The Potential Effects of Alternative Concepts for Managing the Distribution of Resupply Cargo

Stephen J. Carroll, Karen Isaacson
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Stephen J. Carroll, Karen Isaacson

Prepared for the Defense Advisory Group to the National Defense Research Institute Assistant Secretary of Defense (Production and Logistics) Joint Staff

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PREFACE

This report describes an analysis of alternative concepts for managing the distribution of non-unit-related, or resupply, military cargo in wartime, all of which involve techniques for coordinating the operations of a given set of supply and transportation resources. The objective of this effort was to assist DoD in developing a concept for a resupply distribution system that can adapt rapidly to unanticipated changes in its environment and in the demands to which it responds.

Our analysis was one of many aimed at formulating a conceptual design for a future DoD distribution system. Related analyses addressed alternative concepts for the distribution of unit-related cargo in conjunction with the mobilization and deployment of forces, including alternative materiel positioning policies, mixes of strategic transportation assets, and operating procedures for cargo associated with military units. Also examined were trends in the civil transportation systems on which DoD will rely in a major contingency, the transportability of military equipment, and the affordability of future distribution system alternatives.

Correspondence between the Under Secretary of the Army and the Under Secretary of Defense for Acquisition (USDA) provided the impetus for the project. In acknowledging the Under Secretary of the Army's concerns about likely problems in mobilization and deployment, the USDA called for a "blueprint" of a materiel distribution system that could serve the needs of all the U.S. military services. RAND’s National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Office of the Secretary of Defense (OSD) and the Joint Staff, was then asked to formulate a conceptual design for a future distribution system, along with a plan to guide the transition to the new system.

The work was sponsored by the Assistant Secretary of Defense (Production and Logistics) acting in concert with the OSD Defense Advisory Group for the NDRI, the services, the Joint Staff, and the Defense Logistics Agency. It was conducted in NDRI's Acquisition and Support Policy program.
SUMMARY

This report describes an evaluation of alternative concepts for managing the distribution of non-unit-related, or resupply, military cargo in wartime,\textsuperscript{1} all of which focus on procedures for effectively coordinating the day-to-day and week-to-week operations of a given set of supply and transportation resources. Specifically, we considered dynamic approaches to four wartime resupply management tasks:

- Directing specific shipments into appropriate resupply pipelines and managing the resulting flows of cargo and transportation vehicles to most effectively utilize scarce resources;
- Organizing transportation assets to connect materiel sources and destinations;
- Allocating available transportation among competing demands;
- Allocating available materiel among competing demands.

We also considered the potential contribution of an enhanced priority system, one that would provide distribution system operators with more information than is offered by the current DoD priority system, the Uniform Materiel Movement and Issue Priority System (UMMIPS).

METHOD

We used a simulation model of an origin-to-destination resupply distribution system to compare its response to a specified time stream of requisitions when it employed either the current or an alternative procedure to accomplish each of the four tasks and either UMMIPS or the enhanced priority information was provided. We then tested the sensitivity of our results to the assumptions underlying the simulation model by replicating the evaluations of the alternative procedures, invoking different demand streams and different assumptions about the performance of the transportation system and using different standards to score the distribution system's performance. Our results show the improvements to be gained, in terms of the reduction\textsuperscript{1}These alternatives are detailed in S. J. Carroll, D. R. Worley, and G. B. Crawford, Alternative Concepts for Managing the Distribution of Resupply Cargo, N-3249-DAG/P&L, RAND, 1991.
in aggregate weighted days of delay (i.e., lateness of delivery), by using the alternatives.

CONTROLLING THE FLOWS OF CARGO TO A SINGLE THEATER

The distribution system must be able to effectively manage the flows of resupply materiel to a single theater or to each theater involved in a multitheater contingency. We began our study by examining the relative effectiveness of alternative flow control procedures, assuming unlimited availability of materiel and a fixed allocation of transportation to each theater.

Dynamic Scheduling of Cargo Flows

The current system fills requisitions as they arrive. An alternative procedure is to dynamically schedule cargo flows from depots to nodes to avoid undue congestion. In essence, this alternative queues requisitions rather than cargo.

Compared to the current system, the system using this alternative procedure reduces the aggregate weighted days of delay by 4 to 25 percent depending on the assumed conditions. The reduction stems partly from the elimination of congestion at the ports and partly from the more efficient use of available lift. By queuing requisitions until the distribution system is able to handle them, the alternative prevents the system from becoming jammed with materiel awaiting shipment. Later-arriving requisitions for urgently needed materiel can be filled at once, and the resulting shipments can be moved through the system comparatively quickly.

Dynamic Routing of Cargo Flows

In the current system, cargo flows are assigned to the air and sea pipelines without regard for available lift capacities. An alternative procedure is to dynamically route shipments through one or another resupply pipeline so as to make the most effective use of pipeline capacity and capability.

Compared to the current system, the system employing this alternative dramatically reduces the aggregate weighted days of delay, providing improvements of from 15 to 74 percent. These improvements are attributable to the diversion of the less urgently needed air-eligible cargo from the air to the sea pipeline when airlift is constrained. Scarce airlift resources are thereby reserved for the most
urgently needed cargo, and the less urgently needed air-eligible cargo is delivered more quickly, via sea, than if it had waited until airlift became available.

An Enhanced Priority System for Flow Control

For all practical purposes, the UMMIPS divides a theater's requisitions and the resulting shipments into three priority groups. An alternative approach is to provide an enhanced priority system that shows measurable distinctions in the relative importance of demands now classified into one UMMIPS priority group. We found that an enhanced priority system could improve the distribution system's performance by 3 to 8 percent. In other words, if the system's operators were given more information about the importance of each shipment, system performance could improve by roughly 5 percent.

A Dynamic Approach to Establishing Resupply Pipelines

In the current system, all flows of resupply dry cargo other than ammunition are supported by two general-purpose resupply pipelines organized around strategic airlift and strategic sealift. An alternative concept is to organize and operate the transportation resources allocated to a theater—ships, aircraft, trucks, ports, etc.—as multiple resupply pipelines tailored to specific types of resupply movement requirements. The alternative thus is not to establish a particular set of pipelines, because movement requirements will vary from one contingency to another and are likely to also vary over time for any particular contingency. Rather, it is to adopt a procedure for establishing pipelines that would consider the relevant factors as a contingency developed and determine the most effective way to use available transportation assets.

To test this concept, we modified the model to include a rapid response pipeline broadly similar to the Desert Express, the fast delivery service established in support of Desert Shield. We then simulated the system's performance and compared it to that of the current system. The results suggest that the addition of a rapid response pipeline could improve system performance by roughly 8 percent.

Sensitivity Analyses

The sensitivity analyses we ran yielded consistent results. The effects of the alternative procedures varied with the assumptions incor-
porated in the model, but they always had the same sign and order of magnitude.

ALLOCATING TRANSPORTATION AND MATERIEL AMONG THEATERS

Transportation and materiel resources have to be allocated among theaters in a multitheatery contingency. We examined a dynamic procedure for allocating transportation assets between two theaters, assuming dynamic flow control procedures and unlimited materiel stocks. Next, we examined alternative procedures for allocating scarce materiel resources between theaters, first assuming unlimited transportation capacity in order to focus on the relative effectiveness of the alternatives, and then assuming limited transportation capacity that was dynamically allocated between theaters. Both sets of analyses examined the relative effectiveness of the alternatives when system operators were provided with either UMMIPS or enhanced priorities, the goal being to determine the degree to which an enhanced priority system would affect the alternatives' performance.

Dynamic Allocation of Transportation Resources

The current system reallocates transportation assets among theaters on an ad hoc basis in response to problems that have become sufficiently serious to attract attention. An alternative approach is to forecast movement requirements on an ongoing basis using recent consumption experience and updated forecasts of expected resupply demands, and then to reallocate transportation assets among theaters in anticipation of those forecasted movement requirements. Reallocation is done so that the marginal contribution of the last unit of airlift capacity allocated to each theater, measured in terms of the consequent reduction in weighted days of delay, is the same across theaters.

Our analysis showed that the dynamic allocation procedure improves the distribution system's performance by 3 to 12 percent when initial forecasts prove erroneous and yields small benefits when those forecasts prove accurate. It also showed that an enhanced priority system could improve the alternative's performance by about 3 percent.

Alternative Concepts for Materiel Allocation

Materiel is implicitly allocated in wartime on a first-in-first-out basis. One alternative approach is to use stock reservations to allocate
scarce materiel among competing needs. With this technique, specified quantities or proportions of available stocks are reserved for specified customers to ensure that some stocks will be available for them regardless of the requisitioning activities of other customers. In addition, the establishment of control levels within each theater can ensure that materiel reserved for that theater is released by priority group in order not to deplete on-hand stocks. Another alternative is to use a dynamic materiel allocation procedure that takes account of likely future demands for each commodity. In this procedure, predicted future requisitions for an item are pooled with actual requisitions, and the combined queue of demands is then sorted according to the relative importance of filling the requisition (actual requisitions) or reserving some amount of the item in anticipation of a future demand (predicted requisitions). Actual requisitions at the head of the queue are filled; materiel is set aside in anticipation of predicted requisitions at the head of the queue.

Neither the stock reservation procedure nor the control levels procedure had much of a beneficial impact on performance relative to the current system. In fact, in some cases, these procedures adversely affected the system's performance. The "cost" of not filling a current demand when materiel was available—i.e., of reserving materiel for another theater or for a future, higher-priority demand—outweighed the resulting benefits.

As for the dynamic allocation procedure, it responded no better than the current system to transitory materiel shortfalls or materiel shortfalls arising during the initial surge of a contingency. For shortfalls arising after the initial surge, however, it performed much better than the current system—by as much as 30 percent when transportation resources were unlimited, and by 10 to 13 percent when transportation resources were constrained. This procedure's success stems from the fact that it forecasts future, high-priority demands and then reserves materiel for those demands only when the benefits of doing so outweigh the costs of not filling lower-priority but on-hand requisitions.

**Sensitivity Analyses**

Here, too, the results of the sensitivity analyses we ran were consistent in terms of the direction and order of magnitude of the alternatives' effects.
ACKNOWLEDGMENTS

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1. INTRODUCTION

PURPOSE AND SCOPE

This report presents our analysis of alternative concepts for managing the distribution of non-unit-related, or resupply, military cargo in wartime. All of the alternatives studied entailed techniques for coordinating the day-to-day and week-to-week operations of a given set of supply and transportation resources, and all of them were evaluated in terms of their potential for providing better performance than the current system.\footnote{The alternatives are detailed in S. J. Carroll, D. R. Worley, and G. B. Crawford, \textit{Alternative Concepts for Managing the Distribution of Resupply Cargo}, N-3249-DAG/P&L, RAND, 1991.}

This analysis was one of many in the Study of the DoD Future Distribution System. Other analyses carried out in the study addressed the movement of unit-related cargo in conjunction with the mobilization and deployment of forces, and alternative levels of investment in and mixes of strategic transportation assets. Trends in the civil transportation systems on which DoD will rely in a major contingency were also evaluated, as were the transportability of military equipment and the affordability of future distribution system alternatives. Output from the study includes proposed research programs, investment levels, and operating procedures. The study's primary concern was the effectiveness of materiel distribution in a future wartime environment.

THE NEED FOR IMPROVED RESUPPLY MANAGEMENT SYSTEMS

The current system for distributing resupply materiel does not direct, coordinate, and control supply and transportation activities in a manner that is integrated enough to effectively meet warfighters' resupply needs. This lack of integration takes various forms. First of all, distribution of resupply cargo is currently managed piecemeal throughout DoD. Many aspects of DoD's supply, transportation, and traffic management functions are organized separately, each organization concerning itself solely with its own responsibilities and per-
formance standards instead of with its contribution to system-wide performance.²

Second, the current distribution system tends to rely on static decision rules that do not take account of the system's capacities or the effects that specific decisions have on other parts of the system. For example, the formal rules used to determine whether a specific shipment is to be sent by air or sea are based on the shipment's physical characteristics and assigned priority. They do not systematically take into account the status of the relevant air channel (i.e., whether it is congested and thus causing delays) or the likely future volume of demands for that air channel. Consequently, they neglect the possibility that the better course may be to send an air-eligible shipment via sea, either to get it delivered faster than is possible because of congestion delays or to conserve scarce air transport for air-eligible shipments of higher priority. Moreover, these static decision rules lack the flexibility that may be needed to respond well to wartime stresses. During Operation Just Cause, for example, individuals throughout the DoD supply and transportation system had to adapt routine methods, develop new procedures, and find shortcuts—i.e., work around the standard DoD processes for supply and transportation actions.³

Finally, because of the distribution system's size and complexity, much of the decisionmaking that affects resupply operations is decentralized. The system thus needs means for transforming information on warfighters' goals, objectives, and preferences into indicators of the relative importance of specific items (i.e., priorities) that can then be used in allocating scarce materiel or lift when all demands cannot be met. Currently, DoD uses the Uniform Materiel Movement and Issue Priority System (UMMIPS)⁴ to identify the relative rank of requisitions and materiel movements and for coordination across organizations. This system assigns a priority designator to each requisition on the basis of (1) its force/activity designator (FAD), which indicates the

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²This assessment is based on I. K. Cohen et al., Issues in Materiel Distribution: A Background Note, N-2791-P&L, RAND, 1989; interviews with senior-level DoD leaders and working-level staffs responsible for conducting distribution planning and operations; and examinations of "lessons learned" reports from joint exercises conducted during the last decade. See also Command, Control, Communications, and Computer Systems Master Plan, U.S. Transportation Command, 29 September 1989.
requisitioner’s military importance, and (2) its urgency-of-need designator (UND), which indicates the requisitioner’s need for an item to perform his assigned mission. The procedures used to establish the UMMIPS priorities have serious limitations, however. FAD codes provide only limited means for discriminating among requisitioners, and UNDs are subjective, difficult to interpret, and frequently criticized for lack of discipline.

ALTERNATIVE CONCEPTS FOR RESUPPLY MANAGEMENT

Distribution system managers need tools that allow them to effectively accomplish four management tasks:

1. Direct specific shipments into appropriate resupply pipelines\(^5\) and manage the resulting flows of cargo and transportation vehicles within each pipeline to most effectively utilize scarce resources.
2. Organize transportation assets into end-to-end resupply pipelines that connect materiel sources and destinations.
3. Allocate available civil and military transportation resources among competing demands to meet wartime resupply needs.
4. Allocate available materiel among competing wartime resupply demands.

Our goal was to examine alternative techniques for accomplishing each of these tasks and to compare the resultant system performance with the current system’s performance.

The techniques we assessed are dynamic in that they take account of the distribution system’s current status and likely future work loads. They forecast the likely effects of decisions on the flows of cargo through the system and relate expected cargo flows to the capacities of the system’s nodes and networks. They also attempt to anticipate potential imbalances between the capabilities of the system’s components and the demands likely to be placed on those components. For example, we considered a procedure in which the decision to send

\(^5\)We use resupply pipeline to refer to the transportation networks through which resupply cargo flows, the transportation vehicles that move resupply cargo through the network, and the concept of operations that governs the use of these networks and vehicles. One theater may need different pipelines to support different movement requirements. For example, the management systems and transportation assets appropriate for supporting flows of critical spare parts or medical supplies to a specific theater might differ significantly from those appropriate for supporting flows of subsistence to that theater.
a specific shipment by air or sea depends not only on the shipment's priority, but also on the current performance and expected future work loads of strategic air and sea pipelines.

We also assessed the potential value of an enhanced priority system. Starting with the assumption that demands carrying the same UMMIPS priority can nonetheless be significantly different in terms of the importance of their being met, we investigated the degree to which the system's performance could be enhanced if system operators had information on the "true" importance of each demand rather than only UMMIPS information to guide their decisions.

**STRUCTURE OF THIS REPORT**

To investigate the effectiveness of the alternatives, we built a simulation model of an origin-to-destination resupply distribution system. We then simulated the system's response to a specified time stream of requisitions when either the current or an alternative procedure was used to accomplish each of the four management tasks under either the UMMIPS or the enhanced priority system. Our last step was to compare the results to estimate the relative contributions of the alternatives and the enhanced priority system to the distribution system's performance. Section 2 describes the model used and discusses the analyses performed to explore the sensitivity of the results to the simulation's assumptions.

The first alternatives we investigated were flow control procedures, our goal being to determine whether the distribution system's ability to manage the flows of materiel and transportation assets to one theater or to each theater of a multitheater contingency could be improved. We did not want limitations on materiel availability to reduce the quantity of cargo to be moved and thus ease the flow control problem, so we assumed unlimited materiel availability.\(^6\) Section 3 presents the results for these analyses when UMMIPS priorities were the only information available on the relative importance of requisitions and resulting shipments. For comparison, Section 4 then describes the results obtained when the analyses were replicated and an enhanced priority system was assumed to be available.

Section 5 describes the effects of adding a rapid response capability to the distribution system. To keep the focus on the issue of organizing

\(^6\)We are not suggesting that limitations on materiel availability will not be an important DoD concern in the future. Our goal here was to explore the likely effects of alternative flow control procedures on the movement of materiel through the distribution system. To focus on that issue, we ignored the question of materiel availability.
available transportation assets into resupply pipelines, we assumed unlimited materiel availability and a fixed allocation of transportation assets to each theater. We also assumed that the preferred flow control procedures and the enhanced priority system identified in Sections 3 and 4, respectively, were available.

Section 6 covers our analysis of the alternatives for allocating transportation assets among theaters. To focus the evaluation, we assumed the preferred flow control procedures and unlimited materiel stocks. Each alternative was evaluated with UMMIPS priorities and with enhanced priorities available to the system's operator so that we could explore the degree to which an enhanced priority system would affect the alternatives' performance.

Section 7 examines the last set of alternatives—i.e., those for allocating scarce materiel resources among theaters. To focus these analyses, we assumed that the available transportation resources were allocated between two theaters according to the preferred transportation allocation procedure identified in Section 6. We also assumed that the preferred flow control procedures were being used. And, as was the case for the analysis of transportation asset allocation, we supplied the system's operators with both UMMIPS and enhanced priorities to determine how an enhanced priority system would affect the alternatives' performance.
2. EVALUATING ALTERNATIVE RESUPPLY MANAGEMENT CONCEPTS

To investigate the value of alternative concepts for managing resupply operations, we first built a simulation model of an origin-to-destination resupply distribution system. We then specified either the procedure implied by the current system or one of the alternative procedures for managing resupply activities and simulated the distribution system's resulting performance. By comparing the results for different combinations of current and alternative procedures, we were able to estimate the degree to which each alternative improves the distribution system's responsiveness to a specified stream of requisitions.

We also tested the sensitivity of the results to the assumptions underlying the model. We did so by replicating the evaluation of each alternative concept, invoking different demand streams and different assumptions about transportation system performance.

GENERAL APPROACH TO THE EVALUATION

Criterion

Over the long term, DoD and civil-sector investments in the transportation infrastructure and transportation vehicles will determine the assets available for use in a contingency.\(^1\) Similarly, long-term procurement policies and programs will affect the kinds and quantities of materiel available at the outbreak of a conflict. When a contingency arises, the materiel distribution system must be able to effectively organize and manage whatever assets and materiel are available at that time. The standard for judging the concepts considered here is, accordingly, how much they enhance the materiel distribution system's ability to respond to warfighters' needs and priorities given the available transportation assets and materiel.

The importance of delivering any particular item on time depends on how urgently warfighters need that item. Given resupply demands and the corresponding deliveries, we can obtain an index of the dis-

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\(^1\)Other parts of the study of the DoD Future Distribution System analyzed trends in civil-sector investments in transportation facilities and vehicles and the need for DoD to invest in obtaining distribution capacities that the civil sector will not provide.
tribution system's performance—i.e., the number of days the system is late in meeting each demand, weighted to reflect the item's importance to the warfighters' goals and aggregated over all demands.

Method

The first step in the analysis was to specify a time-phased list of resupply demands in the form of requisitions for various commodities. Each requisition provided the needed commodity's class of supply, the requisition's UMMIPS priority, the submission date, and the required delivery date (RDD). We also assigned a "delay-weighting function" to each requisition to indicate the importance of meeting its RDD. This function associated a penalty for each day late in getting the demanded materiel to the customer.

Second, we specified the alternative management procedures to be tested and used the model to simulate the operations of the distribution system when those procedures were employed. The model provided an estimate of how long it would take to meet each of the resupply demands. When that estimate indicated that a requisition would not be filled by the RDD, we used the delay-weighting function associated with the requisition to compute a delay penalty.

Finally, we aggregated the delay penalties over the entire time-phased list to determine the aggregate delay penalty associated with using the specified alternative. We assumed that a simulation's aggregate delay penalty measured the performance of the distribution system when it employed the procedures invoked in that simulation, and that it indicated the degree to which the system managed to meet RDDs when its operations were governed by those procedures. We took the difference between the aggregate delay-weighted penalties for any two simulations to be a measure of the relative effectiveness of the concepts each employed.

MODEL CHARACTERISTICS

We specified resupply demands, transportation system characteristics, and other relevant factors only to the level of detail necessary to test the alternative concepts. We did not address the distribution system's ability to sustain any particular scenario; rather, we examined the effectiveness of the alternatives in different "situations" characterized by notional demands and a limited transportation system.
Resupply Demands

We considered three notional conflicts: a large contingency that gave rise to heavy demands for resupply materiel, a moderate contingency that gave rise to smaller demands but required transportation over greater distances, and a global contingency that combined the large and moderate conflicts. We thus were able to assess the alternatives’ performance in three separate tests. In all cases, the analysis extended over 100 days, with deployment beginning on day 1 and combat beginning on day 20.

We generated a time-phased list of resupply demands for a conflict in three steps: (1) estimate consumption by commodity class by applying a series of planning factors to an assumed profile of in-theater forces; (2) estimate the amount of materiel that would have to be delivered to the theater to meet the estimated consumption and maintain theater stocks at desired levels; and (3) develop a series of requisitions for the needed materiel, introducing uncertainty via random variations in requisition dates, quantities demanded, and RDDs.²

For step 1, we assumed that 14 divisions were deployed over the first 70 days of the large conflict and applied commodity consumption factors developed in past analyses of large European contingencies to the troop profiles to compute each commodity’s daily consumption. For the moderate contingency, we assumed that 5 divisions were deployed over the first 25 days of the conflict and applied commodity consumption factors developed in past analyses of Korean contingencies to the troop profiles to compute daily consumption by commodity.

For step 2, we computed the quantities of each commodity that would be needed in the theater on each day of the contingency to achieve a specified theater stock objective (e.g., 30 days of supply) given expected consumption and specified theater stocks at the outset of the contingency. We developed nine different time streams of resupply requirements corresponding to three assumptions about the initial levels of theater stocks and three assumptions about the theater stock objective. Initial theater stocks of each commodity were assumed to be either at the levels observed in Europe and Korea, respectively, in the late 1980s (“high” stock levels), at half those levels (“moderate”) or nil (“zero”). The theater stock objective was assumed to be either 30, 10, or 0 days of supply.

²We introduced much smaller random variations for items for which consumption is highly predictable (e.g., food) than for items for which demands are much less predictable (e.g., repair parts).
For step 3, we built a time stream of requisitions for each time stream of resupply requirements. We assumed that the predictability of resupply requirements varied by commodity and specified an anticipation time for each commodity, ranging from 30 days for food and personal items to only 2 days for repair parts. This anticipation factor was taken to reflect the average number of days by which requisitions precede the actual need for the materiel. If the anticipation factor for a commodity was N days, we assumed that the quantity required on any day was requisitioned over several days centered on N days earlier. We used random variables, generated by a negative binomial distribution, to determine the quantity of each commodity requisitioned each day to anticipate the computed requirement. Requisitions that would have been submitted before the first day of the analysis were accumulated and submitted on day 1.

We assigned an UMMIPS priority to each requisition in our time stream. The UMMIPS actually provides 15 priority designators, but they are clustered into three issue/transportation priority groups. Depots pick, pack, and ship in order of issue priority group (IPG), and the transportation system processes shipments in accordance with their transportation priorities (TPs). In terms of requisitions from and shipments to deployed units, the UMMIPS thus essentially devolves to a three-level priority system. Accordingly, in assigning UMMIPS priorities, we distinguished among requisitions only in terms of their IPGs, and between the resulting shipments only in terms of their TPs.

We also assigned to each requisition a "commodity-specific" (CS) priority that varied by commodity within each UMMIPS priority group. We saw these as the equivalent of more detailed information on the relative importance of a requisition than is provided by the UMMIPS. As such, we used them to explore the degree to which the distribution system's performance could be enhanced if an enhanced priority system were provided.

In sum, we built 27 time streams of requisitions based on our three different-size contingencies, three levels of initial theater stocks, and three theater stock objectives. For each assumed combination of initial theater stock level and theater stock objective, the large contingency's demands were about twice those of the moderate contingency, and the global contingency's demands were about 50 percent greater than those of the large contingency. Time streams that assumed 0 initial theater stocks generated the largest initial surges in demands because requisitions were submitted to both support current consumption and build theater stocks. Time streams that assumed the
theater wanted to build a 30-day stock of materiel generated the largest total demands. Of the 27 time streams of demands, the one that assumed moderate initial stocks and a 10-day theater stock objective was near the median in terms of both initial surge and total demands. Table 2.1 shows the range in the amount of materiel requisitioned both on day 1 and in total over the 100-day analysis period relative to the total amount requisitioned in the large contingency when moderate initial theater stocks and a 10-day stock objective were assumed.

We used these diverse time streams to test the robustness of our results. We did so by examining the effectiveness of each alternative procedure relative to the current system’s effectiveness for each time stream and then evaluating the results of those tests in terms of their consistency across the wide range of demands reflected by the time streams. Put another way, we viewed the alternative assumptions about contingency size, initial theater stocks, and theater stock objectives as ways to generate very different time streams of demands. By comparing the results for the alternatives to those for the current system across these very different time streams, we were able to explore the degree to which we could be confident that our results truly did reflect the relative performance of the alternatives.

Table 2.1

<table>
<thead>
<tr>
<th>Initial Theater Stock Objective (days)</th>
<th>Percentage Relative to Total Demands in the Large Contingencya</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contingency</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Day 1</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
</tr>
<tr>
<td>Zero</td>
<td>30</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
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<tr>
<td>Zero</td>
<td>10</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
</tr>
</tbody>
</table>

aModerate initial theater stocks and a 10-day theater stock objective assumed.
Transportation Assets and Capabilities

The modeled transportation system comprises five continental U.S. (CONUS) depots, one aerial port of embarkation (APOE) on each U.S. coast, one aerial port of debarkation (APOD) in each theater, two East Coast seaports of embarkation (SPOEs), two European seaports of debarkation (SPODs), one West Coast SPOE, and one SPOD in Korea. Although this system contained nowhere near the actual numbers of CONUS depots and CONUS and theater aerial ports and seaports, it nonetheless sufficed for addressing the basic issues of allocating airlift and sealift to establish resupply pipelines to each theater, allocating materiel between competing demands, and assigning particular shipments to appropriate pipelines.

The model assumed that depots had unlimited outload capacities and provided for unlimited CONUS transportation capacity. Transit times between each depot and port depended on the depot/port combination but were invariant per combination. POEs and PODs were assumed to have limited throughput capacities; congestion was assumed to set in, slowing throughput time, as the volume of materiel awaiting shipment in the port grew. Airlift and sealift capacities were set at approximately current values, and air and sea transit times between each POE/POD combination were invariant. Theater transportation had limited capacity and fixed transit times.

One set of tests assumed that transit times between any two nodes in the transportation system were equal to the average transit times actually observed for Army shipments between those nodes during 1989. These times generally exceeded the UMMIPS transit time standards. We refer to all results based on this assumption as being

---

3We modeled congestion as a reduction in a facility's daily throughput, where the size of the reduction depended on the amount of backlogged materiel at the facility that was waiting to be shipped relative to the facility's capacity. No congestion was assumed so long as the backlog was less than or equal to 10 days' capacity. If the backlog exceeded 10 days' capacity, the facility's throughput declined as the backlog grew until the backlog equaled 25 days' capacity, at which point throughput was seen as having declined 10 percent (to 90 percent of the facility's capacity). Backlogs equal to greater than 25 days' capacity had no further effect on throughput.

4We assumed a strategic airlift capacity of 48 million ton-miles per day. Strategic airlift resources were allocated to deployment operations through the first 15 days of each contingency and therefore were not available for resupply until day 16 of the simulation. We assumed that some sealift was available for resupply operations from the first day of the contingency. The amount of sealift available for resupply grew over the first 50 days of the contingency, reaching 2.5 million tons of capacity.

for "slow" transit times. Another set of tests assumed that transit times between nodes never exceeded the UMMIPS time standards. That is, for each segment, we used the observed average transit times if they were equal to or less than the UMMIPS standards, and we used the UMMIPS standard transit times otherwise. We refer to these results as being for "fast" transit times.

**Delay-Weighting Functions**

The importance of meeting any particular demand was represented in the model by a delay-weighting function. We used two different sets of delay-weighting functions to test the alternatives: the UMMIPS functions, which were based on the assumptions implicit in the current system's procedures, and the CS functions, which were based on the assumption that the importance of meeting various demands differs from one commodity to another.

Current procedures cluster all requisitions and the resulting shipments into three groups. Requisitions/shipments in the first group take precedence over those in the second group, which in turn take precedence over those in the third group. Within each group, requisitions/shipments are handled in the order of their RDDs, with those requiring the earliest delivery given precedence. These procedures imply that every requisition/shipment in the first group is more important than any in the second group and that every requisition/shipment in the second group is more important than any in the third group. They also imply that there are no differences among the requisitions/shipments within each group except in terms of delivery dates—i.e., the requisition/shipment with the closest RDD is the most important.

We defined the delay-weighting function as the number of days late in meeting a demand times a penalty for each day of delay. Table 2.2 shows the UMMIPS delay weights, or penalties, we attached to each

<table>
<thead>
<tr>
<th>UMMIPS</th>
<th>Penalty Incurred per Day of Delay for Days:</th>
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<tbody>
<tr>
<td>Priority Group</td>
<td>1-5</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
day late in meeting a demand. As can be seen, for each priority group, the weight assigned to each of the first 5 days of delay is doubled for each day late from day 6 to 25, and then doubled again for each day late from day 26 on. Moreover, the penalty assigned to each IPG 1 requisition for each day late is larger than that assigned to any IPG 2 requisition, regardless of delay length. IPG 2 requisitions in turn are assigned a larger penalty for each day late than are IPG 3 requisitions. And within each group, larger penalties are assigned for each day late as the time between requisition submission and materiel delivery increases. Also, as is true in the current system, nothing but age distinguishes the requisitions/shipments in each group.

To explore the robustness of our results, we also defined nine other sets of UMMIPS delay-weighting functions and used them to evaluate the performance of the alternatives relative to that of the current system. The weights assigned to priority group 3 demands remained as shown in Table 2.2 in all nine sets. However, the weights assigned to priority group 2 demands for the first 5 days of delay were sequentially increased by 1 for each of the nine sets: from 5 to 6, then to 7, and so on through 14. These weights were then each doubled to produce the weights for days 6 through 25 for the nine sets, and then doubled again to produce the weights for day 26 and up. For priority group 1, the weights assigned to the first 5 days of delay were always equal to the sum of the highest weight assigned to any priority group 2 demand for the particular set plus 1. These weights were then doubled for days 6 through 25, and doubled again for day 26 and up. Table 2.3 shows the penalty weights used in the first and last of these nine additional sets of UMMIPS delay weights.

Table 2.3
UMMIPS Delay-Weighting Functions:
Versions 2 and 10

<table>
<thead>
<tr>
<th>UMMIPS Priority Group</th>
<th>Penalty Incurred per Day of Delay for Days:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5</td>
</tr>
<tr>
<td>Version 2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
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<tr>
<td>3</td>
<td>1</td>
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<tr>
<td>Version 10</td>
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<tr>
<td>1</td>
<td>57</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
The other set of delay-weighting functions, the CS functions, was used to see how the alternatives fared when we assumed requisition/shipment importance could vary within a priority group by more than just RDD. To each UMMIPS priority group 1 demand, we assigned one of three weights; to each UMMIPS priority group 3 demand, we assigned one of four weights—all depending on the commodity demanded.  

Table 2.4 shows the CS delay-weighting functions and the percentage of all requisitions to which each function was assigned in a representative time stream of demands. As can be seen, the rate of penalty points accumulated now varies within priority groups. For example, of the 12 percent of all requisitions assigned to priority group 1, 3 percent accumulate penalties at one rate, 6 percent at another rate, and the remaining 3 percent at yet another rate. The penalties assigned for each day late to priority group 1 requisitions are generally larger than those assigned to priority group 2 requisitions, and those assigned to priority group 2 requisitions are generally larger than those assigned to priority group 3 requisitions. Moreover, within each group, the penalties increase for each day late as the time between requisition submission and materiel delivery increases. The only way in which these functions differ from the UMMIPS delay-

Table 2.4

<table>
<thead>
<tr>
<th>UMMIPS Priority Group</th>
<th>Percentage of Demands</th>
<th>Penalty Incurred per Day of Delay for Days:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-5</td>
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<tr>
<td>1</td>
<td>3</td>
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<td>6</td>
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<tr>
<td>2</td>
<td>13</td>
<td>4</td>
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<tr>
<td>3</td>
<td>30</td>
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<tr>
<td></td>
<td>29</td>
<td>3</td>
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<tr>
<td></td>
<td>11</td>
<td>1</td>
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<tr>
<td></td>
<td>6</td>
<td>1</td>
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</tbody>
</table>

6We thought that our use of different functions for priority group 1 and 3 requisitions/shipments would suffice in testing the alternatives and thus saw no need to similarly distinguish among priority group 2 requisitions/shipments.

7Because of the random variations introduced in building a time stream of demands, the precise share of requisitions assigned each delay-weighting function varies slightly from one time stream to another.
weighting functions is that they distinguish among the requisitions in each UMMIPS group by commodity.

RUNNING A SIMULATION

The model stepped through time, one day per step, carrying out the following tasks:

1. Read in all requisitions that arrive on the current day.

2. Forecast future demands. (The model does not "look ahead" at the requisitions that will be submitted in the future. However, if the procedure(s) being evaluated allows for forecasts, the model uses the assumed troop profiles and consumption factors to forecast expected future demands.)

3. Determine which requisitions are to be filled and which POE-POD link will be used for the resulting shipment. (The specifics of this process are discussed in more detail in Section 3.)

4. Move shipments through the system as follows:

   a. For requisitions that have not yet started through the system, place those that have been assigned a route in the appropriate depot-POE pipeline.

   b. For requisitions in depot-POE pipelines, determine which ones have been in the pipeline long enough to have arrived at the POE.

   c. For shipments at the POE, determine which ones have yet to be loaded. If there is room on the ship/aircraft, load the oldest shipments first, subject to the capacity of the ship/aircraft.

   d. If it is the scheduled departure time for the ship/aircraft (the end of each day, in our analysis), have the carrier depart the POE and start toward the POD. Make another, empty ship/aircraft available for loading.

   e. Determine the time at which the carrier is to arrive at the POD. For each carrier that arrives at a POD, unload the shipments and start them on their way to the customers.

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8The effect of congestion at a port is modelled by reducing the rate at which vehicles (aircraft or ships) are loaded there.
f. When the shipments arrive at the customers, determine whether they met their RDDs and, if not, compute the delay-weighted penalties.

5. Go back and do another day.

No requisitions were submitted after day 100, the “conclusion” of the hypothesized conflict. We continued to run the model and compute delay-weighted penalties until all the demands levied on the system through day 100 had been filled. There are two ways to handle requisitions left unfilled after day 100: they can be instantaneously filled, or the program can continue to run, filling and delivering requisitions but not receiving new ones, until the system has cleared. We chose the latter alternative in our analysis.
3. CONTROLLING THE FLOWS OF RESUPPLY MATERIEL

Using the model described in Section 2, we first tested the effectiveness of alternative concepts for directing flows of resupply materiel into and through resupply pipelines. We carried out multiple simulations of each alternative to determine the effects of the different assumptions on the distribution system's performance. Specifically, we simulated current and alternative system performance for each of the nine different time streams of requisitions in the three contingencies: large, moderate, and global (i.e., simultaneous large and moderate). In each case, performance for both of the defined transportation times, slow and fast, was evaluated.

We scored current and alternative system performance in each simulation according to our two different standards. The first, labeled "UMMIPS" in the tables presented here, assumes that the relative importance of meeting a demand on time depends only on the initiating requisition's UMMIPS priority group, which means it also assumes that all requisitions in the same UMMIPS priority group have the same importance. The second, labeled "CS" in the tables, assumes that the relative importance of meeting a demand varies from one class of commodity to another within each UMMIPS priority group.

For these analyses, we assumed unlimited CONUS stocks of materiel and a fixed allocation of transportation resources for delivery to the theater. These assumptions allowed us to focus on alternative techniques for managing the flows of cargo and transportation vehicles to a theater, leaving aside the issues of allocating materiel and transportation resources among theaters.

THE CURRENT SYSTEM

Resupply operations are actuated by requisitions, each of which indicates a commodity, a quantity needed, an RDD, and an UMMIPS priority. Requisitions that cannot be filled out of theater stocks are automatically directed to the national inventory control point (NICP) that manages the requested materiel. The NICP determines whether the requisition will be supplied out of depot stock or directly from a vendor and then sends a materiel release order to the appropriate source. Depots cluster requisitions into IPGs and pick, pack, and ship
materiel in order of IPG. Within an IPG, requisitions are handled according to their RDDs, with those requiring the earliest delivery given precedence.

The current system moves dry cargo through one of two general-purpose resupply pipelines. One is organized around strategic airlift, the other around strategic sealift. Each includes several loosely coupled transportation networks running from depots through consolidation points, POEs, and PODs to storage points in the theater. When materiel is ready for shipment, the depot transportation officer arranges for the movement of cargo to a POE. Each shipment is assigned a TP on the basis of its UMMIPS priority designator. TP1 and TP2 shipments are eligible for air shipment and are directed to the APOE designated for the requisitioner; TP1 shipments taking precedence over TP2 shipments. The remaining shipments, those assigned a TP3, are directed to the SPOE designated for the requisitioner. In all cases, shipments assigned the same TP are handled in the order of their respective RDDs, with those needed earlier given precedence.

The airlift and sealift allocated to a theater operate in channels between CONUS POEs and theater PODs. Cargo flowing into a POE is held until lift becomes available, at which point it is loaded in TP order and, within each TP, in order of arrival at the POE (first-in-first-out [FIFO]) until the vehicle is fully loaded. Vehicles are dispatched when loaded and are offloaded as they arrive at PODs. The cargo is then moved onward to the user.

Cargo flows freely through each pipeline, possibly building queues and incurring delays due to congestion at each node. Because of the way queues are handled, critically needed materiel can be delayed while less-important materiel that precedes it in the queue is shipped. Queues thus can reduce or eliminate the feasibility of attempting to expedite urgently needed commodities.

**ALTERNATIVE: DYNAMIC SCHEDULING OF CARGO FLOWS**

An alternative approach is to dynamically schedule cargo flows through the established pipelines, timing shipments from depots to nodes to limit congestion. Buffer queues of materiel awaiting shipment could be built up at each node to allow it to continue to operate

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1As noted earlier, a resupply pipeline includes the transportation networks through which cargo flows, the transportation vehicles used to move cargo through the network, and the concept of operations that governs the use of those networks and vehicles.
for a time even if "upstream" activities were disrupted. Requisitioned materiel would be released to the depot or storage area in time to be shipped to the designated POE, and shipments would be timed to minimize the weighted days of delays incurred for all requisitions currently in the system or anticipated.²

**Testing the Alternative**

To test this concept, we simulated deliveries in the current system and then in an alternative system that dynamically scheduled shipments to minimize the expected weighted days of delay. We modelled the current system by filling each requisition as it arrived and immediately dispatching the resulting shipment to the POE, regardless of how congested it was. TP1 and TP2 shipments were sent to the APOE serving the theater; TP3 shipments were routed to the SPOE designated for shipments to the customer. Shipments were loaded onto strategic carriers in FIFO order.

In the alternative system, requisitions were also filled as they arrived. However, materiel was shipped only until the amount of materiel queued at a POE to wait for lift equalled the capacity of the vehicles scheduled to arrive at that port over the next 10 days. Thereafter, arriving requisitions were sorted according to their designated POEs. All requisitions for a POE were then queued in order of their UMMIPS priority group, and by RDD within each priority group. In each subsequent cycle, the amount of materiel shipped from each POE the previous day was computed, along with the amount of materiel in transit to each POE and the capacity of the lift scheduled to arrive there over the next 10 days. Requisitions were then released from the queue, in the order of their priority groups and RDDs, so that the resulting shipments to each POE would maintain the 10-day backlog at that port.³

**Results**

Table 3.1 presents the results of the simulations for time streams of requisitions corresponding to the large contingency. They are ex-

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²Another advantage of queuing requisitions and shipping materiel in time to maintain buffers is that these procedures facilitate materiel allocation schemes for dealing out scarce resources. Section 7 discusses this point in further detail.

³The length of the buffer at the POE, 10 days, was selected solely to test the alternative concept. The optimal size of a buffer against unforeseen delays likely varies from port to port, depending on factors outside the scope of this analysis.
Table 3.1
Marginal Effects of Dynamically Scheduled Cargo Flows on System Performance in a Large Contingency

<table>
<thead>
<tr>
<th>Initial Theater Stock</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UMMIPS Scoring</td>
</tr>
<tr>
<td></td>
<td>Transportation Times</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
</tr>
<tr>
<td>Zero</td>
<td>30</td>
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<tr>
<td>High</td>
<td>10</td>
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<td>Moderate</td>
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<td>Zero</td>
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<td>High</td>
<td>0</td>
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<tr>
<td>Moderate</td>
<td>0</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
</tr>
</tbody>
</table>

pressed as the percentage reduction in aggregate weighted days of delay for the alternative system, compared to the current system, for each case. For example, the first entry in the table indicates the performance of the alternative system, relative to that of the current system, in response to the kind of time stream of requisitions that might obtain in a large contingency if initial theater stocks were high and the theater attempted to maintain theater stocks at levels sufficient to support 30 days of expected consumption. It shows that when the UMMIPS scoring standard was used, the alternative performed about 11 percent better than the current system for the slow (i.e., current) transportation times. It also shows the alternative’s corresponding relative performance when scored by the CS standard. By this measure, the alternative would provide about a 5 percent reduction in aggregate weighted days of delay compared to the current system.

The two scoring systems yielded consistent results in that both show the alternative improving system performance. The reason the improvements for the UMMIPS scoring standard are noticeably larger than the corresponding improvements for the CS scoring standard is that the latter allows variations in the delay-weighting functions assigned to demands within the same UMMIPS priority group, thereby reducing the differences between the demands in different priority
groups. Consequently, the improvements obtained via better scheduling of cargo flows are reduced.

Tables 3.2 and 3.3 present the related results for time streams of requisitions corresponding to the moderate and global contingencies, respectively. As can be seen, the alternative system consistently re-

<table>
<thead>
<tr>
<th>Initial Theater Level</th>
<th>Theater Stock Objective (days)</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>UMMIPS Scoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
<td>20</td>
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<tr>
<td>Zero</td>
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<td>18</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>19</td>
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<td>Zero</td>
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<td>16</td>
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<tr>
<td>Zero</td>
<td>0</td>
<td>20</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial Theater Level</th>
<th>Theater Stock Objective (days)</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>UMMIPS Scoring</td>
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<td></td>
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<td>Slow</td>
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<td>30</td>
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<tr>
<td>Moderate</td>
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<td>High</td>
<td>0</td>
<td>17</td>
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<tr>
<td>Moderate</td>
<td>0</td>
<td>17</td>
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<tr>
<td>Zero</td>
<td>0</td>
<td>18</td>
</tr>
</tbody>
</table>
duced the aggregate weighted days of delay by 10 to 20 percent depending on the assumed conditions. These reductions stemmed partially from the elimination of port congestion and partially from the more efficient use of available lift. Since materiel moves through pipelines on a FIFO basis in the current system, urgently needed materiel must wait its turn to traverse each segment as it moves along to the customer. By queuing requisitions until the distribution system is able to handle them reasonably expeditiously, the alternative keeps the system from becoming jammed with materiel awaiting shipment. Later-arriving requisitions for urgently needed materiel can be filled at once, and the resulting shipment can be moved through the system comparatively quickly.

Note that the results are consistent across the wide range of time streams of demands used to test the alternative. To illustrate this consistency further, Table 3.4 pulls together the results for the UMMIPS scoring standard when slow transportation times were assumed. Despite the very large differences between the various time streams of demands, the alternative's relative performance was consistently in the range of 10 to 20 percent.

**Sensitivity Analyses**

To further examine the robustness of the results, we repeated each test ten times, randomly varying the demands. We found that the random variations had almost no effect on the results. Consider, for example, the time stream of demands for the large contingency when moderate initial stocks and a 10-day theater stock objective were assumed (the median time stream in terms of both initial surge and total demands). The percentage improvement for the alternative over ten runs, assuming slow transportation times, ranged from a low of 12.0 to a high of 14.3, with a mean of 13.0 and a variance of 0.6. Given the assumptions used to generate each time stream of demands, the variation in the results obtained by randomly varying each time stream was small.

We also examined the effects of varying the penalty weights used to assess the effectiveness of the current and alternative systems.

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4For example, each of the three time streams of demands generated for the global contingency when a 30-day theater stock objective was assumed included an initial surge at least ten times greater than the initial surges included in the three time streams of demands generated for the moderate contingency assuming that theater stocks may be drawn down to zero. Similarly, there were three-to-one variations in total demands across the various time streams used in the tests reported in Table 3.4 (see Table 2.1).
Table 3.4
Marginal Effects of Dynamically Scheduled Cargo Flows on System Performance for Different Assumptions Regarding the Time Stream of Demands

<table>
<thead>
<tr>
<th>Initial Theater</th>
<th>Theater Stock Objective (days)</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Contingency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
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<tr>
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<td>30</td>
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</tr>
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</tr>
<tr>
<td>Zero</td>
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<td>11</td>
</tr>
<tr>
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<td>16</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Zero</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>

$^a$UMMIPS scoring and slow transportation times assumed.

Specifically, we used ten different sets of delay weights to compute penalties for the two systems for each simulation described in Tables 3.1, 3.2, and 3.3. Here, too, the results were insensitive to the variations. For example, for slow transportation times, the percentage improvement for the alternative system for the large contingency and median time stream of demands ranged from a low of 12.1 to a high of 14.5, with a mean of 13.4 and a variance of 0.6.

The differences among the 27 time streams of demands gave rise to far greater variation in results than did variations of any one time stream or of the delay-weighting function.

ALTERNATIVE: DYNAMIC ROUTING OF CARGO FLOWS

In the current system, cargo flows are routed to air and sea pipelines without regard to available lift capacities. Materiel issued in response to a requisition is routed to a pipeline solely according to its UMMIPS TP. The system does not match the quantity of cargo assigned air-eligible TPs to the available airlift capacity. The services do have air-challenge programs, but they are not designed to identify and redirect cargo flows that exceed airlift allocations.$^5$ Con-
sequently, the current system must rely on ad hoc methods to assure that aggregate cargo flows to APOEs do not exceed the total capacity of the air resupply pipeline and thus cause congestion and delays.

The assignment of cargo to sea transport is similar. There are no means for ensuring that the amount of cargo routed to an SPOE will match the available capacity. The result can be congestion and delays.

There are also no explicit, formal links between warfighters' goals and priorities and the allocation of pipeline capacity. Warfighters must rely on informal means to ensure that scarce transportation assets are put to the use that best serves their needs.

An alternative to the current system is to dynamically route cargo flows to one or another resupply pipeline so as to make the most effective use of the existing capabilities. We tested this alternative concept by simulating a system in which cargo flows were dynamically directed to pipelines so as to minimize the aggregate weighted days of delay.

The alternative system used a three-step process to route cargo on a daily basis: (1) determine which requisitions are to be filled on the current day so that the resulting shipment can be immediately dispatched to the air pipeline, (2) determine which requisitions are to be held in the expectation that they can be filled and the cargo shipped via the air pipeline the next day, and (3) identify which shipments are to be sent via the sea pipeline on the current day. All remaining requisitions were held for the three-step processing the following day.

Step 1 relied on a computation of the marginal "cost," measured in weighted days of delay, of not immediately routing a shipment to the air pipeline. Available air pipeline capacity was allocated (allowing for depot-to-APOE time and the time expected to be spent in an APOE buffer queue) to those requisitions for which the marginal cost of not immediately using the air pipeline was greatest.

To determine the marginal costs, the requisitions submitted for the day were put in a single queue, regardless of their UMMIPS priority, along with any requisitions submitted earlier but not yet filled. For

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6Equate service. Although the specific challenge criteria vary across the services, they are all defined in terms of the shipment's size or weight or the requisition's age. None of them reflects the amount of lift available.

6In making the determinations in steps 2 and 3, the objective was to hold back shipments that were sufficiently important to have a good chance of warranting space in the air pipeline in the near term while diverting to sea those that were not.
each requisition, the technique computed the difference between the 
expected weighted days of delay if the requisition was filled and the 
cargo dispatched via the air pipeline the next day rather than imme-
diately. Requisitions were then sorted in order of this difference—i.e., 
the expected marginal increase in weighted days of delay if the cargo 
was not immediately released for air shipment—and requisitions 
from the head of the queue (those for which the marginal increase in 
weighted delay was greatest) were released until the resulting ship-
ments exhausted the air pipeline capacity.

Step 2 entailed deciding which unreleased requisitions should be held 
in the expectation that they would successfully compete for air 
pipeline capacity the next day. Planning factors and current force 
densities for the contingency being simulated were used to predict the 
requisitions that would be submitted the following day. These pre-
dicted requisitions were then merged with all remaining actual requi-
sitions, and the combined queue was sorted according to the 
marginal increase in weighted days of delay if the requisitioned ma-
teriel was not sent via air the following day. This marginal increase 
was calculated as the difference between the weighted days of delay if 
the materiel was sent via air the day after next versus the next day.7 
Requisitions were then drawn from this queue until the shipments 
equaled the next day’s expected air pipeline capacity. The actual 
requisitions drawn were tentatively scheduled for next-day shipment 
via the air pipeline; the predicted requisitions were discarded.

For the third step, the system sorted the requisitions left after the 
above two steps in order of the marginal increase in weighted days of 
delay if they were filled and the resultant cargo shipped via the sea 
pipeline the next day rather than immediately. Requisitions were 
then drawn from the queue and the resulting shipments dispatched to 
the nearest SPOE until sea pipeline capacity was exhausted. Any 
remaining requisitions were held for consideration the next day.

Table 3.5 presents the results of the simulations for the dynamic rout-
ing of cargo flows for time streams of requisitions corresponding to

---

7 When the volume of air-eligible shipments exceeds the available airlift capacity, 
some air-eligible shipments have to be sent via sea. Thus, shipments compete for air 
service. We assumed that shipments unable to successfully compete for air on the cur-
rent day and unlikely to successfully compete for air the next day would be unable to 
successfully compete for air any time in the near term and thus should be sent by sea.
Table 3.5
Marginal Effects of Dynamically Routed Cargo Flows on System Performance in a Large Contingency

<table>
<thead>
<tr>
<th>Initial Theater Stock</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UMMIPS Scoring</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
</tr>
<tr>
<td>Zero</td>
<td>30</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
</tr>
<tr>
<td>Zero</td>
<td>10</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
</tr>
</tbody>
</table>

The large contingency. These results indicate the additional improvement obtained when the dynamic cargo routing concept was added to the alternative system that included dynamic cargo scheduling. Thus, if the percentage reduction for a time stream of demands shown in Table 3.5 is added to its counterpart in Table 3.1, the result is the total improvement for a system using the two alternative concepts—dynamic cargo scheduling and dynamic cargo routing—relative to the current system.

For example, if the first entry in the third column of Table 3.5 is added to the corresponding entry for the same contingency (large) in Table 3.1, the result is 31 percent plus 11 percent, which means that adding dynamic routing to dynamic scheduling gives a total performance improvement of 42 percentage points relative to the current system.

Tables 3.6 and 3.7 present the corresponding dynamic cargo routing results for time streams of requisitions for the other two contingencies: moderate and global. As can be seen, compared to the current system, there is a dramatic reduction in the aggregate weighted days of delay for all three contingencies, the improvements ranging from 15 to 74 percent.

The improvements obtained with this technique are the product of air-eligible cargo being diverted from the air to the sea pipeline when
Table 3.6
Marginal Effects of Dynamically Routed Cargo Flows on System Performance in a Moderate Contingency

<table>
<thead>
<tr>
<th>Initial Theater Level</th>
<th>Theater Stock Objective (days)</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
<th>UMMIPS Scoring</th>
<th>CS Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Transportation Times</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
<td>63, 68, 50, 53</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
<td>60, 68, 47, 53</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero</td>
<td>30</td>
<td>61, 68, 48, 51</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
<td>67, 71, 55, 59</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>64, 71, 53, 58</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero</td>
<td>10</td>
<td>65, 71, 52, 58</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
<td>68, 73, 57, 61</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>68, 74, 56, 61</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
<td>64, 72, 53, 58</td>
<td>Slow</td>
<td>Fast</td>
</tr>
</tbody>
</table>

Table 3.7
Marginal Effects of Dynamically Routed Cargo Flows on System Performance in a Global Contingency

<table>
<thead>
<tr>
<th>Initial Theater Level</th>
<th>Theater Stock Objective (days)</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
<th>UMMIPS Scoring</th>
<th>CS Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Transportation Times</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
<td>54, 63, 37, 44</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
<td>53, 63, 35, 42</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero</td>
<td>30</td>
<td>52, 62, 34, 40</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
<td>59, 68, 45, 55</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>57, 69, 42, 52</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero</td>
<td>10</td>
<td>57, 68, 41, 50</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
<td>60, 72, 49, 61</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>58, 70, 45, 57</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
<td>57, 70, 43, 52</td>
<td>Slow</td>
<td>Fast</td>
</tr>
</tbody>
</table>

the available airlift cannot keep pace with the flow of shipments. Diverting the less urgently needed air-eligible cargo to sealift frees scarce airlift resources for the more urgently needed air-eligible cargo, which then encounters shorter queues and fewer delays en route and thus can be delivered more quickly than would otherwise be
the case. Moreover, the less urgently needed cargo that is diverted to sealift is delivered more quickly than if it had waited until airlift became available.

We also explored a variant of this procedure by calculating the marginal cost of not allocating air pipeline capacity to a shipment as the difference between the expected weighted days of delay if the shipment went immediately via the air pipeline versus immediately via the sea pipeline. We sorted the requisitions in order of this marginal cost of delay and then released requisitions for air shipment from the head of the queue until the resulting shipments exhausted the air pipeline capacity, keeping all other aspects of the alternative system as described above. The results were virtually identical to those in Tables 3.5, 3.6, and 3.7.

The precise method used to determine which cargo is directed to the air pipeline and which is diverted to sea will, of course, affect the overall results. However, even though we explored only fairly crude decision rules, both of our implementations of the alternative system offered not only significant improvements over the current system, but similar results as well. This latter outcome implies that the improvements stem from the basic concept rather than the specific implementation.

Because the alternative incorporating both dynamic scheduling and dynamic routing of cargo flows offered significant improvements compared to the current system, we used it throughout the remainder of the analysis.

SUMMARY

The current system fills requisitions as they arrive. So if the quantity of materiel to be shipped exceeds the capacity of the transportation assets, queues build, slowing each shipment's movement through the system. An alternative to the current system is to dynamically schedule cargo flows through the established pipelines, timing shipments from depots to nodes to avoid undue congestion.

When cargo flows were dynamically scheduled, the aggregate weighted days of delay were reduced by 10 to 20 percent depending on the assumed conditions. These reductions stemmed partly from the elimination of port congestion and partly from the more efficient use of available lift.

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8The detailed design of decision support systems is beyond the scope of this analysis. Our purpose was to test the effectiveness of the general concept.
The current system also assigns cargo to the air and sea pipelines without regard for available lift capacities. Aggregate cargo flows to APOEs thus can exceed the total capacity of the air resupply pipeline, causing congestion and delays. An alternative to this approach is to dynamically route cargo flows to ensure that materiel flows are directed so as to make the most effective use of the respective pipeline capabilities.

When this alternative was added to the system that employed dynamic cargo scheduling, system performance improved by an additional 10 to 60 percent. The result for the two concepts was thus a dramatic 20 to 80 percent reduction in the aggregate weighted days of delay compared to the current system.
4. ENHANCED PRIORITY SYSTEMS FOR FLOW CONTROL

The distribution system needs to transmit the relative importance of various cargo to numerous organizations and people involved in resupply operations. The format of the UMMIPS provides a convenient way to indicate the rank of requisitions and their resulting shipments, but the procedures used to establish UMMIPS priorities have serious limitations.

A frequent criticism is that the UMMIPS lacks discipline. UNDs are seen as subjective and difficult to interpret, and the rate of high-priority requisitions in peacetime is so great that it raises questions about the system's ability to identify the most-urgent needs in a wartime environment. During contingencies, FADs and consumption escalate, sharply increasing the number and rate of requisitions that fall into the high-priority groups.

Increased centralized visibility, improved decision support systems, and more-relevant criteria for resource allocation may lead to an alternative, more sophisticated priority system for the distribution of DoD resupply materiel. In particular, the development of specific criteria for each functional area or set of commodities could eliminate some of the ambiguity and uncertainty associated with the current UND criteria. Definitions and guidance could then be expressed in terms directly relevant to the specific functional areas or commodities.

Suppose, for purposes of this analysis, that the CS priorities attached to requisitions reflect the importance of each day late in meeting the RDDs. Our examination of the alternative techniques in Section 3 assumed that only the UMMIPS priorities were available to the system's operators, and thus that all resupply decisions made by those operators were based solely on the information conveyed by the UMMIPS. The CS scores given for those same alternatives reflected the degree to which system performance was improved according to the CS scoring standard even though the system's operators did not have the CS priorities available as guides for their decisions. Here, we describe our exploration of the degree to which system performance could be improved if operators had each requisition's CS priority available to them when making their decisions.
Using the alternative system incorporating both dynamic cargo scheduling and dynamic cargo routing, we again simulated deliveries, but this time we assumed that each requisition’s CS priority was available. The only difference was thus that in calculating the marginal cost of not allocating air pipeline capacity to a requisition, we used the CS delay-weighting functions to weight the days of delay. We assumed that because the operators knew the CS priority attached to each requisition, they could focus on minimizing the days of delay weighted by the CS delay-weighting functions.

Table 4.1 presents the results of the simulations expressed as the percentage reduction in CS weighted days of delay for the alternative system compared to the current system. These results show that the availability of enhanced priorities could improve system performance by 2 to 8 percent. That is, when the CS priorities were assumed to be available to the system’s operators, the alternative system’s performance improved by about 5 percentage points compared to its performance when only UMMIPS information was available.

<table>
<thead>
<tr>
<th>Initial Theater Stock Level</th>
<th>Theater Stock Objective (days)</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contingency</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>Transportation Times</td>
<td>Slow</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Zero</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Zero</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>
5. ESTABLISHING RESUPPLY PIPELINES TO A THEATER

The transportation resources allocated to a theater—ships, aircraft, trucks, ports, etc.—must be organized and operated so as to best meet resupply movement requirements. A theater may need various resupply pipelines to support different types of movement requirements. For example, the management systems and transportation assets appropriate to support flows of critical spare parts or medical supplies to a theater may be very different from those appropriate to support flows of subsistence to that theater. Naturally, managers of resupply operations are likely to base their decisions on the capabilities of available lift resources. But it is more efficient to plan ahead, to provide for alternative approaches for establishing wartime pipelines that more systematically take into account variations in lift resource capability and options for more integrative resource management. We modified our model to test the effectiveness of an alternative technique for establishing resupply pipelines to a theater.

THE CURRENT SYSTEM

Current DoD procedures establish essentially four kinds of resupply pipelines to each theater. The first of these handles the provision of bulk petroleum, oils, and lubricants (POL). It is managed by the Defense Fuel Supply Center, which has its own management systems and transportation assets. The second kind of resupply pipeline handles ammunition, which is generally segregated from other dry cargo, moved in accordance with concepts addressed specifically to ammunition movements, and shipped through unique SPOEs and, sometimes, unique SPODs. Flows of all resupply dry cargo other than ammunition are handled by the third and fourth kinds of resupply pipelines. The first of these two “general-purpose” pipelines uses strategic airlift and runs between APOEs and APODs; the other uses strategic seaport and runs between SPOEs and SPODs. Pipeline capacities are determined when transportation resources are allocated among theaters.

ALTERNATIVE: PERFORMANCE-ORIENTED PIPELINES

There is no reason to believe that one set of pipelines would be preferred in all circumstances. In fact, the appropriate set of resupply
pipelines to a theater depends on the DoD resupply movement requirements that have to be met. And movement requirements not only vary from one contingency to another, but are also likely to vary over time for a particular contingency. The best way to proceed is thus to adopt an approach that can, as the contingency develops, speedily take into account the relevant factors and systematically determine the most effective way to use the available transportation assets for the foreseeable future.

One possibility might be a DoD rapid response concept of operations (similar to that of express delivery services), which would employ strategic airlift in the context of an intermodal system managed origin-to-destination with high visibility and fast turnaround times. A DoD pipeline of this nature might be an effective means for meeting short-notice demands for expensive or rare items that need to be delivered quickly to fighting forces. Such was the case for the Desert Express fast delivery service inaugurated by the Military Airlift Command (MAC) in November 1990 in support of Operation Desert Shield. This service delivered items to Saudi Arabia in as little as 31 hours from the time they were requested.¹ Shipments were reserved for Desert Shield units' most critical needs.

Similarly, fast ships acquired to provide an enhanced deployment capacity might be available for resupply operations after completing their force deployment assignments. If they were, it would be helpful to define separate DoD management procedures to ensure the use of fast sealift in resupply activities for which rapid delivery was most beneficial. The rapid movement of resupply weapon systems and other major end items too large or heavy to be moved efficiently by air might be a particularly effective use of these assets.²

To take full advantage of the opportunities made available by different pipelines, origin-to-destination management will be needed to ensure that all phases of the cargo movement are synchronized. For example, the effectiveness of a separate pipeline built on fast shipping will depend on whether the movements of the premium cargo and ships are coordinated so that both arrive at the SPOE in a timely

manner. It will do little good to have cargo sitting on a dock awaiting a fast ship when it could have been delivered sooner via a slower vessel that was immediately available.\textsuperscript{3} Planning for the movement of materiel to POEs and then onward from PODs to points of issue is also needed to ensure that the distribution system performs effectively.\textsuperscript{4}

To test our performance-oriented pipeline concept, we modified the model to include a rapid response pipeline and then simulated how the resultant system would perform compared to the current system. We assumed that one-sixth of the available airlift capacity was devoted to the rapid response pipeline and five-sixths to the regular air pipeline.\textsuperscript{5} We then simulated deliveries assuming that materiel flows were dynamically directed to pipelines to minimize the aggregate weighted days of delay.

The alternative procedure used a five-step process to allocate pipeline capacity on a daily basis: (1) determine which requisitions are to be filled and the resulting cargo sent via the rapid response pipeline on the current day, (2) determine which requisitions are to be held in the expectation that they can be filled and the resulting cargo sent via the rapid response pipeline the next day, (3) determine which requisitions are to be filled and the resulting cargo directed to the air pipeline on the current day, (4) determine which requisitions are to be held in anticipation of filling them and sending the resultant cargo via the air pipeline the next day, and (5) identify the requisitions that are to be filled and the resulting cargo directed to the sea pipeline on the current day. Any remaining requisitions were held for processing the following day.

For step 1, all requisitions submitted for the day were placed in a single queue, regardless of their priority, along with requisitions submit-

\textsuperscript{3}The Desert Express service is an example of end-to-end planning. This service was originally organized around a daily flight departing Charleston Air Force Base at 1230. Charleston was selected as the CONUS APOE because its joint-use runway expedited commercial air express delivery to MAC; the 1230 departure was selected to dovetail with commercial overnight mail and parcel deliveries and with LOGAIR/QUICKTRANS flight schedules. (A second daily flight, departing Charleston at 1900, was later added to the service.)

\textsuperscript{4}The World War II "Toot Sweet Express" comprised a fast rail service between European ports and forward depots. It was developed to complement the fast shipping service and provide rapid origin-to-destination movement of urgently needed items. Ruppenthal, op. cit.

\textsuperscript{5}This one-sixth share is much larger than the share of airlift allocated to Desert Express. We are not suggesting that a rapid response pipeline be this large. We were concerned only with testing the general concept of a rapid response pipeline, not with specifying its appropriate capacity.
ted earlier but not yet filled. For each requisition, the procedure calculated the difference in the expected weighted days of delay if the requisition was held and the cargo released for rapid response shipment the following day versus filled and the cargo sent immediately via the rapid response pipeline. Next, the requisitions were sorted in order of the marginal increase in weighted days of delay if the material was not immediately released for rapid response shipment. They were then filled in order until the resulting shipments exhausted the rapid response pipeline capacity.

Step 2 involved deciding which requisitions should be held in the expectation that they would successfully compete for the rapid response pipeline capacity the next day. Planning factors and current force densities for the contingency being simulated were used to predict the requisitions that would be submitted the following day. These predicted requisitions were then merged with the remaining actual requisitions, and the combined queue was sorted in order of the increase in expected weighted days of delay each would incur if the requisitioned materiel was not sent via the rapid response pipeline the following day. Finally, requisitions were drawn from the head of the queue until the resulting shipments equalled the next day's expected rapid response pipeline capacity, and actual requisitions so drawn were tentatively scheduled for next-day shipment via that pipeline.

Analogous procedures were used for steps 3 and 4—i.e., to allocate the current day's air pipeline capacity and determine which of the requisitions that did not qualify for immediate air shipment should be held in the expectation that they would qualify for air shipment the next day.

For step 5, the requisitions not accounted for by steps 1 through 4 were sorted in order of the increase in weighted days of delay if they were filled and their cargo shipped via the sea pipeline the next day rather than immediately. Requisitions were then drawn from the queue and the resulting shipments dispatched to the nearest SPOE until sea pipeline capacity was exhausted. Any remaining requisitions were held for consideration the next day.

We found the performance of the system incorporating this alternative procedure, relative to the performance of the current system, to be essentially the same across the nine different time streams of requisitions for each of the three contingencies when scored by either the UMMIPS or the CS standard. We thus restrict the discussion here to the results for three representative time streams of requisitions for the large contingency and the CS standard.
Table 5.1 presents the results for the large contingency when the rapid response pipeline concept was established in the alternative system that included enhanced priorities and dynamic cargo scheduling and routing. These results suggest that a rapid response pipeline can meaningfully improve the performance of the alternative system. This improvement's magnitude is limited, however, by the inclusion of the alternative techniques for dynamic scheduling and routing of cargo flows. The rapid response pipeline improves the alternative system's performance by providing additional capability, but the effective use of the other two alternative techniques limits the opportunity for further improvements.

Table 5.1
Marginal Effects of Rapid Response Capability on System Performance in a Large Contingency

<table>
<thead>
<tr>
<th>Initial Theater Level</th>
<th>Stock Objective</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System Transportation Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>10</td>
<td>Slow 7 Fast 8</td>
</tr>
<tr>
<td>Moderate</td>
<td>10</td>
<td>Slow 6 Fast 6</td>
</tr>
<tr>
<td>Zero</td>
<td>10</td>
<td>Slow 5 Fast 6</td>
</tr>
</tbody>
</table>
6. ALLOCATING TRANSPORTATION RESOURCES AMONG THEATERS

In the event of a multi-theater contingency, the distribution system must be able to allocate transportation assets among theaters so as to establish the pipelines needed to support resupply operations. We used our model to test the effectiveness of alternative concepts for allocating transportation resources among theaters.

THE CURRENT SYSTEM

The Joint Strategic Capabilities Plan (JSCP) apportions strategic transportation resources for planning purposes. If an operation plan (OPLAN) is executed, the associated movement forecasts guide lift allocations during the initial weeks of the war. The Joint Transportation Board (JTB) allocates transportation capabilities to the supported commander in chief (CINC); the theater JTB assigns that theater's total strategic lift capability to deployment and resupply operations. The lift assigned to resupply is then allocated to the components.

The current system provides for the reallocation of transportation assets among theaters in response to changing needs. However, it does so only when those needs turn into problems that are serious enough to attract attention.

ALTERNATIVE: DYNAMIC ALLOCATION OF TRANSPORTATION RESOURCES IN PROPORTION TO MOVEMENT REQUIREMENTS

Even if the allocation of transportation resources developed in peacetime planning governs the initial phase of a contingency, resupply management systems should be able to systematically incorporate the experience of war as it unfolds. Estimated combat consumption rates may prove to be inaccurate indicators of actual wartime consumption, and the uncertainties of combat may lead warfighters to shift their

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goals and priorities and/or their unit deployments, causing resupply needs to vary from those anticipated when the OPLAN was prepared.

The distribution system's performance might be improved if transportation assets could be reallocated in anticipation of what could otherwise become serious problems. An alternative to the current method of allocating transportation resources among theaters is to forecast movement requirements for all theaters on an ongoing basis using recent consumption experience and updated forecasts of future resupply demands. The forecast demands would be compared to available stocks to estimate how well they matched. Transportation assets would then be reallocated to reflect the expected movement requirements.

To test this concept, we explored the performance of an alternative system in which airlift resources were dynamically reallocated among theaters in response to updated forecasts of movement requirements. Specifically, we initially allocated airlift resources between two theaters in proportion to each theater's expected movement requirements for air-eligible resupply demands (requisitions with UMMIPS TP1 or TP2) over the first 100 days of the contingency. Similarly, available sealift was allocated to each theater in proportion to that theater's expected movement requirements for UMMIPS TP3 resupply demands.

The initial airlift allocations were assumed to hold for the first two weeks of the contingency. At the beginning of the third week and of every week thereafter, the system updated the movement requirement forecasts using updated troop profiles and consumption factors to "predict" consumption for each theater from the first day of that week through day 100. The predicted future demands for each theater were then multiplied by the ratio of the demands submitted by that theater to the predicted demands for that theater for the same period. In other words, we assumed that the predictions for the future would be as inaccurate as the past predictions had proved to be. The future TP1 and TP2 shipments to each theater were then predicted, and the expected future demand for airlift was added to the air-eligible demands from that theater that had been submitted earlier but not yet shipped. The system then reallocated airlift resources between the theaters in proportion to the updated predictions of movement requirements to each theater.\(^2\) We did not modify the initial sealift allocations throughout the simulations.

\(^2\)We made no attempt to account for the short-term losses in airlift capacity that might be experienced while airlift assets are being transferred between theaters.
To test the robustness of this concept for the case in which initial expectations prove inaccurate, we simulated the current system's performance for the global contingency for time streams of requisitions consistent with initial expectations and inconsistent in that they were either systematically less than or greater than estimated. We focused on the relative performance of the alternative technique when demand forecasts were misestimated and examined the performance of the current and alternative systems in response to variations in the median time stream of demands (i.e., the one that assumed moderate initial theater stocks and a 10-day stock objective). We used that time stream as the base case and then considered two variations: (1) a systematic increase in the demands of the larger of the two theaters by 5 percent over the base case, accompanied by a reduction in the smaller theater's demands by 10 percent; (2) a systematic increase in the larger theater's demands by 10 percent over the base case, accompanied by a reduction in the smaller theater's demands by 20 percent.

We first carried out the analysis assuming that only the UMMIPS priorities were available to the system's operators, using both the UMMIPS and the CS scoring standards to measure system effectiveness. We then replicated the analysis assuming that the system's operators were provided with the enhanced, CS priorities.

Table 6.1 presents the results. As can be seen by the first two rows of percentages, dynamic allocation of airlift capacity does little to improve system performance when the operators have only UMMIPS information and initial expectations either prove accurate (base case demand stream) or vary from the actual demands by only 5 to 10 percent (variant 1). The reason for these outcomes is that when initial expectations are accurate, initial allocations are consistent with experience. There thus is no need to reallocate, which means the ability to dynamically reallocate transportation resources offers little advantage.

The results for the variant 2 demand stream are more interesting. They show that the improvement provided by being able to update movement requirement forecasts and reallocate airlift resources accordingly is somewhat greater if initial expectations prove to be less accurate (i.e., 10 to 20 percent off).

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3Here and in the ensuing tables, negative entries indicate that the alternative performed worse than the current system.
Table 6.1
Marginal Effects of Dynamically Allocating Airlift in Proportion to Movement Requirements in a Global Contingency

<table>
<thead>
<tr>
<th></th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
<th>UMMIPS Scoring</th>
<th>CS Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transportation Times</td>
<td>Slow Fast</td>
<td>Slow Fast</td>
</tr>
<tr>
<td>With UMMIPS information</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base case</td>
<td>1 0</td>
<td>0 -1</td>
<td></td>
</tr>
<tr>
<td>Variant 1</td>
<td>4 4</td>
<td>-1 -1</td>
<td></td>
</tr>
<tr>
<td>Variant 2</td>
<td>6 10</td>
<td>3 4</td>
<td></td>
</tr>
<tr>
<td>With enhanced priorities</td>
<td></td>
<td>0 0</td>
<td></td>
</tr>
<tr>
<td>Base case</td>
<td></td>
<td>0 0</td>
<td></td>
</tr>
<tr>
<td>Variant 1</td>
<td></td>
<td>0 0</td>
<td></td>
</tr>
<tr>
<td>Variant 2</td>
<td></td>
<td>4 5</td>
<td></td>
</tr>
</tbody>
</table>

The results of the simulations in which CS priorities were assumed to be available to the system's operators appear in the last three rows of Table 6.1. The differences between these results and the corresponding ones in the first three rows indicate the extent to which the performance of the alternative concept (relative to that of the current system) would be improved if an enhanced priority system were available. As can be seen, the effects of dynamic airlift reallocation are about the same whether or not enhanced priorities are made available to the operators.

ALTERNATIVE: DYNAMIC ALLOCATION OF TRANSPORTATION RESOURCES IN RESPONSE TO OPPORTUNITY COSTS

The amount of lift capacity required to move a given quantity of materiel to a theater varies with distance. Allocating strategic lift among theaters in proportion to movement requirements does not take into consideration the opportunity costs of allocating transportation resources to more distant theaters. For example, Korea is approximately 6000 miles from CONUS by air, a distance roughly twice that from CONUS to Europe by air. The airlift capacity needed to move X tons of materiel to Korea could thus move approximately 2X tons of materiel to Europe. In allocating airlift between these two theaters, it might be worthwhile for decisionmakers to weigh the rel-
ative importance of delivering $X$ tons to Korea versus $2X$ tons to Europe.

An alternative way to allocate transportation resources among theaters is to enhance the concept just discussed—forecasting movement requirements on an ongoing basis and reallocating transportation resources in anticipation of those requirements—by also taking account of the opportunity costs of allocating lift to more distant theaters.

To test this concept, we explored the relative performance of an alternative system in which airlift resources were dynamically reallocated among theaters in response to updated forecasts of movement requirements weighted by the distance to each theater. Specifically, we initially allocated airlift resources between Europe and Korea in proportion to each theater's expected movement requirement for air-eligible (TP1 or TP2) resupply demands over the first 100 days of the contingency. Similarly, available sealift was allocated to each theater in proportion to the expected movement requirements for UMMIPS TP3 resupply demands.

As before, the initial airlift allocations were assumed to hold for the first two weeks, and the procedure described above was used to update movement requirement forecasts. The forecast airlift movement requirements for resupply of each theater were then weighted by the inverse of the distance to the theater, and airlift resources were reallocated between the theaters in proportion to the weighted movement requirements. Airlift resources were allocated between theaters so that the marginal contribution of the last unit of airlift capacity allocated to each theater, measured in terms of the consequent reduction in weighted days of delay, was the same across theaters.

Table 6.2 presents the results. Except for the weighting of the forecast airlift movement requirements, the simulations carried out were exactly as described above for the first transportation resource allocation technique. As can be seen, the UMMIPS-only results for the base case demand stream for this alternative are slightly better than those obtained for the previous alternative (see Table 6.1). Thus, even when forecasts of movement requirements prove accurate, somewhat improved performance can be obtained by considering opportunity costs when dynamically reallocating transportation resources.

What we saw earlier for the variant demand streams when only UMMIPS information was available was that dynamic allocation of airlift capacity in proportion to movement requirements improved
system performance when initial expectations proved erroneous. The results here suggest that reallocation with a view to opportunity costs will offer one and a half to twice the improvement achieved when opportunity costs are not considered.

For the enhanced priority system, Table 6.2 shows that when the CS priorities are assumed to be available to the operators, consideration of the opportunity costs of allocating airlift resources to one theater rather than another could improve performance by 3 to 4 percent.

We did not explicitly address the extension of this concept to the dynamic allocation of sealift resources, but the principles would be the same. If initial expectations of resupply demands prove erroneous, movement requirement forecasts will be correspondingly inaccurate, and sealift allocations based on those forecasts will be inefficient. By updating movement requirement forecasts in the light of experience, sealift resources can be reallocated as appropriate.
7. MATERIEL ALLOCATION

The demands of a global contingency may exceed the available stocks of some materiel. The distribution system thus must be able to allocate scarce materiel so as to best meet warfighters' needs. In this section, we turn from the subject of enhancing materiel movement to that of improving stock management.

THE CURRENT SYSTEM

Logistics, including materiel management, is largely a service responsibility. In wartime, the Joint Materiel Priorities and Allocation Board (JMPAB) addresses interservice materiel allocation issues on a management-by-exception basis. However, because the JMPAB may be hard pressed to render time-sensitive decisions or consider more than a few specific items, some materiel allocation problems may never reach the JMPAB or may not be handled soon enough to avoid misallocations.

Absent JMPAB intervention, materiel is allocated in wartime by the Military Standard Requisitioning and Issue Procedures (MILSTRIP), the Defense Logistic Standard System that governs materiel requisitioning and issue. MILSTRIP mandates that requisitions be processed in sequence according to their UMMIPS priority designators. Within each priority designation, certain requisitions can be marked for expedited handling, but all remaining requisitions are filled in order of receipt. For all practical purposes, the current system thus allocates materiel on a FIFO basis. And when stock levels for an item are exhausted, requisitions for that item are held until additional stocks become available.

Neither the UMMIPS procedures for determining a requisition's priority designator nor the MILSTRIP procedures for issuing materiel in response to requisitions consider available materiel stocks, procurement lead times, or competing materiel requirements across theaters and military services and over time. Low-priority requisitions may be filled as they arrive, leaving inadequate stocks to meet later-arriving,

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2Requisitions that bear OSD/JS (Office of the Secretary of Defense/Joint Staff) project codes or are for not-mission-capable supply (NMCS) are processed before other requisitions with the same priority designator.
higher-priority requisitions. And one theater or, in the case of a common-use item, one service may "empty the bins" before the needs of another theater or service are considered.

ALTERNATIVE CONCEPTS

Stock Reservation

An alternative concept for allocating scarce materiel among competing needs is to reserve specified quantities or proportions of available stocks for specified customers to ensure that some stocks will be available for them regardless of the requisitioning activities of other customers. For example, a specified proportion of the available stock of an item might be reserved for each theater. Requisitions from a specific theater for that item would then be filled until that theater exhausted its allocation. Subsequent requisitions for the item from that theater would be backordered until additional stocks of the item were obtained.

Control Levels

Another alternative technique is to use control levels to limit the probability that a high-priority requisition will go unfilled because low-priority requisitions have exhausted the available stocks. In this concept, lower-priority requisitions are filled until available stocks drop to specified levels, at which point only higher-priority requisitions are filled. For example, IPG3 requisitions might be filled so long as available stocks exceeded 10 days of supply, IPG2 requisitions so long as stocks exceeded 5 days of supply, and IPG1 requisitions in all cases.

Control levels can be established for all customers or combined with stock reservations to apply to specific customers. For example, the Air Force has developed a concept for a wartime wholesale allocation system that would introduce control levels into the basic notion of a stock reservation system. Available stocks would be allocated among theaters on the basis of projected weapon-system flying hours, an application factor, and theater demand rates. Control levels would be established within each theater to release materiel by priority group so as not to deplete the stocks reserved for that theater.

Dynamic Materiel Allocation

Another possibility is to make dynamic materiel allocation decisions on the basis of both expected and current demands. The materiel al-
located in this way would then be shipped or not shipped depending on the availability of the transportation resources.

TESTING

For these tests, we explored the relative performance of a simplified version of the distribution system when materiel was distributed in accordance with the current system's procedures and with each of the three alternatives. (As before, dynamic cargo scheduling and routing were assumed in the alternative systems.) In each case, we simulated system performance for the global contingency for the median time stream of requisitions (i.e., the one corresponding to moderate initial theater stocks and a 10-day theater stock objective).\(^3\) We also considered a variant of this base case time stream in which demands in the larger theater were increased by 5 percent and demands in the smaller theater were decreased by 10 percent. As before, the simulations that used the base case time stream tested the efficacy of the alternative concepts when initial predictions proved accurate; the simulations that used the variant time stream tested the efficacy of the concepts when initial predictions proved inaccurate.

Because a materiel allocation procedure must be able to effectively deal with shortfalls regardless of how severe they are or when they occur, we tested the alternative concepts' responses to different kinds of shortages. We did so by replicating the analysis for three different assumptions regarding CONUS stocks at the outset and the rate at which additional stocks became available from new production. To simplify the analysis, we assumed that CONUS stocks of all commodities other than major end items (class VII) and repair parts (class IX) were sufficient to meet all demands throughout the contingency.

The first set of simulations assumed that initial CONUS stocks of major end items and repair parts were sufficient to meet all demands expected for the first 30 days. It also assumed that new production would begin to deliver additional stocks of these items at day 30, and that the rate of new production would be such that the sum of the initial stocks and the newly produced items through the first 100 days would equal the total expected demands over the first 100 days of the contingency. In other words, these simulations assumed that, on average, sufficient materiel would be available to meet all demands

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\(^3\)Our earlier analyses had demonstrated that alternative assumptions regarding initial theater stocks and the theater stock objective did not significantly affect the relative efficacy of the current and alternative management concepts.
throughout the contingency, but that variations in demands would cause temporary shortfalls from time to time. These simulations thus tested the effectiveness of the alternative concepts for smoothing day-
to-day fluctuations in materiel availability. Their results are labeled "transitory shortfalls" in the tables.

The second set of simulations made the same assumptions about new production as the first set but assumed that initial CONUS stocks of major end items and repair parts could meet only one-half of the demands expected over the first 30 days. These analyses thus tested each alternative's ability to cope with a severe shortfall at the outset of the conflict. The results for these analyses are labeled "early shortfalls" in the tables.

The third set of simulations assumed that initial CONUS stocks of major end items and repair parts were sufficient to meet expected demands for the first 30 days but that no additional stocks would become available from new production through day 100. In other words, stocks were sufficient to meet the initial surge, but shortfalls then arose and continually worsened over the course of the contingency. These simulations tested each alternative's ability to manage the problem of reserving stocks for later-arriving requisitions. The tables refer to these results as "late shortfalls."

We also looked at the effects of two assumptions about transportation system performance. First, we assumed that transportation resources were unlimited—i.e., that all UMMIPS TP1 and TP2 shipments would be sent via air, all TP3 shipments would be sent by sea, and the quantity of materiel allowed to move through any particular segment of the transportation system at any given time was unconstrained. The results for this assumption indicate the relative effectiveness of the current and alternative approaches to materiel allocation when the effects of constrained transportation resources are not considered.

Second, we assumed that transportation resources were limited. For this case, sea capacity was distributed between the theaters in proportion to the expected total demands for sea transport and not modified over the course of the simulation. Air capacity was initially distributed between the theaters in proportion to the expected total demands for air transport, and was then reallocated between the theaters on a weekly basis via the dynamic allocation procedure described in Section 6. Performance for both slow and fast transportation times was simulated.
RESULTS

Once again, we used both the UMMIPS and the CS scoring standards. Performance outcomes are given for the base case and variant time streams under the three materiel availability assumptions, two transportation resource assumptions, and two transportation time assumptions.

Stock Reservation

To assess the potential effects of the stock reservation concept, we simulated the system’s performance when initial CONUS stocks and new production of each commodity were allocated to each of two theaters in proportion to their respective shares of total expected base case demands for that commodity. Requisitions for an item from each theater were filled in UMMIPS priority order, and FIFO within each UMMIPS priority group, until the theater’s reserve for that item was depleted. At that point, any further requisitions from the theater for that item were held until additional stocks became available. Materiel reserved for one theater was never used to fill a requisition from the other theater.\(^4\)

Table 7.1 presents the results for the stock reservation concept. As can be seen, this technique does not offer an improvement over the current system in any of the cases examined. In fact, it is outperformed by the current system in several cases, most noticeably in those for which unlimited transportation resources were assumed.

The reason behind these results is that the use of stock reservations affects system performance whenever a requisition for an item from one customer goes unfilled solely because the remaining stock of that item is reserved for another customer. Assuming that the item will eventually be issued to the customer for whom it was reserved, the net effect of the procedure depends on the importance of the demand that went unfilled (because the materiel was reserved for another customer) relative to the importance of the demand that will be filled. If, as we assumed, the demands from one theater are not systematically more important than those from the other theater, requisitions that go unfilled because of the procedure are, on average, as important as those that are filled.

\(^4\)We are not implying that materiel should be reserved for each theater in proportion to its expected demands. One theater may be deemed significantly more important than another and therefore allocated a disproportionate share of the available materiel, for all items or for selected items.
Table 7.1
Marginal Effects of Stock Reservation Concept

| Percentage Reduction in Weighted Days of Delay Relative to Current System |
|--------------------------|--------------------------|
| UMMIPS Scoring          | CS Scoring               |
| Transportation Resources|                          |
| Unlimited               | Limited                  |
| Slow                    | Fast                     |

<table>
<thead>
<tr>
<th>Base case</th>
<th>Slow</th>
<th>Slow</th>
<th>Fast</th>
<th>Slow</th>
<th>Slow</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitory shortfalls</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Early shortfalls</td>
<td>-5</td>
<td>1</td>
<td>-1</td>
<td>-7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Late shortfalls</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>-1</td>
<td>2</td>
</tr>
<tr>
<td>Variant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transitory shortfalls</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Early shortfalls</td>
<td>-4</td>
<td>0</td>
<td>0</td>
<td>-5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Late shortfalls</td>
<td>1</td>
<td>0</td>
<td>-2</td>
<td>1</td>
<td>-1</td>
<td>-2</td>
</tr>
</tbody>
</table>

Transportation constraints slow the movement of materiel through the distribution system. Both the current and the alternative system incurred large amounts of weighted days of delay when the transportation resources were limited. Compared to those effects, the effects of stock reservation were small and had only a negligible impact on the relative performance of the current and alternative systems for both slow and fast transportation times.

When unlimited transportation was assumed, transportation system performance had a comparatively small effect on distribution system performance, and the comparisons of the current and alternative systems were dominated by the effects of the stock reservation technique. In these analyses, the alternative system performed noticeably less well than the current system.

Control Levels

We examined the concept of control levels by simulating the system's performance when control levels were added to the stock reservation technique described above. Specifically, one-sixth of the materiel allocated to each theater was reserved for UMMIPS IPG1 requisitions, and another one-sixth was reserved for UMMIPS IPG2 requisitions. IPG1 requisitions were always filled so long as the materiel was available for the requesting theater. If the quantity of an item demanded by IPG1 requisitions was less than the quantity reserved for IPG1 requisitions, the remainder was reserved for future IPG1 de-
mands. IPG2 requisitions were filled after all IPG1 requisitions had been filled. If IPG2 requisitions accounted for less than the quantity reserved for them, the remainder was reserved for future IPG2 demands. IPG3 requisitions were then filled, FIFO, using any materiel left after all IPG1 and IPG2 requisitions had been filled and all IPG1 and IPG2 reserve requirements had been satisfied.⁵

Table 7.2 presents the results for the control level concept. They are virtually identical to those obtained for the stock reservation concept, and for much the same reasons. The cost of not filling a current demand when materiel is available—i.e., of reserving materiel for another theater or for a future, higher-priority demand—can outweigh the resulting benefits. When a current demand is not filled, it eventually incurs weighted days of delay, and it continues to do so until additional materiel becomes available from new production. At some future date, the reserved materiel will be used to fill a demand that otherwise could not have been filled, so the benefit of the concept is the savings in weighted days of delay obtained by having materiel available for the future demand.

The costs connected with reserving materiel begin to accrue as soon as a demand goes unfilled because materiel is reserved for another

Table 7.2
Marginal Effects of Within-Theater Control Level Concept

<table>
<thead>
<tr>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
<th>UMMIPS Scoring</th>
<th>CS Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation Resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlimited</td>
<td>Limited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Transportation Times</td>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td>Base case</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transitory shortfalls</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Early shortfalls</td>
<td>-5</td>
<td>1</td>
</tr>
<tr>
<td>Late shortfalls</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Variant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transitory shortfalls</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>Early shortfalls</td>
<td>-4</td>
<td>1</td>
</tr>
<tr>
<td>Late shortfalls</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

⁵We arbitrarily chose one-sixth as a control level, our purpose being solely to demonstrate the concept. The optimal control level may be quite different and also may vary across items and theaters.
demand, and the resulting benefits do not begin to accrue until the future demand is filled. These savings and costs continue until new production allows both demands to be filled. Because costs accrue over a longer period, they can outweigh the savings, even if the weight attached to the future demand is greater than that attached to the current demand.

Here, too, the relatively poor performance of the alternative concept is particularly noticeable when transportation resources are assumed to be unlimited. The cost of holding back materiel that could have been used to meet a current demand proves particularly high when the transportation system would have moved that materiel to the theater without delay.

Dynamic Materiel Allocation

To assess the potential effects of a dynamic approach to materiel allocation, we simulated deliveries in a system in which materiel was allocated on a daily basis and expected future demands were taken into account. With this concept, each theater’s planning factors and current force densities were used each day to predict the quantity of each commodity expected to be requisitioned, by theater and priority group, on each of the next 30 days and without regard for prior expectations.\textsuperscript{6,7} Predicted requisitions were then merged with the actual requisitions (those submitted on the current day plus those submitted earlier but not yet filled), and the combined queue was sorted according to the marginal increase in weighted days of delay that would be incurred if the requisitioned materiel was sent via air 30 days hence rather than on the current day (actual requisitions) or 30 days hence from the requisition’s expected arrival date rather than on the requisition’s expected arrival date (predicted requisitions). This marginal increase in weighted days of delay indicated the relative importance of allocating materiel to the requisition, either by filling it (actual requisitions) or reserving materiel in anticipation of its eventual submission (predicted reservations).

The system then estimated the quantity of the item expected to be available over the next 30 days (the sum of on-hand stocks of the item

\textsuperscript{6}The 30-day horizon was chosen solely for demonstration purposes. We are not suggesting that it is optimal or that the same horizon would be preferred for all commodities.

\textsuperscript{7}In testing this basic concept, we made no attempt to model the full range of class IX items. In application, it would probably be necessary to limit this procedure to a comparatively narrow range of critical items.
and expected deliveries from new production over the 30 days), after which it tentatively allocated materiel, starting with the requisition at the head of the queue. If that requisition was an actual one, it was tentatively filled; if it was a predicted one, the quantity of materiel it requested was set aside. The rest of the queued requisitions were then treated similarly until the quantity of materiel expected to be available over the next 30 days was exhausted.

These allocations were all tentative in the sense that no commitment was made to fill a requisition until the system was prepared to ship the resulting materiel. When the total demands for materiel exceeded the system's transportation capacity, requisitions incapable of successfully competing for the available transport were not filled, even if they had successfully competed for limited materiel. Nor were the most urgent demands for a specific item filled if they were not sufficiently urgent in comparison to the total demands for transportation capacity. If they were not to be shipped, there was no reason to commit scarce materiel to them.

Similarly, materiel was not earmarked or reserved for specific predicted future requisitions. The predictions served only to provide a means for weighing the relative system performance benefits of filling current, less-urgent requisitions instead of reserving materiel for the possibility of future, more-urgent demands.

Table 7.3 presents the results for the dynamic materiel allocation concept. For transitory shortfalls, the concept provided no improvement over the current system, regardless of demand forecast accuracy or transportation system performance. It did provide significant improvements over the current system in responding to early shortfalls when transportation resources were assumed to be unlimited—10 and 13 percent for the UMMIPS scoring system, and 17 and 19 percent for the CS scoring system. When transportation resources were limited, however, it did no better than the current system.

The dynamic materiel allocation technique explicitly considers the benefits and costs of reserving materiel against expected future demands. That is, it compares the weighted days of delay that would be incurred if a current demand was filled immediately to the weighted days of delay that would be incurred if the materiel was reserved to fill an expected future demand. Because the arrival dates and priorities of future demands are not known with certainty, this calculation is not exact. But consideration of future demands when making decisions about materiel allocations can provide improved performance.
Table 7.3
Marginal Effects of Dynamic Materiel Allocation Concept

| Percentage Reduction in Weighted Days of Delay Relative to Current System |
|--------------------------------------------------------|------------------|
| UMMIPS Scoring | CS Scoring |
| Transportation Resources | Unlimited | Limited | Unlimited | Limited |
| Transportation Times | Slow | Slow | Fast | Slow | Slow | Fast |

Base case
- Transitory shortfalls: 0 0 1 0 0 0
- Early shortfalls: 10 0 0 17 0 0
- Late shortfalls: 27 12 11 26 12 10

Variant
- Transitory shortfalls: 0 0 0 0 1 1
- Early shortfalls: 13 0 0 19 1 0
- Late shortfalls: 31 13 11 30 13 10

The flows of cargo through the distribution system are constrained when transportation is limited. The dynamic cargo scheduling and routing concepts developed in Section 3 allocate the transportation capacity available to a theater among the shipments destined for that theater so as to minimize the weighted days of delay. These procedures implicitly allocate materiel in that they queue demands as they arise and draw from that queue (fill requisitions) in order of the demands' relative importance. Demands are not filled unless they warrant access to scarce transportation capacity, which means that the alternative concepts for managing cargo flows effectively reserve materiel for the most important demands, regardless of the formal materiel allocation rule.

The dynamic materiel allocation procedure performed much better than the current system in responding to shortfalls arising after the initial surge—by as much as 30 percent when transportation resources were assumed to be unlimited, and by 10 to 13 percent when limited transportation was assumed. The procedure did well because it forecast the likely arrival distribution of high-priority requisitions and then reserved materiel to meet those demands when the benefits of doing so appeared to outweigh the costs of not filling on-hand, lesser-priority requisitions. In contrast to the stock reservation procedure, it did not expend scarce stocks on early-arriving low-priority requisitions. Nor did it hold back stocks beyond the point at which the costs associated with not filling current demands exceeded the benefits of reserving stocks for future, higher-priority requisitions.
The Effects of an Enhanced Priority System on Dynamic Materiel Allocation

The analysis of the dynamic materiel allocation concept just described assumed that only an UMMIPS priorities were available to the system's operators. As a result, the CS scores obtained for the concept (see Table 7.3) reflect the degree to which it provided better performance than the current system when the operators had only UMMIPS information to guide their decisions.

How much of an improvement would the concept provide if the system's operators had an enhanced priority system available to them? To find out, we simulated deliveries in an alternative system in which system operators were given each requisition's CS score and those scores were used by the system to weigh the days of delay.

Table 7.4 presents the results, which show that the availability of enhanced priorities had little effect on the performance of the dynamic materiel allocation technique. For unlimited transportation capacity, the results were the same as those obtained when operators had only UMMIPS information. And when transportation resources were constrained, there was little effect on system performance so long as new production continued. The only entries showing improvement are those for the late-shortfall cases. Since new production was not available until the end of the analysis period in these cases, the avail-

<table>
<thead>
<tr>
<th></th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
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<tbody>
<tr>
<td></td>
<td>UMMIPS Scoring</td>
</tr>
<tr>
<td>Transportation Times</td>
<td>Unlrditd</td>
</tr>
<tr>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td>Base Case</td>
<td></td>
</tr>
<tr>
<td>Transitory shortfalls</td>
<td>0</td>
</tr>
<tr>
<td>Early shortfalls</td>
<td>0</td>
</tr>
<tr>
<td>Late shortfalls</td>
<td>0</td>
</tr>
<tr>
<td>Variant</td>
<td></td>
</tr>
<tr>
<td>Transitory shortfalls</td>
<td>0</td>
</tr>
<tr>
<td>Early shortfalls</td>
<td>0</td>
</tr>
<tr>
<td>Late shortfalls</td>
<td>0</td>
</tr>
</tbody>
</table>
ability of the enhanced priorities augmented the contribution of the
dynamic approach to materiel allocation.

SUMMARY

When unlimited transportation capacity was assumed to be available,
both the concept of stock reservation and the concept of control levels
both impaired system performance. Each concept increased the
weighted days of delay incurred in responding to either the base case
or the variant time stream of demands by 5 to 7 percent according to
either scoring standard. In contrast, the dynamic materiel allocation
concept provided substantial improvements for unlimited transporta-
tion capacity—10 to 13 percent under the UMMIPS scoring standard,
and 17 to 19 percent under the CS scoring standard—in response to
either time stream of demands. These improvements stem from the
fact that this concept explicitly considers the benefits and costs of
reserving materiel for expected future demands.

When transportation capacity was limited but was effectively man-
aged using the dynamic cargo scheduling and routing concepts, none
of the three techniques for allocating materiel offered a noticeable
improvement over the current system. This lack of improvement is
carried by the dynamic approach to traffic management concept's im-
licit allocation of materiel in the sense that it queues demands as
they arise and then draws them according to their relative impor-
tance. As a result, requisitions are filled only when they warrant an
allocation of scarce transportation capacity. Materiel thus ends up
being reserved for the most important demands regardless of the for-
mal materiel allocation rule.

The availability of enhanced priorities was found to have little effect
on the dynamic materiel allocation technique. The CS priorities im-
proved the contribution of late-shortfall cases.
8. CONCLUSIONS

Resupply operations in a single- or multitheater contingency must be managed so as to most efficiently handle three related problems. First, logistics support response times are often too long for deployed combat units to tolerate. Second, the high volume of urgent materiel demands creates congestion at aerial ports, slowing the movement of all goods to customers.¹ And, third, in allocating scarce transportation and materiel resources, the needs of forces deployed to a theater are not always balanced against the needs of forces deployed elsewhere and the need to maintain adequate reserves for unforeseen contingencies.

When uncertainty is great and needs are unknown, a resupply system based on materiel requisitions from the theater is appropriate. Deploying units take resupply packages with them, but experience in the theater is the only true indicator of what the actual materiel demands will be. If the contingency persists, experience may accumulate to the point at which the rear echelons can understand the materiel needs enough to determine what the resupply packages should be.

We analyzed several alternative concepts for improving the effectiveness of the current resupply system in supporting a single theater of operations. We also examined alternative concepts for allocating transportation and materiel resources among competing demands. While the specific results obtained varied depending on the different conditions assumed in our simulations, the direction and general magnitude of those results were consistent across the various tests.

IMPROVING RESUPPLY RESPONSIVENESS TO A SINGLE THEATER

We estimate that resupply system responsiveness—measured by the reduction in weighted days of delay in delivering requisitioned materiel—to a single theater or to each theater involved in a multitheater contingency can be improved by on the order of 40 percent. This

Improvement is the cumulative result of four alternative management procedures, as shown in Table 8.1.\footnote{The results in this table are for tests in which the CS scoring standard was used to evaluate the relative performance of the alternatives in response to the median time stream of demands (the one for moderate theater stocks and a 10-day theater stock objective) for the large contingency considered and slow (i.e., current) transportation system performance. Tests in which different time streams of demands, transportation system performance, and scoring standards were assumed yielded similar results.} The first procedure, dynamic scheduling of cargo flows, is a simple but important change. It involves queuing requisitions in supply system computers and controlling their release for filling so as to minimize cargo congestion and delays at airfields and seaports. By itself, this technique promises a modest 6 percent reduction in weighted days of delay.

The second procedure, dynamic cargo routing, builds on the first in that it takes advantage of the many more requisitions that would be stored in the computer records as a result of the first procedure’s implementation. Materiel distribution managers would review those requisitions regularly to determine the fastest way to get supplies to the theater, which could involve shifting air-eligible cargo to sealift if the volume of requisitions grew large enough to imply long air pipeline delays. This dynamic procedure offers a further 22 percent reduction in the weighted days of delay involved in getting requested materiel to the combat units.

<table>
<thead>
<tr>
<th>Management Procedure</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic scheduling of cargo flows (timing of cargo release to avoid congestion)</td>
<td>6</td>
</tr>
<tr>
<td>Dynamic routing of cargo flows (directing of less-urgent air-eligible shipments to sea when airlift is constrained)</td>
<td>A further 22</td>
</tr>
<tr>
<td>Addition of a rapid response channel</td>
<td>A further 6</td>
</tr>
<tr>
<td>Enhanced priority system</td>
<td>A further 4</td>
</tr>
<tr>
<td>Total improvement</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 8.1
Marginal Effects of Four Procedures for Improving Resupply Performance for a Single Theater
The third procedure entails introducing a rapid response resupply channel along the lines of the Desert Express system initiated during Operation Desert Shield to move top-priority supplies to Saudi Arabia. That system used dedicated MAC airlift and a strictly enforced cargo allocation to overcome delays in more-acute air resupply channels. Such a capability would yield another 6 percent reduction in weighted days of delay.

The final procedural change is to provide distribution system operators with an enhanced priority system. The technique we considered used a commodity-specific (CS) measure indicating the importance of on-time delivery of the requested material to suggest the kinds of effects that might be obtained if an enhanced priority system were available. We found that when added to the three other procedures, an enhanced priority system could offer another 4 percent reduction in weighted days of delay.

ALLOCATING TRANSPORTATION AND MATERIEL RESOURCES AMONG COMPETING DEMANDS

We estimate that the allocation of transportation and materiel resources among competing demands would be improved by basing decisions on updated forecasts of future demands. Such an approach is particularly effective for cases in which initial forecasts prove inaccurate. For example, if initial demand forecasts are off by 10 percent, reallocation on the basis of updated forecasts can improve resupply system responsiveness by roughly 17 percent when only UMMIPS information is provided to the system's operators. If enhanced priorities are provided, this approach offers an additional 7 percent improvement. The three techniques involved, and their contributions, are shown in Table 8.2.3

The first procedure shown in the table entails forecasting movement requirements on an ongoing basis. Transportation resources are then reallocated in anticipation of those requirements, taking account of the opportunity costs of allocating lift to one or another theater.

The second procedure involves a similar approach to the allocation of materiel among competing demands. This procedure forecasts the likely arrival distribution of high-priority requisitions on a continuing

3The results in this table are based on the same assumptions and conditions used to produce the results in Table 8.1.
Table 8.2
Marginal Effects of Three Procedures for Improving the Allocation of Transportation and Materiel Resources Among Competing Demands

<table>
<thead>
<tr>
<th>Management Procedure</th>
<th>Percentage Reduction in Weighted Days of Delay Relative to Current System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic allocation of transportation resources (based on updated forecasts)</td>
<td>3–4</td>
</tr>
<tr>
<td>Dynamic allocation of materiel (based on updated forecasts)</td>
<td>A further 1–13</td>
</tr>
<tr>
<td>Enhanced priority system</td>
<td>A further 1–7</td>
</tr>
<tr>
<td>Total improvement</td>
<td>5–24</td>
</tr>
</tbody>
</table>

basis. It then reserves materiel to meet those demands when the benefits of doing so appear to outweigh the costs of not filling on-hand, lesser-priority requisitions. The objective is to avoid two pitfalls: expending scarce stocks on early-arriving but low-priority requisitions, and reserving stocks beyond the point at which the costs of not filling on-hand demands begin to exceed the benefits of reserving stocks for future, higher-priority requisitions.

These procedures rely on quick decisionmaking, so their implementation will require communications links and software. Their implementation will also require real-time joint-service management to coordinate materiel resupply actions across the services if the estimated benefits are to be gained.

An alternative to the current system is to have a theater-oriented organization that is responsible for allocating pipeline capacity. Its primary tasks would be to ensure that resupply pipeline capacities are allocated so as to make the most effective use of pipeline capabilities, and to bring together the four types of information needed to support effective assignment of cargo to pipelines: (1) the materiel requisitions being levied on the distribution system, (2) the warfighters' goals and priorities, (3) the resupply pipeline capacities, and (4) the amounts of stocks available.

Variants of this alternative are possible. The theater airlift clearance authority (TACA) could use information on demands and stocks to estimate the likely fill rates and consequent transportation requirements. It would compare the estimated transportation requirements with the resupply pipeline allocations and capacities to determine the
ability of the pipelines to meet the demands placed on them as depots and vendors fill the materiel requisitions. If it found pipeline capacities to be sufficient, it would take no further action. If it found them to be insufficient, it would work with the JTB and theater JTB to alter lift allocations.

If additional lift could not be made available, the TACA would provide guidance to the airlift clearance authority (ACA) on how the existing challenge criteria should be modified to make the best use of the available resupply airlift capacity. Using information from the warfighters on their goals and priorities, the TACA would identify the units whose performance is most critical to forthcoming operations, the commodities most needed to support those operations, or some other specifications of resupply priority appropriate to the situation. The TACA would then direct the ACA to modify its challenge criteria as needed to ensure that the particular cargo most needed to support operations was afforded premium transportation. For instance, the TACA might divert certain types of cargo, even if it carried a high UMMIPS priority, if other commodities were deemed more important to the warfighters' goals and priorities.

Another variant, a system with a theater distribution control point (TDCP), would merge the ACA's role in challenging resupply cargo directed to the air pipeline with the functions of the TACA, as described above, in a single organization. The TDCP would itself be the intermediary between the requisitioner and the NICPs. Rather than modifying the challenge criteria, it would dynamically assign issue and transportation priorities so as to direct cargo to appropriate pipelines.

An adaptation of the current system that reflects the concept underlying this TDCP alternative was used in Operation Just Cause. Units in Panama sent representatives to the APOEs to ensure that the most-important cargo was put on the earliest available Panama-bound aircraft. These expediters provided a direct connection between the military leaders in Panama and the distribution system's operators. When the system could not meet all demands made on it, they identified the forces' most important needs.

Either of these variants, a TACA or a TDCP, could be located in the theater or in CONUS. The requisite staff would be small, numbering in the tens, and secure communications links with the theater would be needed to obtain information on warfighters' goals and plans. The Army's Logistics Information File now receives information on demands as requisitions are transmitted to the NICPs, and it gets in-
formation on fill rates as the NICPs send materiel release orders to depots and vendors. Its procedures would serve the needs of a theater-oriented organization attempting to allocate pipeline capacities.