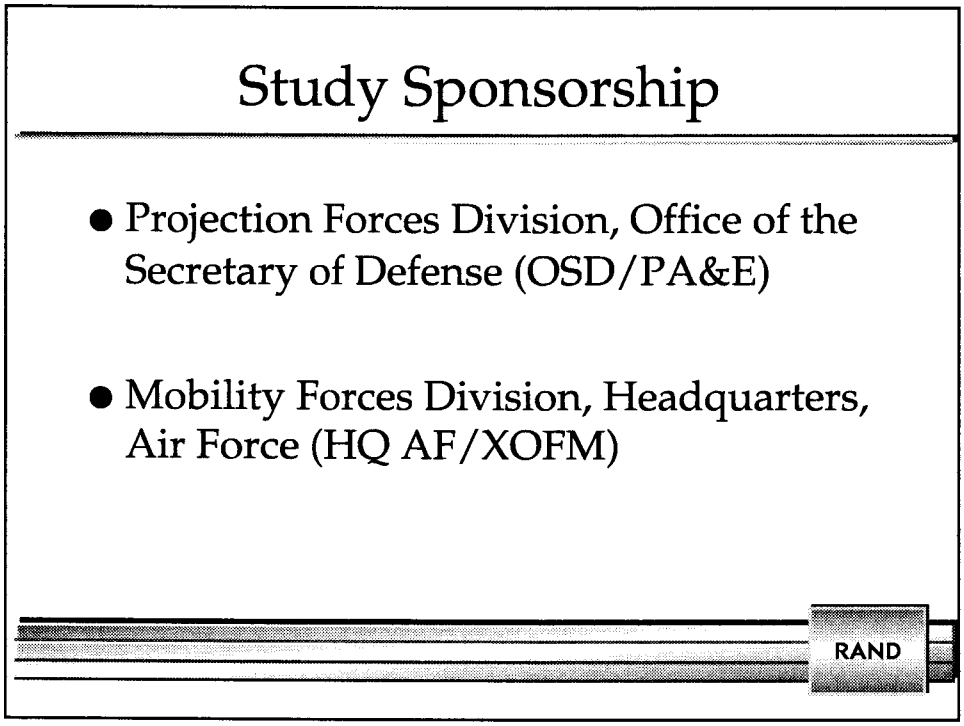


RAND was asked to participate in the Tactical Utility Analysis (TUA), a study of possible C-17 theater roles[8] conducted by the Office of the Secretary of Defense, Program Analysis and Evaluation (OSD[PA&E]), in 1995 to support the decision process of the Defense Acquisition Board. The Board's mandate was to determine the appropriate mix of C-17s and civil-derived aircraft in the U.S. military airlift fleet into the twenty-first century.[9] While most analysis to support the Board's decision focused on the C-17's strategic airlift capabilities, the Tactical Utility Analysis

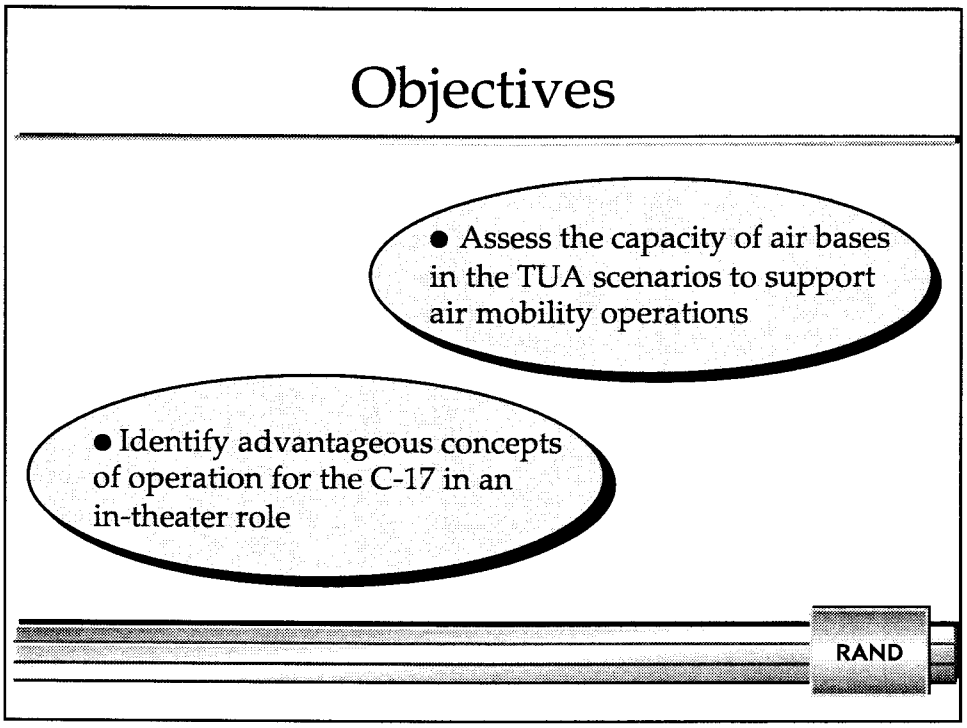
[8]Information on TUA is contained in unpublished documents by OSD(PA&E).

[9]In November 1995, the Defense Acquisition Board recommended to the Secretary of Defense that this mix should consist of 80 additional C-17s, bringing the total to 120. It did not recommend the purchase of any civil-derived airlift aircraft.

addressed the need for the C-17 to help move cargo within an overseas theater of operations.



RAND's work was sponsored by the Projection Forces Division of the Office of the Secretary of Defense and by the Mobility Forces Division of Headquarters, U.S. Air Force.



RAND researchers provided support in two areas. First, we examined the aerial ports and en route bases used in the scenarios investigated by the Tactical Utility Analysis. Applying the Airfield Capacity Estimator (ACE)[10] developed at RAND, we assessed the capability of those facilities to support the required numbers of airlifters.

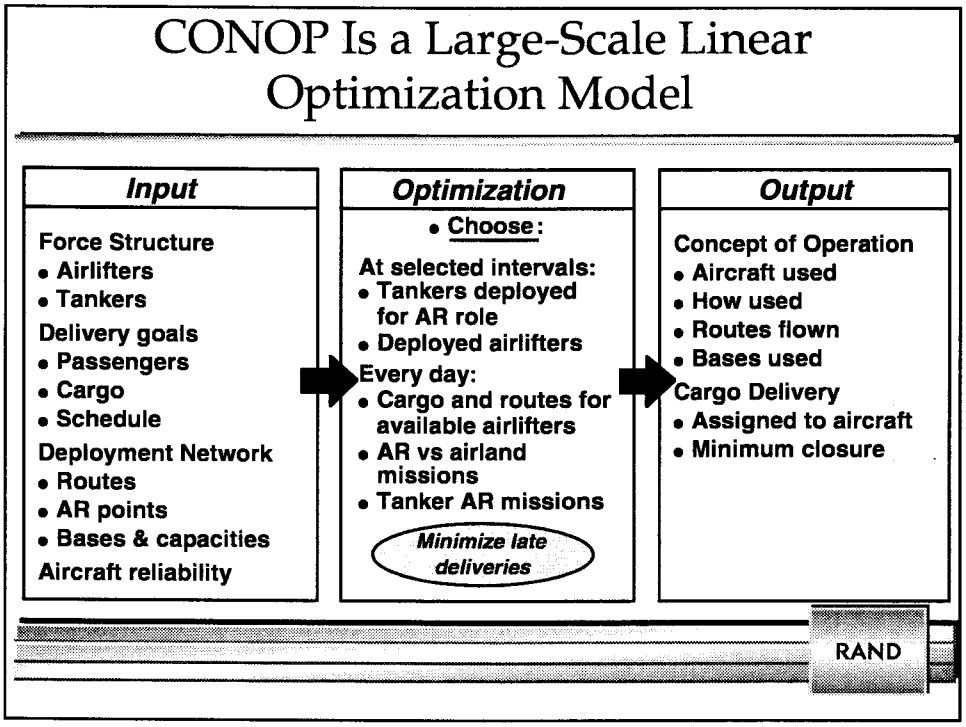
The work described in this Documented Briefing focused on the second objective of examining potential concepts of operation for in-theater operations using the C-17. Implicit in this objective was the possibility that *no* advantageous in-theater roles would be found, with the conclusion that the C-17 should always remain in a strategic cargo-hauling role.

To conduct this analysis, we used CONOP, an optimization model of the air mobility system, which we had developed over the previous two years.

[10]James P. Stucker, Ruth T. Berg, et al., *Understanding Airfield Capacity for Airlift Operations*, Santa Monica, CA: RAND, MR-700-AF/OSD (forthcoming).

In the next section, we summarize the overall features, inputs, and outputs of the CONOP model. In Section 3, we describe how we applied the model to the scenarios of the Tactical Utility Analysis. Section 4 describes our findings and conclusions.

2. HOW THE CONOP MODEL WORKS



CONOP is a large linear optimization model of the air mobility system. It incorporates, in substantial detail, the routes, bases, aerial-refueling points (not used in our analysis), cargo types, and delivery timelines of actual military deployment operations. As an optimization model, it seeks to mathematically minimize a function representing the delivery dates of cargo, subject to a large number of constraints that describe the air mobility system and its infrastructure. These constraints draw on detailed data describing aircraft availability and reliability, cargo- and passenger-delivery schedules, and the deployment network. For example, the daily flows through en route bases are constrained by the resources available at those bases, including ramp space, materiel-handling equipment, fueling capability, and maintenance personnel.

To minimize the objective function and deliver cargo and passengers on time, the model adjusts variables representing how resources in the air mobility system are used. Some of the variables represent the deployment and redeployment of tankers to en route bases at selected intervals to support the aerial refueling (AR) of airlifters.[11] Similarly, the model represents deployment of tactically capable airlifters such as the C-17 and the C-130 to a theater of operations to move in-theater cargo and passengers. In every time period, the model assigns cargo and passengers to airlifters and airlifters to the most-efficient routes in order to minimize the time to deliver the entire requirement. The routes can either involve aerial refueling (if tankers have been deployed to support this operation) or can rely completely on en route bases for refueling.

The result of this process is a concept of operations recommending how air mobility resources should be used--i.e., which aircraft, on which routes, through which bases, for what kinds of cargo, and how use should change as an operation proceeds. Cargo and passengers are assigned to aircraft moving from aerial ports of embarkation (APOEs) to aerial ports of debarkation (APODs) or forward operating bases (FOBs), with the objective of minimizing the time to deliver all the cargo and passengers.

Note that the general description in this section mentions some CONOP model capabilities that were not used in our TUA work.

Finally, it should also be noted that since we completed the analysis, the CONOP model has been further extended and developed in a cooperative effort between RAND and the Naval Post-Graduate School. The resulting model is tentatively named the NPS-RAND Mobility Optimization, or NRMO.

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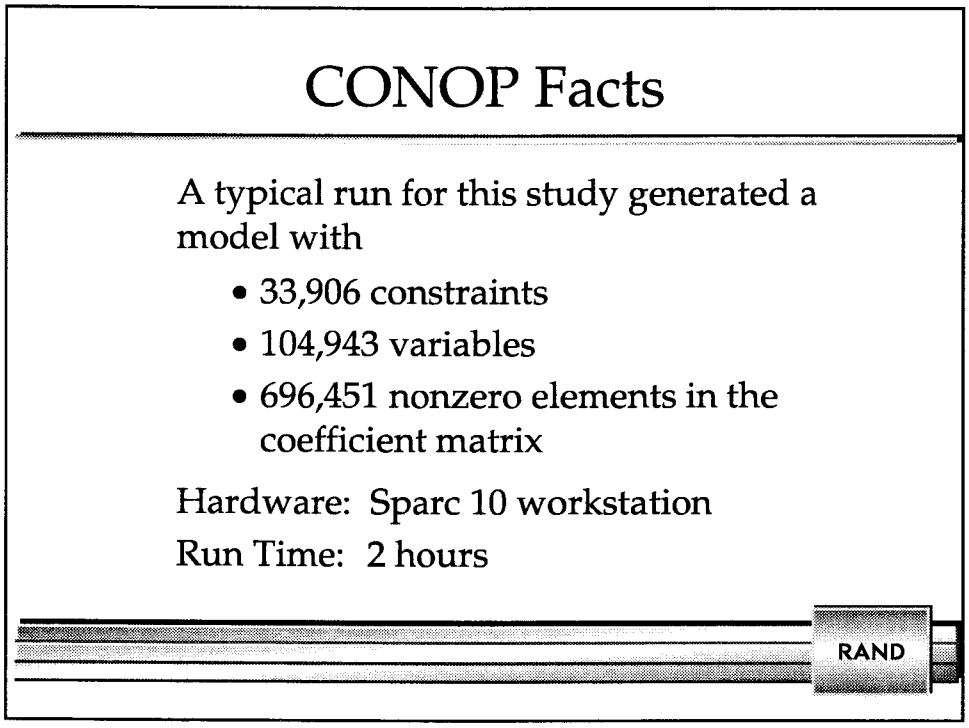
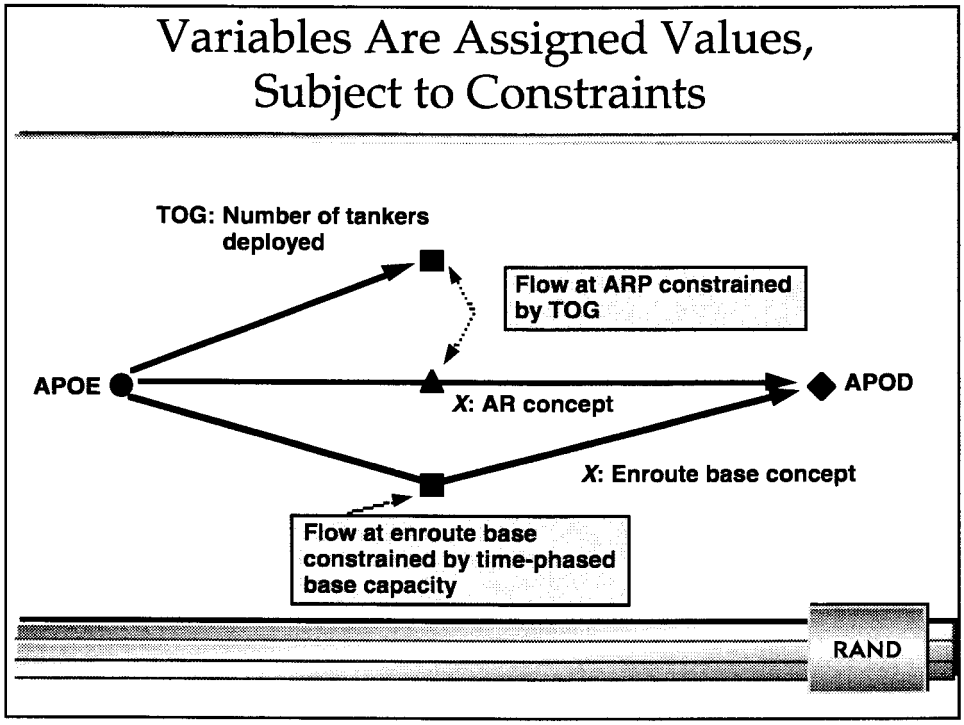
[11]This feature of CONOP was not used for the TUA work, but Paul Killingsworth, Keith Henry, Laura Melody, and James Stucker include it in "Tankers: Air Mobility Roles for the 1990s," an unpublished RAND draft.



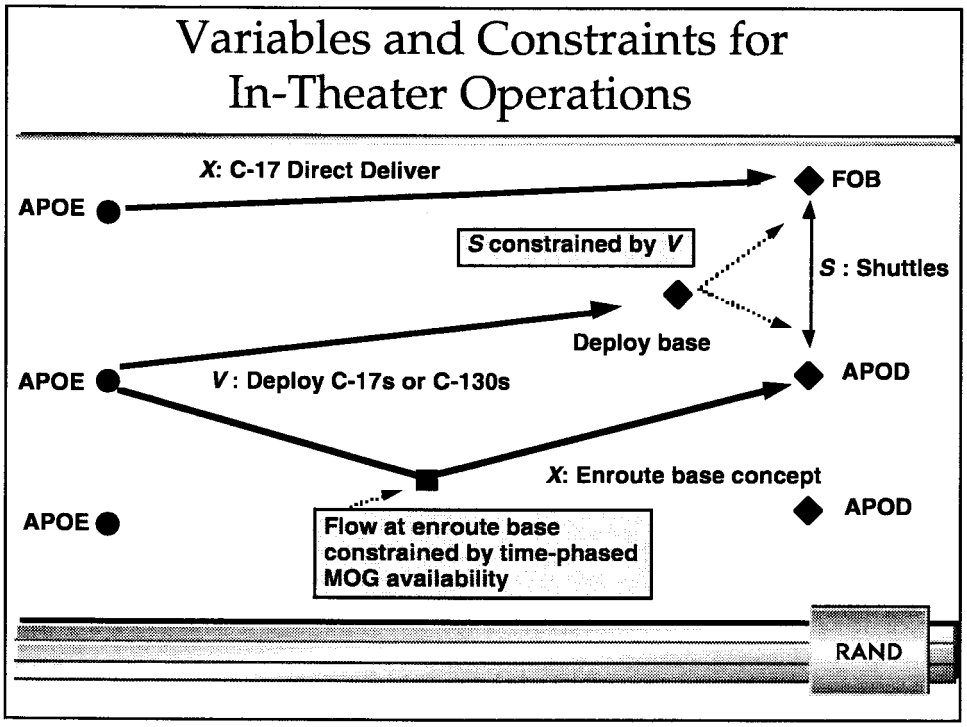
The model itself is coded in the GAMS algebraic modeling language.[12] It runs on a Sun Sparc 10 workstation, and usually reaches an optimal solution for a single set of conditions within 2 hours.

[12]A. Brooke, D. Kendrick, and A. Meeraus, *GAMS Release 2.25: A Users Guide*, South San Francisco, CA: Scientific Press, 1992.



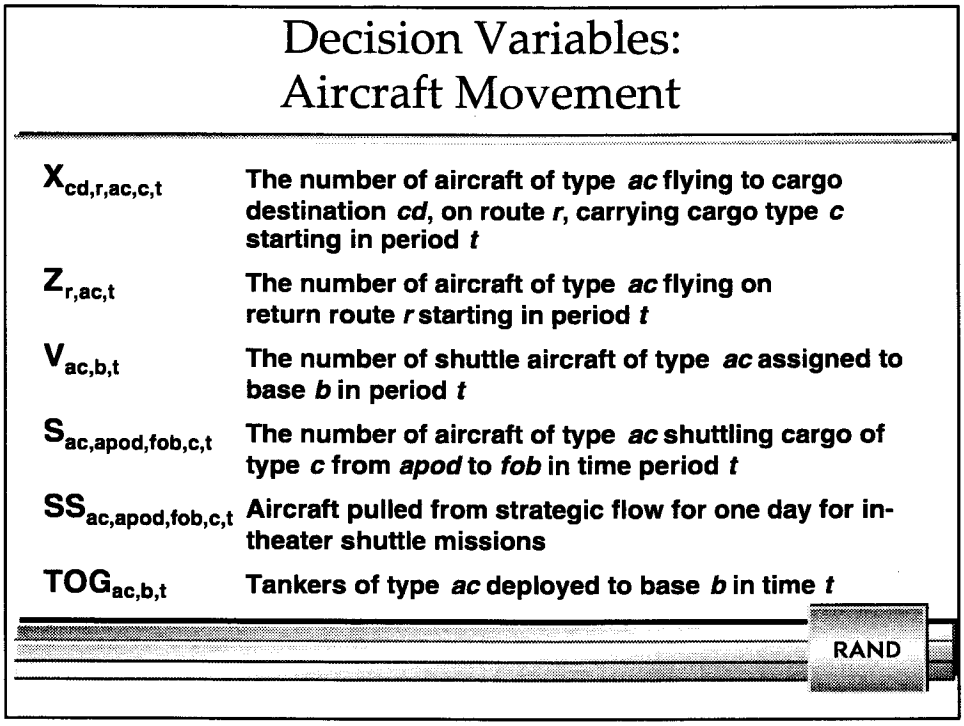
This chart illustrates in simple terms how one aspect of CONOP works. TOG and *X* are variables that represent the number of tankers deployed to overseas bases and the number of airlifters moving along a route from an APOE to an APOD, respectively. The model can choose among a variety of routes. A *direct route* is generally quicker, but it requires aerial refueling by the deployed tankers. But if tankers are deployed, they cannot serve as airlifters and they may compete with airlifters for parking space at overseas bases. The other, two-leg route requires refueling at an en route base and may take longer, but it may accommodate more aircraft. The capacity of bases to support a deployment is time-phased, in accordance with Air Mobility Command's Global Reach Laydown Concept.[13]

[13]The Global Reach Laydown Concept expands en route base capacities as a deployment progresses. Expansion occurs as more resources for command and control, logistics, and aerial ports are shipped to and set up at en route bases.



Here is another example of how CONOP works that is more specific to our analysis of C-17 in-theater operations. Multiple origin-destination pairs are possible, and some of the destinations can be FOBs. FOBs can be served only by tactically capable airlifters such as the C-17 and C-130. These aircraft can either fly cargo direct from an APOE, as shown at the top of the graph, or from a major in-theater APOD to the FOB. Shuttle operations (*S*) must be supported by deployed C-17s or C-130s (*V*). If an aircraft such as the C-17 is deployed to fly shuttle routes, it cannot move strategic cargo from the APOEs to APODs or FOBs.[14]

[14]Deploying aircraft for in-theater shuttle operations is only one concept of operations. We also investigated concepts such as "stratshuttles," in which a C-17 used in a strategic movement is temporarily used to fly shuttle routes and then returns to the strategic routes.

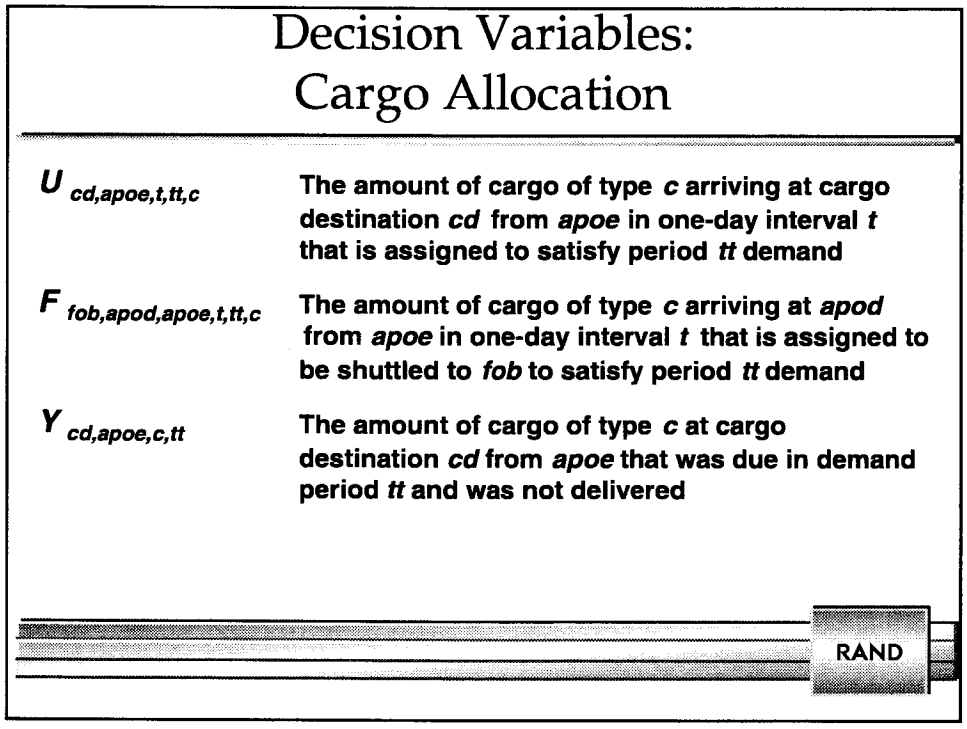


These model variables represent aircraft movement. The model's large size is necessary because a separate variable exists for each possible combination of these subscripts.

The variable *X* represents the number of aircraft of a specific type, moving to a given cargo destination, along a particular route, carrying a certain type of cargo, on a particular day. The variable *Z* represents the flow of these same aircraft back to APOEs to pick up more cargo.

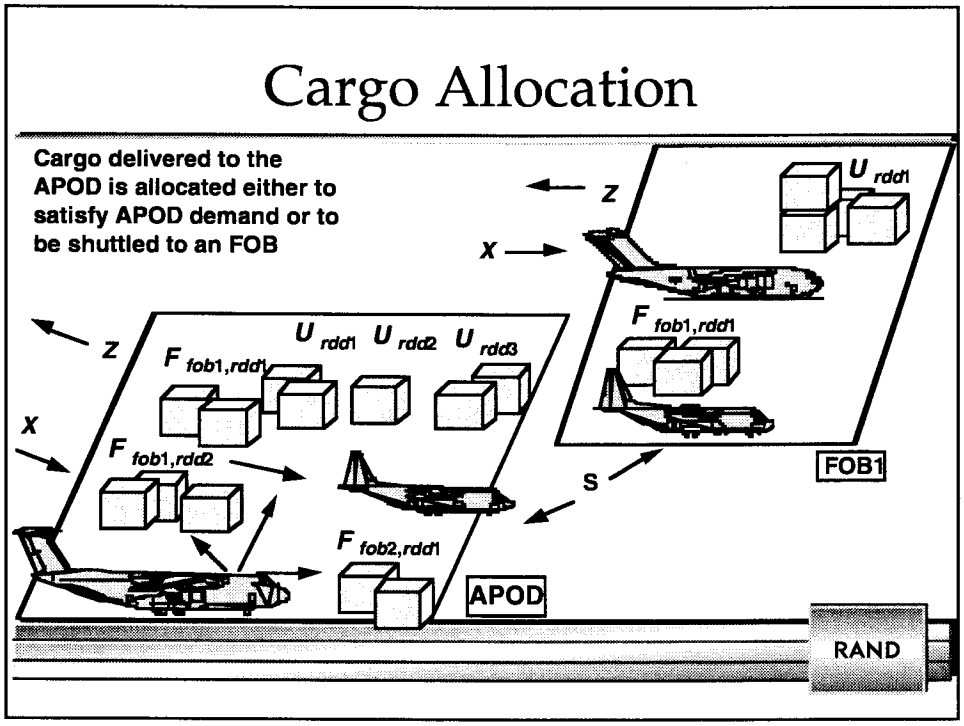
If the model gives *V* a positive value, it represents the deployment of an aircraft to an in-theater base to fly shuttles between APODs and FOBs. The variable *S* represents the number of shuttle missions, constrained by the corresponding values of *V*. The variable *SS* allows C-17 "stratshuttle" missions.

The TOG variables, representing deployed "tankers on the ground," both enable and constrain the aerial refueling of airlifters.

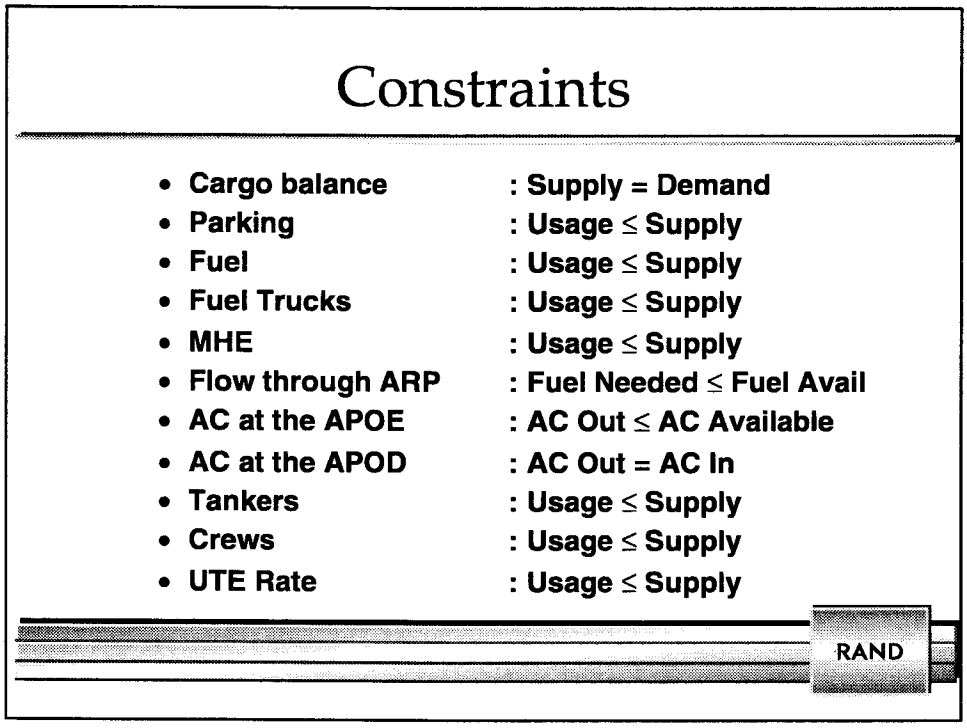


The variables shown determine how the cargo demand is satisfied. As aircraft arrive at APODs or FOBs, represented by the *X* variables, the cargo is allocated to *U* and *F* variables. If *U* is selected, the cargo is used to satisfy a delivery demand at the destination base itself (APOD). If *F* is selected instead, the cargo is designated to be transshipped at the APOD and forwarded via shuttle to an FOB.

The *Y* variable gives the optimization an alternative, in case some cargo cannot be delivered within the limits of en route resources, available aircraft, and allowable lateness.



Here we see how the *X* , *U*, and *F* variables interact. At the lower left, aircraft arriving via *X*s at an APOD have their cargo allocated to either *U* variables, to satisfy a required delivery date (RDD) at the APOD, or to *F* variables, to satisfy a demand at a downstream FOB. The cargo represented by the *F*s is shuttled to the FOB via C-130s or C-17s, described by values given to *S* variables. At the FOB, both the shuttled cargo and the direct-delivered cargo are allocated to *U* variables to satisfy the cargo demands at that base.



This list is a representative sample of constraints used in the model. Several cargo-balance equations ensure that the demand for cargo at APODs and FOBs is satisfied either by being allocated to a *U* variable or by not being delivered at all, which is represented by being allocated to a *Y* variable.

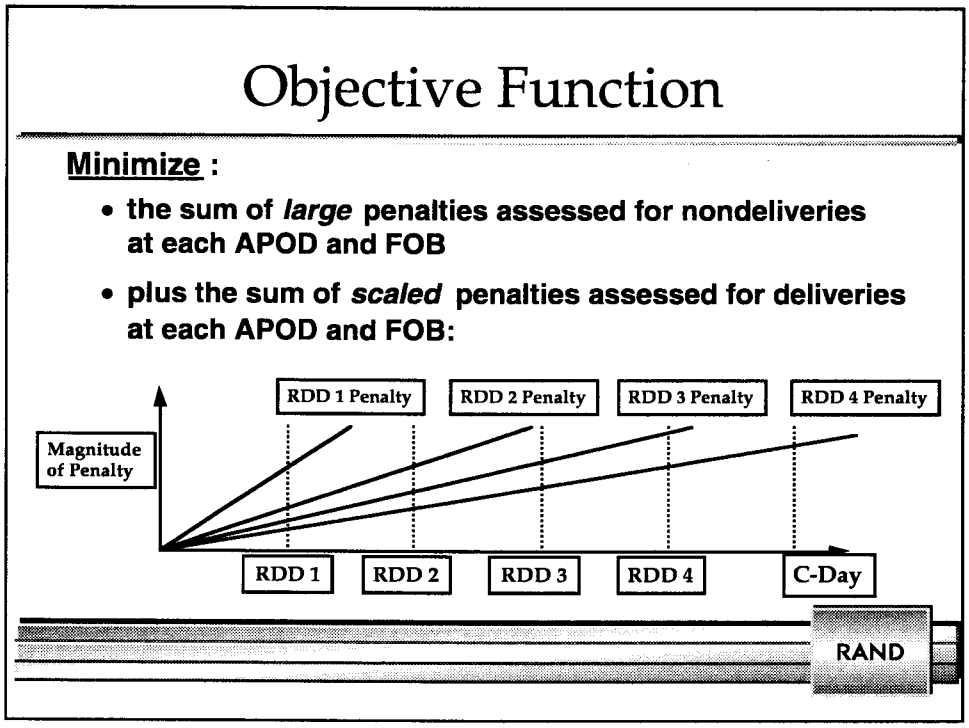
At en route bases, APODs, and FOBS, the daily flow of aircraft is limited by constraints that represent the availability of parking, fuel, fuel trucks, and materiel-handling equipment (MHE).

Routes that go through aerial-refueling points (ARPs) are constrained by the amount of fuel that can be delivered to the ARP by the deployed tanker aircraft (represented by the TOG variable). The fuel amount is further affected by the distance of the ARP from the base used by the tanker.

The number of aircraft used to deliver cargo (represented by X) must not exceed the number that are available at APOEs. Similarly, the number of tankers that are deployed to support aerial-refueling operations cannot

exceed the number available. Aircraft that arrive at APODs must depart via a Z variable and return to an APOE.

The use of aircraft throughout the air mobility system is also constrained by the number of crews available and the total hours they are allowed to fly each 30 days. Although crew availability is in theory reflected in the feasible utilization (UTE) rate of the aircraft, the model also uses UTE rate as an overall daily constraint on the usage of aircraft.



The model assigns values to all its variables to minimize the numeric value of the objective function. This function sums the *U* and *V* variables, each multiplied by an associated coefficient, or "penalty." To ensure that the model will choose nondelivery of cargo only when absolutely necessary, the penalties are quite large for the *Y* variables.

The penalties associated with the *U* variables, by contrast, are *scaled* according to the required delivery date, or RDD, of the cargo represented. That scaling determines what cargo is delivered, and when, during the scenario. The magnitude of the penalties themselves is of little importance compared with the different *slopes* of the penalty lines associated with each RDD. For example, if the model were addressing a particular delivery day (C-day) sometime between RDD 1 and RDD 2 on the graph, it might have to decide whether to deliver late cargo that was due on RDD 1 or early cargo due on RDD 2. Since the slope of the RDD 1 line is steeper than that for RDD 2 on the same day, the penalty for not delivering the first cargo before the second cargo will be higher, even though the

delivery is already late. So the model tends to schedule cargo with earlier RDDs before cargo with later RDDs.[15]

With this scheme, a limitation must be placed on the allowable earliness of cargo; otherwise, cargo due on C+90 could conceivably be delivered on C+1. Similarly, a limitation must be placed on the lateness of cargo, since extremely late cargo is likely to be of less value than currently demanded cargo. In addition, extremely late cargo should not be allowed to make all subsequently demanded cargo even later. For this analysis, we allowed cargo to be delivered to APODs no more than one week early or one week late. Since we assumed that the demand at FOBs was more closely related to current military operations, we required cargo for the FOBs to be delivered by the given dates.

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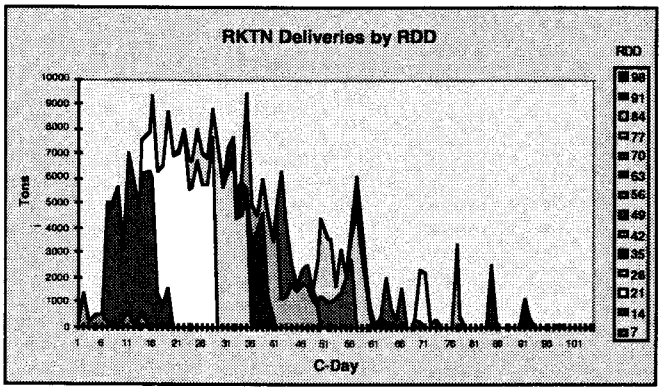
[15]We found in sensitivity analyses that, as long as the penalty slope for RDD1 is greater than that for RDD2 or later, RDD1 is always preferred for earlier delivery. Decreasing the slope for RDD1 should not affect the allocation of C-17s for in-theater use. The penalty for lateness of RDD1 cargo can be smaller, but it should still be greater than that for RDD2 cargo, and the penalty for nondelivery will still be arbitrarily much larger.

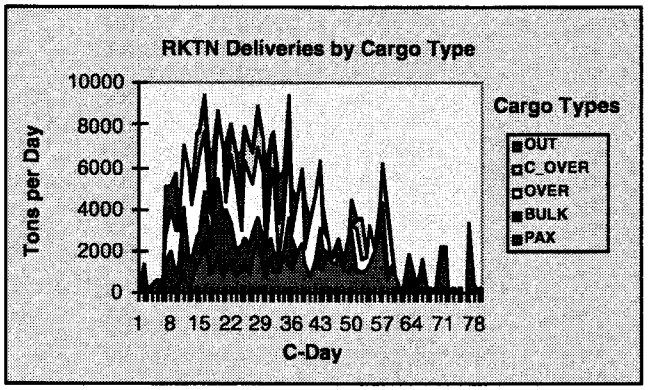
Objective Function Provides for Orderly Delivery of Requirements (1)



RAND

Shown here is the penalty approach's effect on deliveries at one APOD in the analysis, Taegu AB, Korea (RKTN). The various shades represent the RDD dates, which were grouped by week. The earliest requirements, for the first week, are delivered first, and the subsequent requirements are delivered in the order of their RDDs. The demands later in the deployment horizon were small, so they are delivered in "spikes," starting one week prior to each RDD (the maximum earliness allowed).

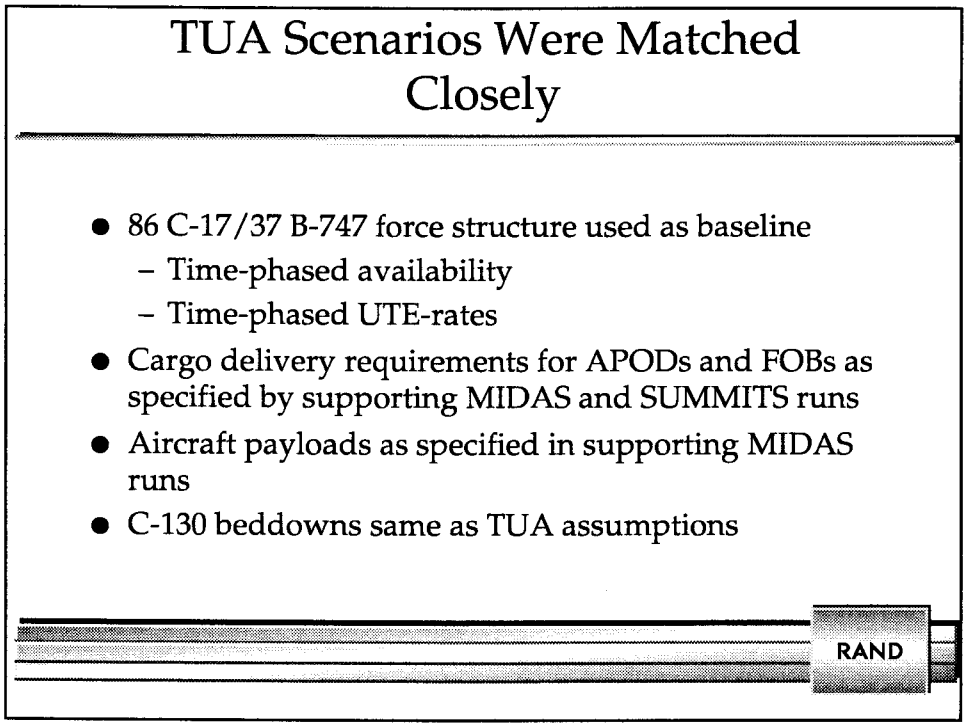
Objective Function Provides for Orderly Delivery of Requirements (2)



RAND

This graph shows the same deliveries as the last graph (although for only the first 78 days), this time displaying the five types of cargo instead of the RDDs. It shows that deliveries of the cargo types are being scheduled similarly to a real deployment--i.e., spread across the deployment horizon.

3. HOW THE ANALYSIS WAS CONDUCTED



We extensively modified and expanded the CONOP model to address the Tactical Utility Analysis scenarios in detail. Five force-structure alternatives were examined, ranging from 40 C-17s to 120 C-17s. Eighty-six C-17s was the third alternative of the five and was used as a baseline. For each alternative, the actual availability of the aircraft for operations varied with time, building up as the deployment progressed. Similarly, the aircraft UTE rates built up to targeted levels, then degraded as the fleet shifted from surge to sustained operations. These time-phased availability and usage constraints were the same as those used in the TUA.

Research sponsors provided the strategic cargo-delivery requirements for APOE-APOD pairs in Time-Phased Force and Deployment Data (TPFDD) for a dual-MRC scenario, along with in-theater cargo-delivery

requirements developed using their MIDAS[16] and SUMMITS[17] models. The sponsors used MIDAS and SUMMITS to help determine whether air-movement requirements were preferable to ground-movement requirements. Their work established the theater airlift requirement as a "given" for our analysis. Aircraft payload capacities were also taken from these supporting MIDAS runs.

The allowable basing of in-theater airlifters within the theater was taken from the number of C-130s used in the Tactical Utility Analysis. That number was assumed to indicate the capacity of the supporting in-theater airlift deployment bases. Our analysis allowed this capacity to be shared by both C-130s and C-17s, assuming that a C-17 would take 1.5 times the parking space of a C-130.

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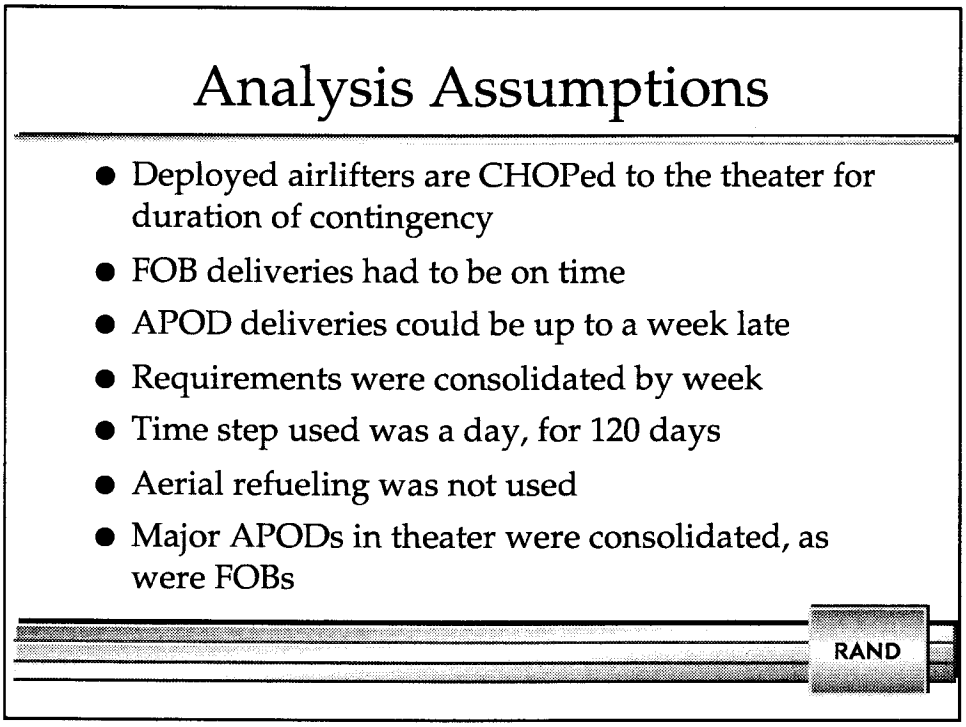
[16]See Carroll J. Keyfauver et al., *Model for Intertheater Deployment by Air and Sea (MIDAS): Users Manual, AMP Version 2.1*, General Research Corporation, June 1995.

[17]See Gregory Hawk, *Scenario Unrestricted Mobililty Model for Intratheater Simulation (SUMMITS) Scheduler Users Manual*, McLean, VA: General Research Corporation, Technical Support Group, September 1992.



The TUA scenarios were modeled closely; nevertheless, we made simplifying assumptions to render the problems computationally feasible.

Although the frequency of the deployment and redeployment of tactical airlifters to the theater of operations is adjustable within the model, for this analysis we required a single decision about how many aircraft to deploy to each theater for the entire deployment horizon. This allowed the number of aircraft used in-theater to be evaluated unambiguously. The "permanent CHOPping" of the C-17s to the theater was also useful in that it ensured that the model was clearly evaluating alternative employment policies. That is, the C-17 could be used as either a strategic airlifter or as an in-theater airlifter, but not both.[18] If the model deploys the aircraft as an in-theater airlifter, it clearly must be quite advantageous

[18]Our analysis of the "stratshuttle" concept was an exception to this rule. In it, we allowed the C-17 to be used in both roles.

to the overall flow of cargo, since the opportunity cost of the loss to the strategic flow is high.

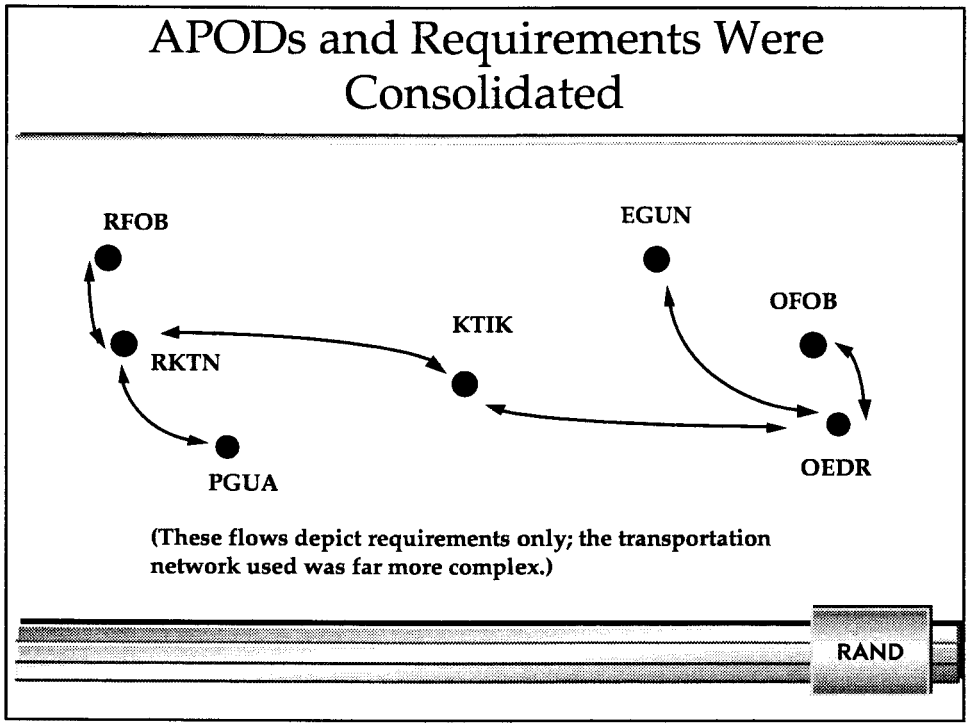
As indicated earlier, we required that deliveries to FOBs be on time, or not at all. The strategic deliveries to APODs were allowed to be up to a week late or early.

It was important to consolidate the required delivery dates (RDDs) by week. Although the model allows RDDs to be evaluated on a daily basis, or at any other desired level of aggregation, very detailed treatment of RDDs adds little to the accuracy of the analysis, and it generates problem sizes that are unwieldy and sometimes unsolvable. With this simplifying assumption, we could use a deployment horizon of 120 days, encompassing most of the cargo requirements for both MRC-East and MRC-West in a single run of the optimization model.

Although the CONOP model can represent aerial refueling of airlifters, we did not model aerial refueling in this analysis, thereby substantially reducing the size of the problems to be solved. While previous research has indicated that aerial refueling can increase cargo deliveries to APODs about 5 percent per day, this amount was not considered significant enough to include in the analysis.[19]

Finally, an important simplifying assumption was to consolidate the major APODs in each theater of operations, as well as the many possible FOBs that had separate delivery requirements. This "centroid" approach is common in studies of this kind, since the APODs and FOBs in each theater are geographically proximate and vary little with respect to the delivery time from each APOE.

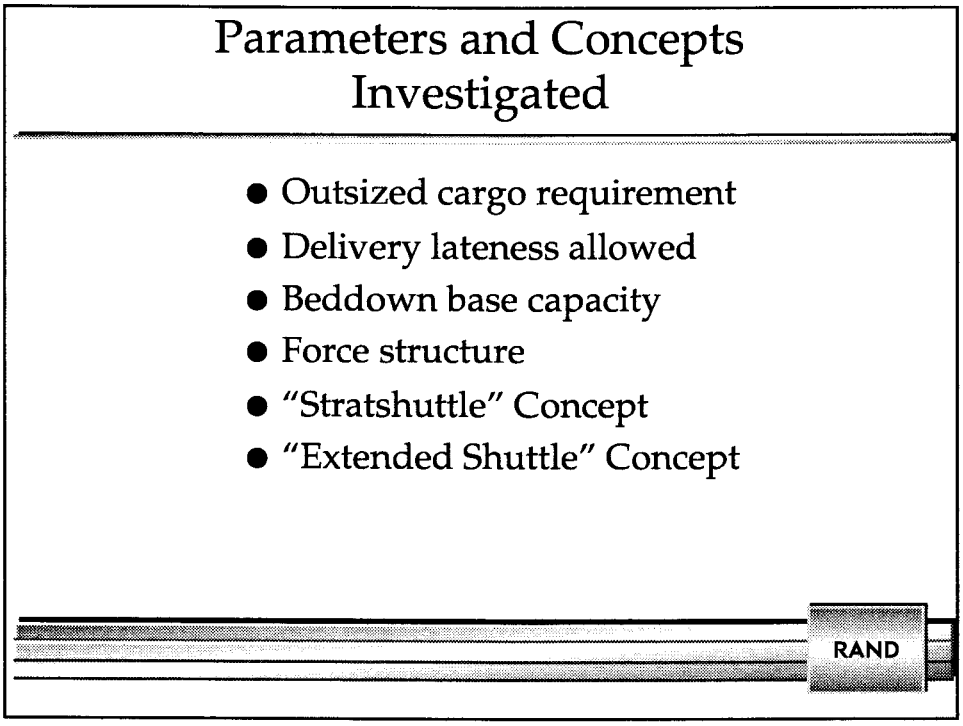
[19]Aerial refueling adds to daily cargo deliveries, primarily because it enables a decreased cycle time for the airlifters.



This graphic shows the results of the APOD and requirements consolidations. Tinker AFB, OK (KTIK), was the sole CONUS APOE used in the 2-MRC TPFDD. Guam (PGUA) and RAF Mildenhall, UK (EGUN), were also large non-CONUS sources of cargo for deployment. We used Taegu AB, South Korea (RKTN), as the consolidated APOD for MRC-West, and Dhahran AB, Saudi Arabia (OEDR), for MRC-East. The FOBs in each theater were consolidated and called "RFOB" for MRC-West, and "OFOB" for MRC-East.

The deployment routes and bases used in the actual model runs are not depicted here. The graphic shows only the origins and destinations.

4. ANALYSIS RESULTS

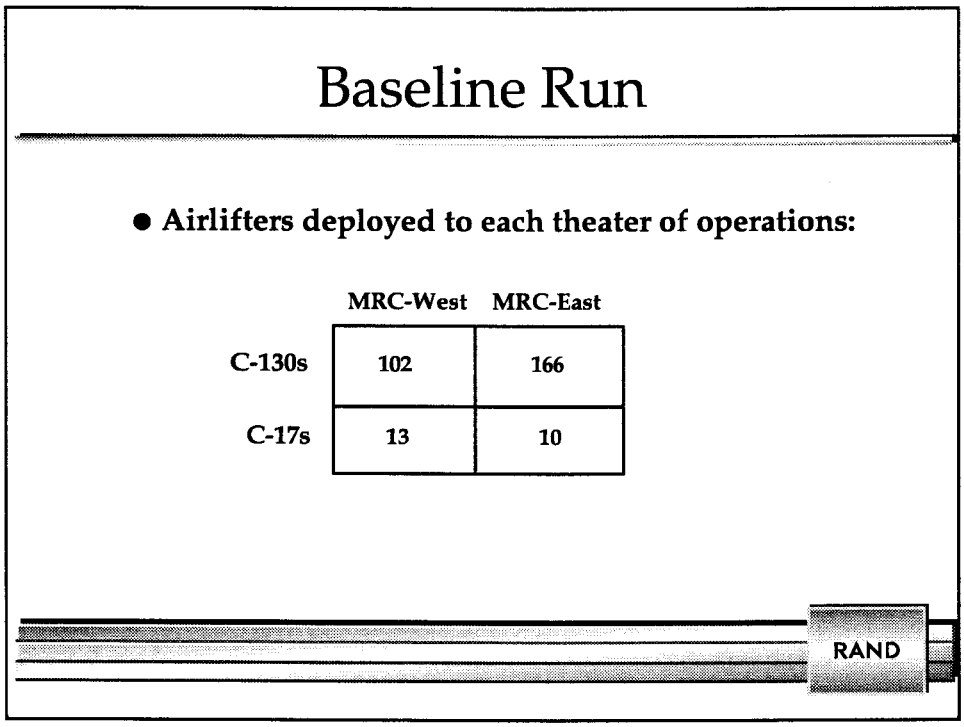


We analyzed the C-17's in-theater utility by first running the CONOP model against a baseline scenario, then varying the parameters shown above to assess the effects on the mix of C-130s and C-17s deployed to meet the in-theater requirement for airlift.

As already noted, for the baseline run the outsized cargo requirement and beddown base capacities were those used in the Tactical Utility Analysis. Cargo deliveries to the FOBs were required to be on time, and the beddown-base capacity was determined as described previously. Five mixes of C-17s and B-747s were used in the Tactical Utility Analysis, varying from 40 to 120 C-17s. We used the force structure in the middle of this range, 86 C-17s and 37 B-747s, for our baseline.

Then we systematically varied each parameter of interest. For each CONOP run, we observed the numbers and mix of deployed theater airlifters.

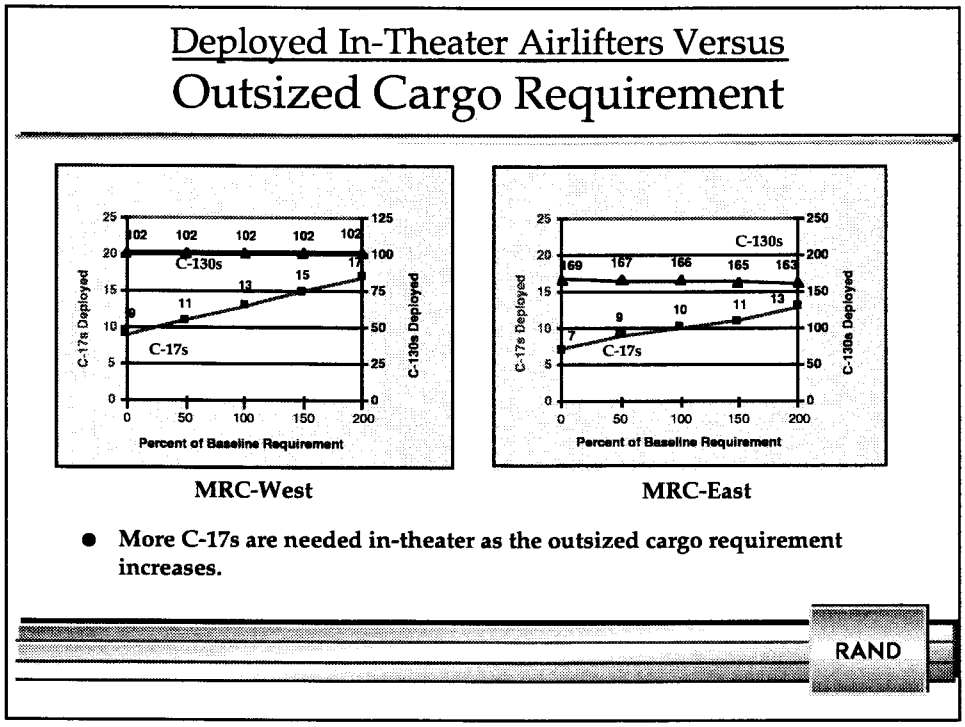
We also investigated two alternative concepts of operation, the "stratshuttle" concept and the "extended shuttle" concept, which are described later in this section.



The result of the baseline run is shown in this chart. The CONOP model recognizes that the C-130 is not effective as a strategic airlifter because of its limited range and cargo capacity, and so does not use the airplane in that role. Recognizing that the C-130 is highly effective in its designed in-theater role, the model would deploy many C-130s to each theater. It does so without affecting the strategic flow of cargo, since other aircraft are better suited for these longer-distance missions.

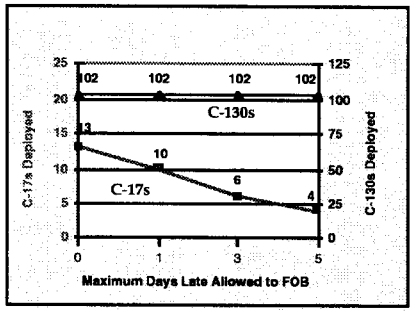
But the C-17 is highly effective as either a strategic airlifter or in-theater airlifter. The model recommends deploying C-17s as in-theater assets, because doing so maximizes the overall flow of strategic *and* theater cargo. The flow of strategic cargo is slowed somewhat, but this is offset by improving in-theater deliveries. Additional parametric analysis showed not only that the need to move outsized cargo motivates the in-theater use of the C-17. It is also the large volume of bulk and oversized cargo that needs to be moved, which can be accomplished with relative efficiency by the C-17. At the baseline values of the parameters, the model saw a need

for about one squadron of C-17s to operate within each theater throughout the 120-day scenario.

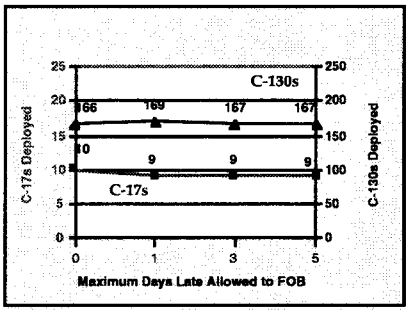


The need to move outsized equipment such as Patriot missile batteries and M-1 Abrams tanks is one of the most frequently cited justifications for procuring the C-17. Generally, this argument has been made with respect to moving cargo over strategic distances. However, in these graphs, we see that moving such cargo is an important driver of the need for the aircraft *within* theaters of operations. Note that, in both theaters, outsized cargo is evidently not the only reason for needing the aircraft in-theater. Even when no outsized cargo is part of the requirement, the remaining amounts of oversized and bulk cargo still indicate deploying nine C-17s to the theater for MRC-West and seven for MRC-East.

Deployed In-Theater Airlifters Versus Allowed Delivery Lateness



MRC-West

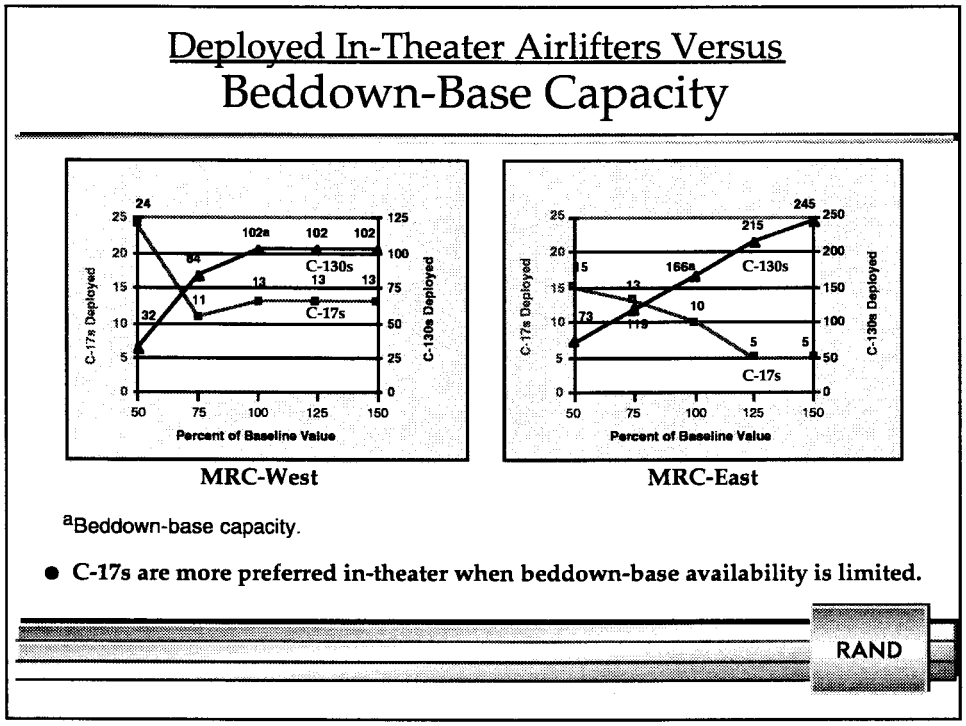


MRC-East

- **C-17s in-theater are affected not only by outsized requirements but also by the total amount of cargo and its delivery schedule.**

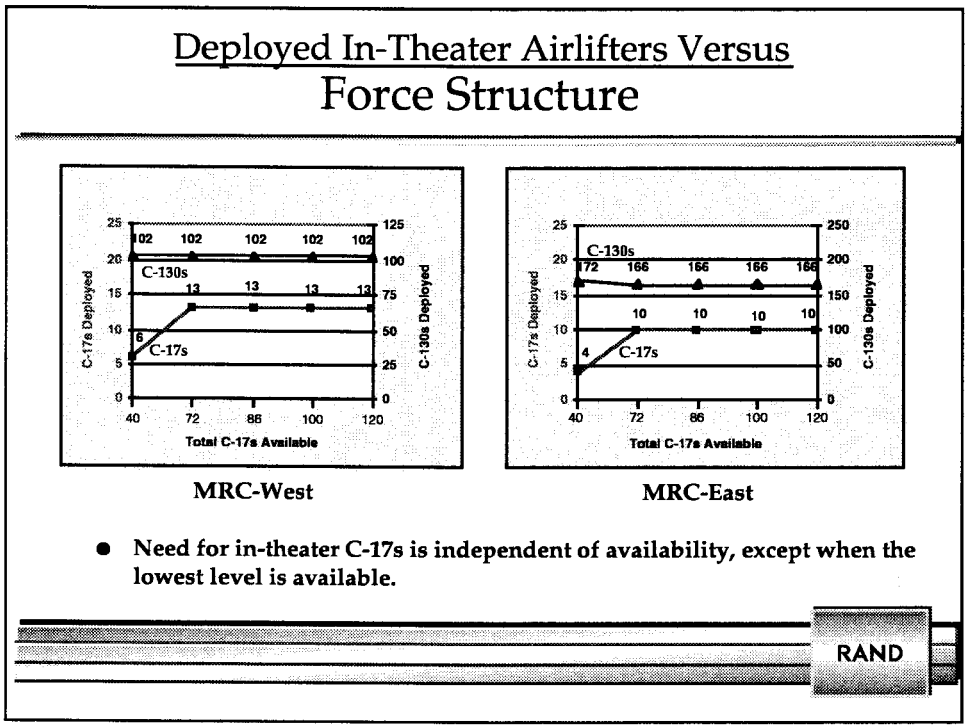
RAND

The allowable lateness for deliveries to FOBs is more of an issue in MRC-West than in MRC-East. It is more difficult to pull C-17s out of the strategic flow for the Korean scenario than for the Southwest Asia scenario, because the delivery distances are much longer and more strategic airlifters are needed to fill the "pipeline." As the allowable lateness increases for in-theater Korean deliveries, the model prefers the C-17 to fill the pipeline in the strategic role, and would deploy fewer C-17s to the theater. For the Southwest Asia deployment, however, the strategic distances are shorter, and the pipeline is evidently already full of capable aircraft. Nine C-17s are deployed in this theater even though the cargo RDDs have been relaxed, because the aircraft is highly effective in the in-theater role and the strategic pipeline to the theater has already been filled.

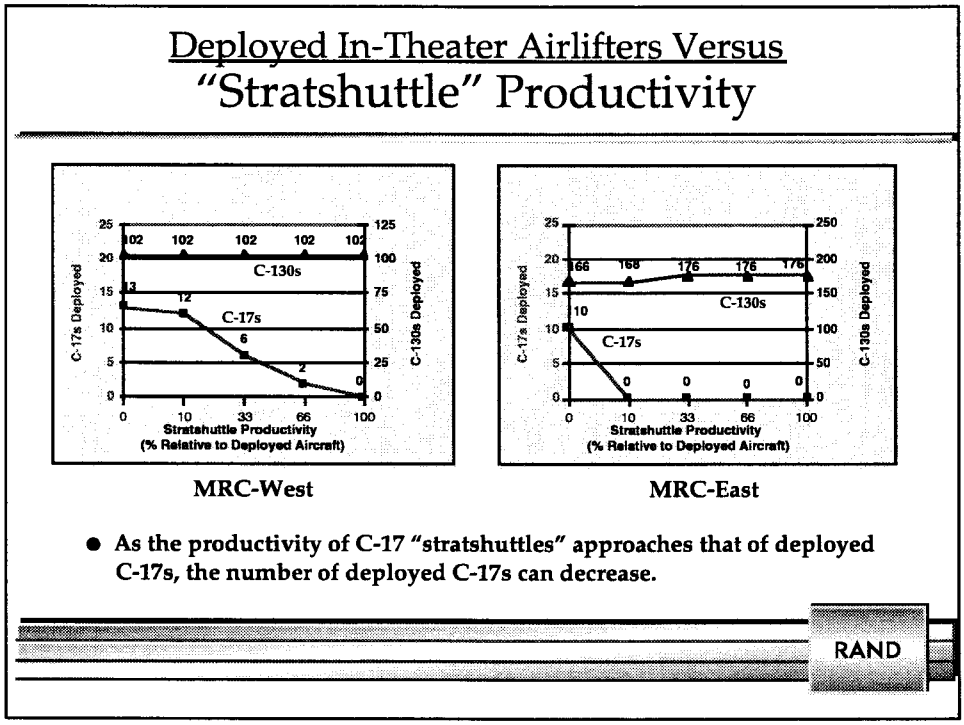


Perhaps the chief constraint upon in-theater airlift operations is the capacity of the theater to accommodate, or *bed down*, the aircraft and crews. As we saw during Operation Desert Shield, tactical airlifters must compete for limited ramp space and runways with hundreds of other deploying aircraft of many types, most of them "shooters." We investigated how changes in the parking capacity of the in-theater deployment base would affect the mix of deployed C-130s and C-17s. The effect was striking. For both MRC-West and MRC-East, more-constrained beddown conditions resulted in an enormous exchange of C-17s for C-130s. As the capacity increased beyond the baseline value, deployments for MRC-West remained stable; for MRC-East, the exchange continued.

An alternative way of interpreting these results would consider the overall capacity of the theater to bed down aircraft of all types. By substituting C-17s for C-130s, more space would be made available for deployments of other aircraft such as fighters, bombers, and tankers.



The last parameter we investigated was the effect of changing C-17 availability on the numbers deployed for theater operations. The allocation of C-17s to this role was, for the most part, independent of the total number available. Only with the fewest C-17s did their deployments finally drop off. Requiring in-theater cargo to be on time obviously gives those movements a high priority, making the model reluctant to take C-17s out of the theater even as their total number decreases.



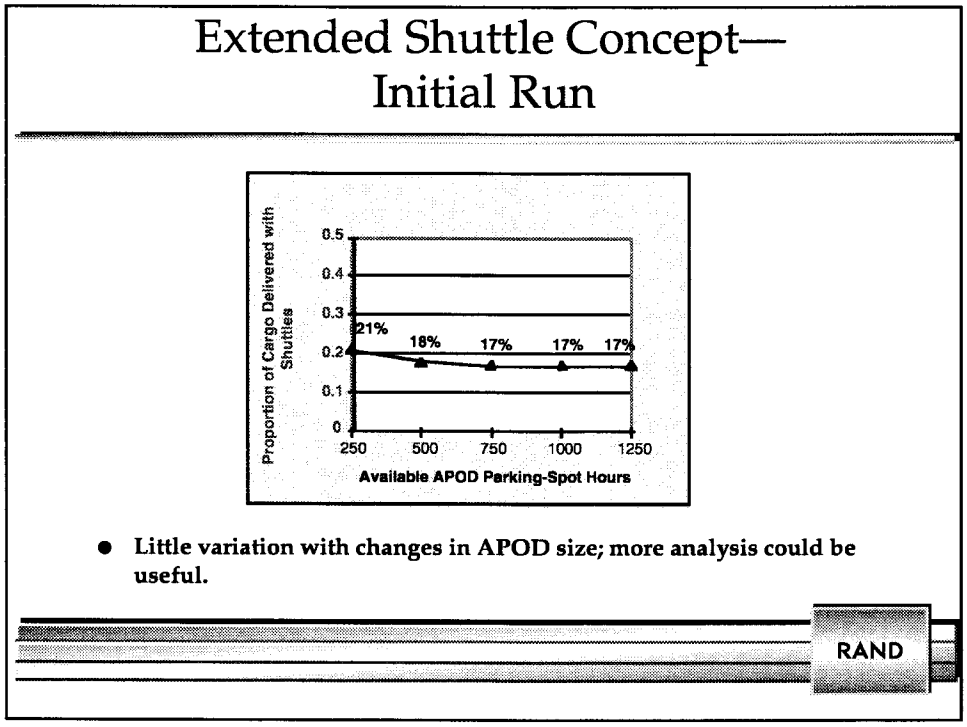
An alternative to deploying C-17s to the theater of operations for the duration of a contingency would be to direct some of the C-17s arriving at APODs to fly a number of in-theater shuttles from the APOD to an in-theater FOB. The aircraft would then be released to return to an APOE and reenter the strategic flow. We called this a "stratshuttle" concept and tested its potential to reduce C-17 in-theater deployments.

Our concept called for the aircraft to be delayed in its return to an APOE by 24 hours while the inbound crew entered crew rest and a staged crew flew shuttles to an FOB. It is not clear whether such a "stratshuttle" aircraft would be as productive as a C-17 based within the theater. From the theater commander's perspective, there would be less certainty that a "stratshuttle" C-17 would be available to carry possibly time-sensitive in-theater requirements, as well as an increased probability of delays from off-loading the aircraft at the APOD, maintenance, crew management, mission planning, or reconfiguring the cargo compartment.

Since the effect of these activities is, for the most part, unknown, we tested the effect of the "stratshuttle" concept relative to deploying the aircraft permanently to the theater. We examined the "stratshuttle" effect by varying the number of shuttles the aircraft could fly in its 24-hour period of availability. At the 0-percent level shown in the graphs above, "stratshuttles" are essentially not allowed, and the baseline results are obtained. At the 100-percent level, a "stratshuttle" C-17 was allowed to fly as many in-theater shuttles per day as an aircraft permanently deployed to the theater. For both theaters, this level of productivity resulted in no deployed C-17s.

For MRC-East, even minimal "stratshuttle" productivity meets the in-theater requirement for an aircraft of this size, which indicates that the concept could be highly effective in this theater, precluding the need to deploy C-17s. Another reason why "stratshuttles" work better for MRC-East is that the shorter cycle time for the strategic airlifters going to Southwest Asia makes it possible for more C-17s to be pulled out of the flow for a day, with less cost to the strategic cargo throughput. So even when "stratshuttles" are less productive, the need is met by the larger numbers that are available.

For MRC-West, however, the cycle time for a C-17 flying from CONUS to Korea and back is extremely long, and there may not be enough aircraft to fill the pipeline. This situation makes it harder to pull a C-17 out of the flow without substantially curtailing deliveries to APODs. The presence of less-productive "stratshuttles" in this theater results in fewer of them being flown and requires that more C-17s be deployed in-theater in order to achieve the delivery schedule.

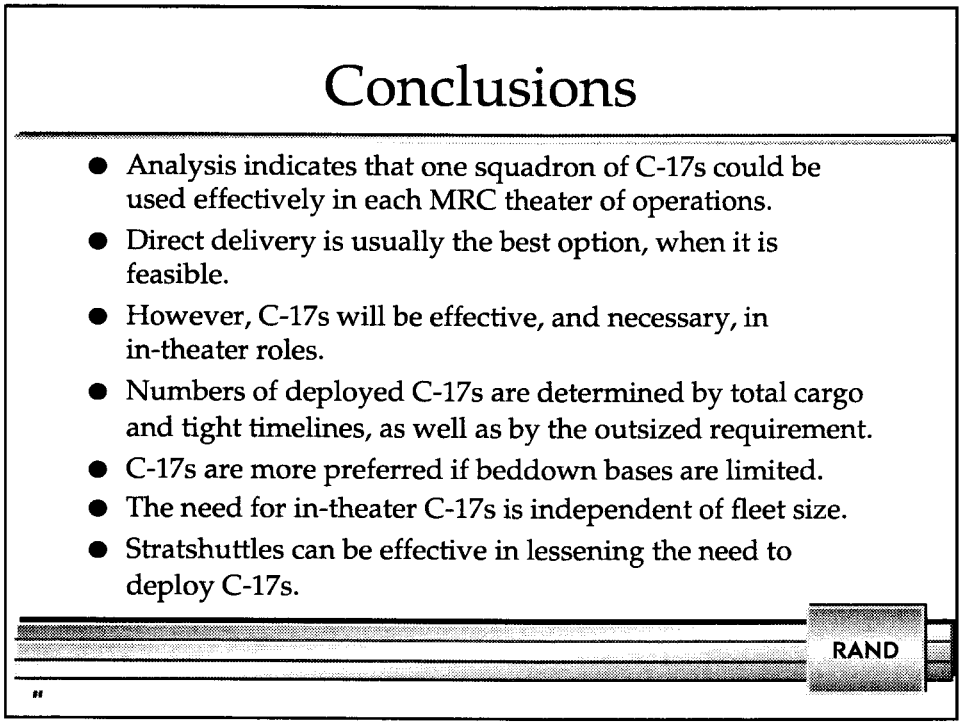


The "extended shuttle" concept is an alternative use of the C-17 for strategic delivery. It proposes that civil airlifters, such as Boeing 747s, be used to deliver bulk and oversized cargo to large, high-capacity bases somewhere near the theater of operations. At those bases, the cargo would be transshipped to C-17s for further movement to the theater. The concept would seem to play to the strengths of both the B-747 and C-17: The B-747 flies the longest distance nonstop to a major airport in the area; the C-17 then flies the rest of the way, a moderate distance, to presumably capacity-constrained airfields in the theater of operations.

For our preliminary look at this concept, we used Anderson AFB, Guam, for the MRC-West transshipment base, and Cairo West for MRC-East. We assumed that the use of this concept by the CONOP model would be most sensitive to the capacity of the APOD bases. As that capacity decreased, we expected that the desirability of the concept would increase.

To investigate this hypothesis, we varied APOD parking availability and measured the proportion of cargo moving into the theater via extended shuttles compared with the more usual air-land routes. We found that it was apparently difficult for the concept to overcome the delay associated with the transshipment operation. Also, for MRC-West, using Guam as the transshipment base probably placed the concept at a significant disadvantage, considering the possibility of a shorter, more-direct northern routing via Alaska. As the graph shows, only when the in-theater capacity to accommodate airlifters is extremely constrained does the model show much inclination to shift to this concept of operations. Further investigation might indicate that other bases offer greater advantage as transshipment points for strategic cargo.

5. CONCLUSIONS



We conclude that there is a robust role for about one squadron of 12 C-17s in-theater during major regional contingencies. However, this number holds only if the assumption is made that the aircraft must be assigned to the theater for the entire duration of the contingency. Even greater benefit may be obtained by deploying more C-17s for in-theater operations during some parts of the contingency and fewer at other times. As an alternative, we found that the "stratshuttle" concept, in which shuttles are flown by C-17s arriving in the theater on strategic missions, could probably fly most of the missions that would otherwise require theater-assigned C-17s. Regardless of the concept of employment, there seems to be a clear in-theater role for the C-17 during MRCs.

The approach taken in this analysis was unique in that it considered both the strategic and in-theater cargo requirements together, as a whole. In the past, since the two requirements were met separately, by airlift aircraft

with different capabilities (C-130s for in-theater, and C-5s and C-141s for strategic), it was reasonable to consider the requirements as two different problems. Now, with the entry of the C-17 into the inventory, informed decisions must be made about how its availability should be divided between its strategic and in-theater roles. Any use of the C-17 as a theater airlifter must come at a price to the strategic flow and vice versa. By analyzing both the strategic and in-theater cargo requirements together, we were able to account for interactions between the two. We analyzed several parameters that could be considered determinants of the need for theater-assigned C-17s, with the following results:

- When it can be accomplished, direct delivery from CONUS APOEs to FOBs is clearly the preferred option, because any transshipment takes longer and consumes APOD capacity. However, opportunities for direct delivery could often be limited. Much cargo will originate within the theater itself, from prepositioned stocks and inventories built up from strategic deliveries. In addition, responsiveness to theater commanders' operational needs will require that a substantial airlift capability be available locally.[20]
- We found that the need for C-17s in-theater was quite sensitive to the requirement to move outsized cargo, but this type of cargo was not the sole determinant. Even when there was no outsized cargo, a few C-17s were still needed to perform in-theater shuttles. The total amount of cargo of all types and the tight timelines for its delivery, indicated that some level of in-theater operation by C-17s is probably advantageous.
- When we relaxed the requirement that in-theater deliveries be on time, the requirement for deployed C-17s decreased substantially. The delivery timelines seem to be a major driver of the theater's need for C-17s.

[20]Theater airlift aircraft are not just logistics assets, they are also operational assets, as the "left hook" maneuver during Desert Storm confirms.

- We also observed that the C-17 was increasingly favored in our results over the C-130 as beddown-base capacity became more constrained--a situation that is increasingly likely in future contingencies. The C-17 makes better use of parking space per ton of cargo delivered.
- The number of C-17s that the model deployed to meet in-theater demand turned out to be quite insensitive to the total number of C-17s in the fleet. This result occurred partly because of the priority we placed on the in-theater cargo and partly because of the efficiency of the aircraft in hauling cargo in the in-theater role. The rapid on- and off-load capability, fast en route speeds, and large cargo capacity of the C-17 make the in-theater mission a preferred role.
- Finally, we also examined the "stratshuttle" concept, in which C-17s flying strategic cargo into APODs could be diverted to perform a day of in-theater shuttles prior to returning to the strategic flow. We investigated this concept by varying its efficiency relative to that of deployed C-17s and found that it would be effective in decreasing the number deployed to the theater, particularly for MRC-East.

Our conclusions depend on the data we were provided, especially the TPFDDs for MRC-East and MRC-West, which specified the mix of cargo types and their delivery dates. These data were the requirements generally used for defense planning at the time we performed the analysis, and were used as well in the Tactical Utility Analysis. Nevertheless, the in-theater requirement for delivery by air should be sensitive to the availability of alternative modes of transportation, especially line-haul by trucks. Outsized cargo items that require a C-17 for air delivery might be delivered over roads if their delivery dates allowed. That we were unable to perform such trade-offs with alternative modes of transportation is a limitation of our analysis, especially since the current state of the art in optimization modeling would allow a full analysis of both the strategic and in-theater cargo movement requirements, including all modes of transportation. Such an analysis would be a worthwhile follow-on research effort.

At the levels of requirements assumed in the Tactical Utility Analysis, we found evidence that theater operations by C-17s will be necessary in order to maximize the combined movement of both strategic and theater cargoes. We recommend that the Air Force plan to use substantial numbers of C-17s in-theater during major regional contingencies.

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