EFFECT OF CHANGING DEPOT ON-TIME STANDARDS

Operations Research and Economic Analysis Office

DECEMBER 1985
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December 1985

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This report summarizes the work done and conclusions reached in a study of alternative depot time standards for routine requisitions. The analysis was performed by the Operations Research and Economic Analysis Management Support Office for the Directorate of Supply Operations, Transportation Division.

DLA has been considering changing the current fifteen day depot time standard for CONUS delivery of requisitions in Issue Priority Group Three (IPG 3), for the purpose of improving the cost effectiveness of DLA depots. The analysis quantified the estimated transportation costs and other measures of comparison for all time standards from 15 to 21 days. Changing the time standard to 21 days would save approximately five million dollars annually in transportation charges alone, without significantly impairing the mission of responding to military customers.

ROGER C. ROY
Acting Assistant Director,
Policy and Plans
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Executing Summary

The Problem

The Defense Logistics Agency is considering extending its "on-time" standard for depot handling and delivery of supplies for routine requisitions from military customers. Regulations require delivery within 21 days after a requisition is received by a DLA depot, but DLA policy insures that over 90% of all such requisitions are delivered by only 15 days. By limiting the duration of shipping cycles, this policy may cause excessive transportation charges or other inefficiencies at depots without significant advantages to customers. A longer time standard such as 18 or 21 days may be beneficial, but the actual consequences need to be quantified.

The Approach

The analysis consisted of estimating several measures of comparison for the baseline (15-day) and alternative time standards. The primary measures were transportation charges, numbers of shipments according to type, numbers of shipping units, and on-time performance. Each time standard was evaluated for all six DLA depots separately.

The materiel analyzed in each case represented requisitions in Issue Priority Group Three (IPG 3) from military customers in the continental United States. Records of supplies delivered by DLA from January 1985 to June 1985 by truckload, less-than-truckload, United Parcel Service, or Fourth Class mail provided the necessary requisition history data.

A simulation model of relevant depot processes used the requisition data from a given depot to estimate the desired output measures based on the value of the time standard inputs. Simulation results were generated for time standards of 15, 18, and 21 days. Analytic formulas were derived to estimate the costs and numbers of shipments for additional time standards ranging from 12 to 24 days.

Results

The analysis concluded that extending the depot "bank" times, during which materiel to be shipped is consolidated, by increasing the time standard would significantly increase depot efficiency.

An IPG 3 time standard of 21 days would save over five million dollars per year, or about 15%, in transportation charges alone. Additional benefits include 27% reductions in numbers of shipments and 18% reductions in numbers of shipping units. Furthermore, on-time performance would probably improve, and the average customer pipeline time would increase by less than three days.
I. INTRODUCTION

A. Background

The Defense Logistics Agency (DLA) has traditionally measured the performance of its six depots by monitoring the separate processing, transportation hold, and intransit segments of operations for compliance with distinct time standards for each. Recently, however, DLA improved its service and efficiency by merging the three time segments into one with the aid of computerized workload planning. The greatest benefits were found in the processing of shipments for Issue Priority Group Three (IPG 3) requisitions, or Materiel Release Orders (MROs), the routine category of materiel constituting a majority of peacetime shipments. The time standard for this combined segment for IPG 3 requisitions was set at 15 days instead of the 21 days authorized by the Uniform Materiel Movement and Issue Priority System (UMMIPS). The resulting measure, "Depot Transportation On-Time Performance," is the percentage of MROs (requisitions, or lines) processed and transported within the DLA time standard.

The DLA goal for depot on-time performance has been set at 90% for several years, and all six depots are now meeting or exceeding this goal based on the 15-day standard. Performance above 90% appears to be a by-product of a "worst case" approach to meeting the goal. That is, MRO processing is designed to give the oldest MROs at a depot for a given set of customers at least a 90% on-time probability; hence the performance for newer MROs shipped with them is much higher. This behavior combined with the 15-day time standard and the 90% goal may be causing unnecessary inefficiencies, in terms of transportation charges and depot productivity, for a marginal gain in service to the customer. This is especially true if customers do not desire receipt of IPG 3 supplies before 21 days.

For example, many shipments must leave the depot eight or more days before due date in order to reach a cross-country customer on time. These supplies typically cannot be held at the depot long enough to combine with materiel intended for the same customer on subsequent days, missing the opportunity to combine into larger shipments at lower transportation rates. Similarly, additional processing must often be done when such consolidation is missed, because the numbers of shipping units and shipments are not minimized. The shipping cycle is longer for nearer customers, and some customers currently receive enough material to use low rates, but more consolidation could probably still be achieved with a longer time standard.

Alternative time standards closer to 21 days have been proposed, but the potential increase in consolidation, and the resulting benefits and costs, have not been quantified and analyzed in detail.

B. Objectives. The purpose of this study was to quantify the primary benefits and costs of alternative DLA time standards for IPG 3 shipments, and provide general insights about the causes and results of consolidation.
C. Scope

The analysis investigated time standards ranging from 12 to 24 days, but focused primarily on the 15-day, 18-day, and 21-day standards.

The materiel analyzed in each case included all IPG 3 requisitions from military customers in the continental United States (CONUS) which were delivered by one of the six DLA depots in a six month period by truckload (TL) or less-than-truckload (LTL) freight modes or by mail (UPS - United Parcel Service, or USPS - United States Postal Service). Annual results were estimated by extrapolation.

D. Overview. This report serves two purposes. First, it documents the methodology developed, for inspection and possible use by analysts. Chapters II, III, IV and VI and the appendices perform this function. Second and more importantly, it reports the insights gained from the analysis for use by decision makers. These are summarized in Chapter VII, based on results reported in Chapter V and Section E at the end of Chapter VI.
II. METHODOLOGY OVERVIEW

The study approach consisted of selecting appropriate analysis scenarios, defining useful measures of comparison, and designing and performing an analysis experiment to estimate the measures to compare alternative scenarios.

A. Scenarios

Three primary scenarios were chosen for comparison: the 15-Day Time Standard, the 18-Day Standard, and the 21-Day Standard. Six cases, one for each depot, were analyzed for each primary scenario. The depots are:

1. Defense Depot Mechanicsburg, Pennsylvania (DDMP)
2. Defense Depot Memphis, Tennessee (DDMT)
3. Defense Depot Ogden, Utah (DDOU)
4. Defense Depot Tracy, California (DDTC)
5. Defense Construction Supply Center (DCSC), Columbus, OH
6. Defense General Supply Center (DGSC), Richmond, VA

Less detailed results for time standards of 12 to 24 days are estimated from the 18 primary cases. A detailed description of the baseline (15-day) and alternative scenarios is presented later.

B. Measures of Comparison

The information needed to evaluate time standard alternatives included the following measures for each scenario:

1. Total transportation charges for each depot and all depots combined.
2. Total shipments from each depot, by each mode of transportation: TL, LTL or UPS/USPS.
3. Total shipping units from each depot, by warehouse type (Pit or Bulk) and transit type (freight or mail).
4. On-time performance (percentage of lines on-time to customer) for each depot.
5. Average transit time per shipment for each depot.
6. Total bank cycles and average bank time for each depot by distribution area.
It would also be useful to know in detail how processing operations vary from scenario to scenario, in terms of saturation levels and delays at different stages of processing, as well as administrative and personnel costs. The analysis did not explicitly quantify those measures, but the measures which were provided were expected to be useful inputs for understanding in such areas.

C. The Analysis Experiment

Given the defined scenarios and measures of comparison, the analysis performed the following steps:

1. Data Development. Sufficient data were selected to characterize the distribution of customer requisitions, transportation costs and transit times for each depot. Other information was obtained to describe the MRO process at each depot.

2. Methodology Development. The primary analysis tool was a detailed simulation model of the depot MRO process. For comparison sake, some independent analytic modeling was performed using probability assumptions.

3. Generation of Results. Simulation runs estimated the measures of comparison for the 18 input cases. Then the analytic methodology was calibrated to the simulation output to provide output estimates for a wider range of time standard alternatives.

4. Interpretation of Results. Insights gained from the results or during the analysis process were formulated as conclusions or recommendations.

Some steps were done concurrently, and several were iterated when necessary to satisfy the study objectives.
III. DATA DEVELOPMENT

The analysis methodology required three types of data about the system being modeled: MRO data, transportation charges, and transit times.

A. Depot MRO History Records

DLA retains a computer record of every MRO successfully processed and delivered to a military customer. Each customer is identified by its own account number, the Department of Defense Activity Address Code (DODAAC), and by its installation number, the Destination Cross-Reference Code (DCR). Detailed inspection of the records pertinent to the analysis scenarios revealed many different types of MROs and substantial diversity among types. The requisitions differed greatly in volume, weight, item type, and frequency of demand; furthermore, over 2000 separate installations (DCRs) received materiel from each depot, with the total weight received by individual DCRs ranging from a few pounds to millions of pounds a year.

Materiel to be shipped is consolidated on a DCR basis, so the simulation results were expected to be sensitive to the volume and nature of each DCR's business. As a result, the task of characterizing DCRs and their MROs with probability distributions for modeling purposes posed uncertainty about the accuracy and confidence of model results. Therefore, actual MRO records from a six-month period were used as inputs to the simulation model. This use of historical data meant that the model would be in a sense deterministic, because one could not test its sensitivity to inputs by varying the distribution of MROs. On the other hand, the large number of MROs (an average of over 200,000 per depot) was expected to produce statistically stable results, and use of two quarters of data would remove some of the seasonality of the results. Use of the same data for a given depot's three cases is also a variance reduction technique useful for significant comparison of alternatives.

The inputs used by the simulation model required only a few of the data fields from each MRO record. The simulation language used, SLAM II, also required that the data be in strictly numeric form. Thus the computer program which selected the desired records also substituted unique numbers for each DCR and each DODAAC, replaced postal state abbreviations with numeric state codes, and unpacked the packed-decimal fields recording the weight, cube and MRO receipt date.

The program matched each MRO by NIIN (National Item Identification Number) to a separate stock number file to look up the corresponding special requirements code, cargo code, and hazardous storage compatibility code. The first two codes were transformed to numbers and appended to the input record for use in the model, along with the modified DODAAC, to determine the compatibility of MROs for shipping unit consolidation. The hazardous storage code was used to eliminate radioactive items from the input MROs.

Other conditions were required for an input MRO record to be selected. Specifically, the MRO records selected for analysis were those which showed:
1. R1 - 7. MROs from IPG 1 and IPG 2 were not used as inputs, but the lower bounds for the selected MROs was considered when modeling warehouse processes.

2. Numeric or postal state code had to show that the receiving activity is located in the continental United States.


4. Warehouse Report Code or Transportation Charges. An entity must have weight or volume input for water in the model, or cost to be assigned. Because some MRO quantities are 'rolled up' to the lead MRC in a transportation unit, the weight and cube on a selected record may not always be attributable to the item (NIIN) on the record; however, the resulting compatibility codes are representative of the items accounting for the weight, and the other information is accurate.

5. Mode = A (Truckload), B (Less Than Truckload), G (Surface Parcel Post), or S (United Parcel Service). Material shipped by any other modes is rarely evaluated in TP on-time performance.

6. Geographic Area Code in range A - Z. Each depot can also assign codes in range 0 - 9, but appears to reserve these for unusual (e.g. disposal shipments) or overseas shipments.

7. Matchable NIIN. Needed for consolidation criteria. Rare MROs show blanks or non-MOWASP items in this field.

8. Document Identifier Code not equal to 'A5J'. This value indicates a properly disposed shipment.

9. Hazardous Storage Compatibility Code not equal to 'A1'. Rare radioactive items are discarded from the analysis.

The magnitudes of the six input cases are shown in Table 3-1.
Table 3-1
INPUT CASE AGGREGATE STATISTICS

<table>
<thead>
<tr>
<th>Depot</th>
<th>Number of Records</th>
<th>Number of DCRs*</th>
<th>Number of DODAACs</th>
<th>Total Weight Shipped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanicsburg</td>
<td>221,636</td>
<td>5461</td>
<td>14,453</td>
<td>40,112,592</td>
</tr>
<tr>
<td>Tracy</td>
<td>213,110</td>
<td>4326</td>
<td>12,148</td>
<td>35,766,953</td>
</tr>
<tr>
<td>Columbus</td>
<td>144,779</td>
<td>3340</td>
<td>11,098</td>
<td>8,627,052</td>
</tr>
<tr>
<td>Memphis</td>
<td>402,951</td>
<td>6165</td>
<td>19,485</td>
<td>98,428,861</td>
</tr>
<tr>
<td>Richmond</td>
<td>277,482</td>
<td>5109</td>
<td>14,398</td>
<td>46,929,401</td>
</tr>
<tr>
<td>Ogden</td>
<td>214,107</td>
<td>3389</td>
<td>6,899</td>
<td>22,733,508</td>
</tr>
<tr>
<td>All Depots</td>
<td>1,474,065</td>
<td>6165**</td>
<td>19,485**</td>
<td>252,598,367</td>
</tr>
</tbody>
</table>

* Includes single DODAACs at installations with no DCR.
** Minimum, based on Memphis figures, in lieu of actual combined count.

B. Transportation Costs

Two cost-estimating methodologies were derived: one for freight modes A and B, and another for parcels modes G and 5.

Six recent quarters of shipping records in the Freight Information System (FINS) file provided the data used to estimate mode A and B charges. The average charge per pound was computed for nine weight classes for each depot and state (including D. C.). Only the first 80% of each weight class, e.g. - 500 to 900 pounds for the 500 to 999 class, was used because shipments in the heaviest 20% of the class might have been billed at a discount at a higher weight. In addition, the minimum charge was estimated for each depot and state by averaging the costs of shipments under 200 pounds. Scaling factors were derived to estimate rates for cases with missing or insignificant values.

The cost of mailing a parcel through fourth class USPS or UPS ground service was computed by encoding current published cost tables, based on the weight of the parcel and the parcel post zone. The lower of the two charges would be selected for a given parcel.

C. Transit Times

Transit time estimates were based on historical military supply and transportation evaluation procedure document (MILSTEP) TK4 shipping times for FY84. A TK4 time is the number of days from the departure of a truck from the depot until its arrival at final destination. The mean TK4 time was computed for mode B shipments from each depot to each state and was used as the mean for the model's mode B transit time distribution.

The mode A data were incomplete because full truckload shipments are rare compared to LTL shipments. Nevertheless, mode A average times were found...
for enough depot-state pairs that a general linear relationship between mode A and mode B times was found, permitting an approximation of any mode A time given the corresponding mode B estimate. Mode A times averaged about two-thirds as long as mode B times.

TK4 data is only available for freight delivery, so different data were required for mail, modes C and 5. The only such data available were the MILSTEP takeup times from D6S documents. The D6S times are measured from the recorded date of shipment until the date the customer has the supplies in stock, which includes the transit time and a usually small but variable receipt and takeup processing time at the receiving installation. Extensive D6S data are available for mode B as well as mode C and 5, so a statistical relationship was sought between median D6S times for the two types. The times for modes C and 5 appeared to be slightly less than corresponding mode B times, but a high variance about this relationship made the approximation technique statistically insignificant. It was decided that substituting mode B estimates for mode C and 5 would be conservative but analytically simple, and reasonable enough to avoid biased comparisons of alternatives.
IV. SIMULATION MODEL

A. System Description: The MRO Process

The process of satisfying IPG 3 MRO demand differs from depot to depot because each depot processes a unique set of MROs and employs different resources to perform its mission. The number of supply warehouses and the physical layout of each depot is different, as is the degree of use of automated conveyors, forklifts, and various packing devices. Furthermore, the unique geographic relationship of each depot to its customers has led them to divide the country differently into distribution areas for planning, banking and transportation purposes.

Despite these differences, each depot behaves according to the uniform Mechanization Of Warehousing And Shipping Procedures (MOWASP). This set of regulations describes detailed policies and procedures for processing MROs the same way at all depots. Therefore, while the depots may employ different internal means for certain tasks, one can describe a general system which all six depots conform to.

DLA Supply Centers (DSCs) transmit military supply requests to depots as MROs, where each MRO represents some quantity of only one type of item. Each requisition is identified by the customer's activity address code (DODAAC), the corresponding installation's Destination Cross-Reference Code (DCR), and its geographic distribution area. The MROs are also distinguished by Issue Priority Group. Those MROs which are IPG 1 or IPG 2 are separated from the IPG 3 MROs because they have shorter delivery suspenses and will rarely combine with the latter for shipment.

Each IPG 3 MRO arriving at a depot is stored in a computer "bank" for its distribution area, where it is combined into a shipping unit with other MROs from the same DODAAC when certain compatibility criteria are met. An MRO is then identified by shipping unit number and its own line number for that shipping unit. When the oldest MROs in an area's bank must begin physical processing at a warehouse in order to reach the customer on time, some or all of the area's shipping units are "dropped" from the computer.

When a shipping unit drops from the bank, it queues for processing at the appropriate warehouse behind higher priority IPG 1 and IPG 2 MROs. The warehouse is allowed typically one to three days to "pick" the material on each line from its storage location, pack the lines together (in boxes or on pallets) as the shipping unit, and send it to the freight or small parcel terminal for shipping. If designated for freight, a shipping unit will be held at the terminal for consolidation with other units destined for the same DCR and loaded on a truck to leave on a predetermined day. The total time at the freight terminal is usually between 24 and 48 hours.

B. Modeling Approach

The similarity between analysis scenarios motivated development of a single general model of the depot "system". The model could represent a specific scenario when driven by the appropriate input MRO data set and two input parameters: one to identify the depot and another to set the time standard. Subroutines which computed bank times, transportation charges, and transit
times used the input parameters to index the appropriate data or logic for that case.

The model-building process was an iterative sequence of steps. First, the general form of the model was derived from study of MOWASP regulations, direct observation of depot operations and conferences with DLA supply and transportation personnel. Successive and increasingly detailed flow diagrams were created depicting the essential model elements, as detailed assumptions were made about the behavior of the system. When the behavior was specified in sufficient detail, the model was explicitly diagrammed using the network elements of SLAM II, which could be directly translated into computer code (Appendix A). Extensive use of FORTRAN subroutines (Appendix B), possible in combined network-discrete modeling with SLAM, was needed to depict the system in a manner permitting estimation of the desired measures of comparison. Once the model was encoded and debugged, output was generated to verify and validate the methodology.

C. Model Features and Assumptions

1. General Model Concept

The MRO process can be described as the flow of entities (lines or shipping units) through a network of queues, branching nodes, and service activities. This network consists of essentially four different processes: arrival, banking, processing and transportation. Each MRO passes sequentially through the four processes by itself or as part of a larger unit, or entity. In its simplest form, the model is depicted by the network in Figure 4-1.

Figure 4-1. FOUR PROCESSES IN SIMULATION MODEL

Events occur in each box which permit an entity to move to the next box and eventually leave the system. The assumptions made to fully describe the nature and timing of these events are described in the following sections, and are illustrated in the model flowchart in Figure 4-2.

2. MRO Arrivals

An entity is created each time an MRO record is read from the input file. Each entity arrives at a SLAM node which triggers two events. First, a subroutine is called to reference the current MRO record and assign the following attributes to the entity:
1: MARK TIME (Time in run when entity was created)
2: GEOGRAPHIC AREA CODE (Numeric, 1-25)
3: STATE CODE (Numeric)
4: DCR (Numeric Destination Cross-Reference Code)
5: SHIPPING UNIT TYPE (Based on DODAAC and compatibility codes)
6: PARCEL POST ZONE
7: WEIGHT (in pounds)
8: CUBE (in tenths of cubic feet)
9: BIN/BULK INDICATOR (1=Bin, 2=Bulk)
10: TIME TILL NEXT ARRIVAL (Zero or multiple of 24 hours)

Second, the same subroutine call reads another MRO record and stores the attributes for assignment to the next entity to arrive at the node. The difference in the two receipt dates (attribute 10) is used to schedule the next arrival. Thus, MRO entities arrive only at integer multiples of 24 hours: 0 (for the same day), 24, 48, etc. The first entity created also initiates the printing of daily processing results. The corresponding portion of the SLAM network is shown in Figure 4-3.

Figure 4-3. SLAM NETWORK FOR MRO ARRIVAL PROCESS
3. Bank Cycles

Each arriving MRO entity is routed immediately to one of two "bank" nodes for its geographic area, depending on the storage type (BIN or BULK) of the item on the MRO. The entity is stored in a file for its node until combined with homogeneous entities at that node into a shipping unit entity before the area's bank drops. The individual MRO entities are destroyed; the shipping unit entity retains their attributes as the following:

1: MARK TIME (Randomly chosen from MROs')
2: GEOGRAPHIC AREA CODE
3: STATE CODE
4: DCR
5: SHIPPING UNIT TYPE
6: PARCEL POST ZONE
7: WEIGHT
8: CUBE
9: NUMBER OF LINES (MROs) ON SHIPPING UNIT
10: FREIGHT INDEX (=1 if DCR will receive freight this cycle)
11: OLDEST MRO MARK TIME
12: NEWEST MRO MARK TIME

A subroutine call immediately prior to drop consolidates the MRO entities based on the value of attribute 5. The effect of this condition and the use of two nodes per area is that a given pair of MROs combine into a shipping unit if and only if:

a. The customer DODAACs match; and
b. Special Requirements Codes
   1) are identical and not A (A's cannot combine), or
   2) are both from the group H, J, 1, 9, and Z; and
c. Cargo Codes match and are H, Q, Z, or blank; and
d. Both are BIN or both are BULK.

The last condition assumes that stock is positioned at warehouses in such a way that two otherwise compatible MROs of the same approximate size (large or small) will not fail to combine due to stock locations.

All of the entities waiting at both nodes are dropped at the same time, which is actually two hours before the first planned processing day begins for the cycle, in order to exclude entities reaching the bank exactly when the day starts. The next MRO entity arriving after a drop has occurred begins a new drop cycle for that area. It becomes the first in the BIN or BULK node file for that area and its duplicate is routed independently to a "scheduling" network, where it calls a subroutine which schedules the next drop. The same entity goes on to trigger the drop at the scheduled time, call a subroutine to combine shipping units at the freight terminal into freight, and schedule the needed truck resource(s). The bank portion of the SLAM network appears in Figure 4-4.
Figure 4-4. SLAM NETWORK OF THE BANKING PROCESS
The duration of the bank cycle is based on the day of the week and the estimated shipping time for the distribution area. Statistics provided the highest integer number of days by which at least 90 percent of the mode B freight shipments to the area have been delivered. The model uses the depot and area to locate such a number in a data table and subtract it from the input time standard. The result gives the date by which the oldest MRO in the bank must be shipped (assuming mode B travel) to reach the customer with 90 percent reliability. Then three days processing and hold time are subtracted to yield the maximum bank time. The general model assumes that no processing occurs on Saturday or Sunday, so two additional days are subtracted if the three processing days intersect the weekend. If the resulting drop day is a Saturday, the MROs are dropped on Friday; if Sunday, they are dropped on Monday. If the computed bank time is less than one day, MROs drop within 24 hours after arrival.

A consequence of this banking methodology is that an area does not drop on the same day or days each week as is often done in reality. Rather than attempting to duplicate actual depot drop schedules, which would surely change for a different time standard, the model allowed an area's bank cycles to vary in timing and duration about the expected norm. The assumption of mode B travel times probably gives a lower average bank time in cases where the actual drop planners assume faster mode A travel, as does the absence of weekend processing days for some depots. On the other hand, three processing and hold days is less than some depots plan for, so the modeled bank time may be longer.

The workload timing constraints caused by IPG 1 and IPG 2 processing were not explicitly modeled, but the use of twenty-five distinct banks was assumed to produce a representative variability of daily IPG 3 processing. It was also felt that such "free-flow" cycle scheduling would provide useful insights about the timing of drops.

4. Shipping Unit Processing

The picking and packing operations at a depot are complex and labor-intensive, and differ greatly between depots and between warehouses at a depot. The details of warehousing were not critical to estimation of the analysis measures of comparison. The chief modeling needs in this area were to create an appropriate delay between the time a shipping unit drops for processing and the time it is shipped, and to route processed shipping units to the correct transportation terminal (freight or small parcel).

The processing time of a shipping unit is computed by a subroutine in the model as soon as the entity is dropped from the bank node. A random variate is drawn from a triangular distribution with a minimum time of 12 hours, a mode (and mean) time of 42 hours, and a maximum time of 72 hours. If the processing time intersects the weekend, a 48 hour delay is added. The shipping unit's processing time is assumed to be independent of the number of lines and the other shipping units being processed. The triangular distribution was conservatively estimated from the statistical
distribution of the difference between MRO drop dates and the dates offered to transportation, which were almost always two days or less. Perfect supply is assumed: any shipping unit dropped will be successfully picked, packed, and delivered to transportation.

Shipping units were sent to transportation terminals according to the size of the shipping unit and the total amount of material going to each DCR from the same bank cycle. Any shipping unit of ten pounds or less which did not exceed 3.5 cubic feet automatically went to the small parcel (UPS/USPS) terminal, while any shipping unit exceeding 50 pounds or 3.5 cubic feet went to the freight terminal. Any remaining entity (11 to 50 pounds, less than 3.5 cubic feet) went to the freight terminal if any single shipping unit to the same DCR qualified for freight. Otherwise, such units were sent by UPS or USPS. The freight eligibility had been indicated in an attribute on each shipping unit when created at the bank node, following inspection of all the MROs going to each DCR. Any shipping unit processed at the BULK warehouse went freight because any parcel post-eligible item (50 lbs. or less, 3.5 cubic feet or less) was defined as a BIN item on the input record.

5. Transportation

Two transportation terminals were modeled: one for mail and another for freight. The SLAM network is shown in Figure 4-5.

Figure 4-5. SLAM PROCESSING AND TRANSPORTATION NETWORK
Shipping unit entities reaching the mail terminal become individual small parcel UPS or USPS shipments. Each calls a subroutine which computes the cost and transit time and updates the output statistics for the model run. The transit time is a triangularly distributed random variable for the state and depot, with endpoint parameters chosen such that about ten percent of the transit times exceed the planned transit time. The transit time found is added to the elapsed time in the system of one of the shipping unit's MROs, based on the value of attribute 1. This yields the total days from depot receipt until delivery to the customer.

Freight shipments are created through the interaction of several model elements. Shipping unit entities which have been processed and routed to the freight terminal are grouped by DCR at a freight node. There they wait until matched with an available SLAM "resource" corresponding to trucks.

The same scheduling network entity which initiated the bank cycle and the drop for a given area reaches a final event node three processing days after the drop is made. At that time a subroutine consolidates the area's shipping units at the freight node into shipments. Units destined for the same DCR combine into the minimum number of shipments possible such that the average shipment weight to the DCR is 40,000 pounds or less and the average volume is 1600 cubic feet or less. Charges are computed based on the total weight to the DCR. A shipment can be billed in a higher weight class if doing so reduces the total charges. A random variate is generated to compute the LTL mode B (less than 10,000 lbs.) transit time, which is scaled downward for a TL mode A (10,000 lbs. or more) shipments. A half day is added to the transit time to reflect additional hold time required to load the shipping units onto the truck. The total processing and hold time is therefore between 12 and 72 hours (not counting weekends) per shipping unit, because these shipping units had already been at the terminal for between zero and sixty hours (72 hours since the drop minus 12 to 72 hours processing time).

Although individual shipping units are destroyed when the shipment entities are created, their attributes are retained until after the shipment's transit time has been found. This permits on-time statistics to be computed for each shipment just as at the small parcel terminal node. After the consolidation has been done, the scheduling entity creates one truck resource unit for each newly created shipment entity. The resources are labelled by area, so that only the desired shipments are matched with the resources needed to leave the node.

D. Model Verification and Validation

Model debugging and verification required creation of a small (5000 records) data set to minimize program run times. The SLAM network was debugged to the point where an input case would run to completion. Then, additional runs were performed to verify that the program accurately executed the model's assumptions. SLAM event trace reports were inspected to determine if each node and subroutine performed as desired in the desired order.
When the code was verified as a correct representation of the model, larger data cases were run to validate the model. The same MRO data which was transformed for model inputs was used to recover the historical numbers of shipments and transportation costs by transit mode. Model results for the 15-day time standard were compared to the historical results. When the differences were attributable to specific modeling assumptions which could be easily improved, model refinements were made. Some differences were regarded as acceptable, because the simplifying assumptions causing them were not expected to bias the comparison of alternatives. A comparison of actual and model results is shown in Table 4-1.

Table 4-1

MODEL VALIDATION STATISTICS

<table>
<thead>
<tr>
<th></th>
<th>&quot;Best&quot; Match Columbus</th>
<th>&quot;Worst&quot; Match Richmond</th>
<th>All Depots Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Weight Freight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>86.67%</td>
<td>94.65%</td>
<td>95.62%</td>
</tr>
<tr>
<td>Simulated</td>
<td>91.77%</td>
<td>98.68%</td>
<td>98.39%</td>
</tr>
<tr>
<td>% Weight Not Freight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>13.33%</td>
<td>5.35%</td>
<td>4.38%</td>
</tr>
<tr>
<td>Simulated</td>
<td>8.23%</td>
<td>1.32%</td>
<td>1.61%</td>
</tr>
<tr>
<td>Freight Shipments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>9,982</td>
<td>20,359</td>
<td>140,857</td>
</tr>
<tr>
<td>Simulated</td>
<td>9,470</td>
<td>16,288</td>
<td>100,630</td>
</tr>
<tr>
<td>UPS/USPS Shipments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>73,102</td>
<td>87,614</td>
<td>637,308</td>
</tr>
<tr>
<td>Simulated</td>
<td>56,083</td>
<td>66,592</td>
<td>411,468</td>
</tr>
<tr>
<td>Total Shipments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>83,044</td>
<td>108,973</td>
<td>778,165</td>
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<tr>
<td>Simulated</td>
<td>65,553</td>
<td>82,860</td>
<td>512,098</td>
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<tr>
<td>Transportation Charges</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>$.996M</td>
<td>$3,021M</td>
<td>$17.081M</td>
</tr>
<tr>
<td>Simulated</td>
<td>$1.027M</td>
<td>$2,516M</td>
<td>$15.711M</td>
</tr>
</tbody>
</table>

The comparison suggests that the model's level of consolidation may be an ideal which is difficult to achieve in practice, particularly in consolidation of small parcels into freight. Part of the difference may be due to the model's assumption that only shipping units weighing ten pounds or less will automatically travel by UPS or USFS. Actual depots may use higher weight thresholds, or may merely be imperfect consolidators.
Modeled bank times are another source of differences. For a number of reasons, the actual depots appeared to bank MROs for an average of about one day less than the model estimated. The depots each appeared to use longer transportation hold times than in the model, and the time difference was most pronounced for the depots matching the model results the least. Although transportation hold times contribute to consolidation, planning for extended hold times is suboptimal because it generally shortens bank times. It can be shown that this actually reduces consolidation because hold times do not combine materiel from subsequent cycles as effectively as extending the cycle with bank times.

DLA transportation officials and the depots know that unnecessary use of small parcel shipments and short bank times is inefficient, so they are continually striving to perform more optimally. Therefore, rather than alter the modeled threshold or design imperfections into the model, best-case estimates of depot performance were sought. This should insure that the benefits of increased time standards would not be overstated.

E. Output Generation

1. Outputs Provided. Each run of the model produced a variety of output. The categories of output were:

   a. Shipping unit summaries by warehouse type and day of the week, including the total shipping units. The number completed, the number dropped and the number reaching each transportation terminal are given.

   b. Drop cycle durations by customer area and all areas.

   c. The total weight shipped by each mode of transit.

   d. A transportation cost summary by mode and customer area.

   e. The number of shipments by mode and customer area.

   f. The average transit times by mode and customer area.

   g. The distribution of the number of days for a shipping unit to reach the customer, by area and overall.

   h. A day to day count of shipping units processed for each day of the model run.

Sample output from a single case is shown in Appendix C.

2. Primary Cases Run. Three time standard cases (15, 18, and 21 days) were run for each depot, for a total of 18 primary cases.

Some cases were run several times with alternate model versions to test the impacts of key input parameters such as the ten pound automatic mail threshold for shipping units and alternative algorithms for transit time, costing, and freight consolidation logic. The outputs tended to change slightly in magnitude, but not in a way which changed percentage differences between scenario costs or shipments.
V. SIMULATION RESULTS

Simulation outputs were collected for all input scenarios and summarized for each measure of comparison. The results were estimates for only six months of depot operations.

A. Transportation Charges

The total estimated transportation costs for the baseline (15-day) scenario at all six depots was $15.71 million for six months. This was reduced to $14.21 million for the combined 18-day standard, a savings of $1.5 million or 9.6 percent. The 21-day standard total cost was $13.36 million, a savings of $2.35 million or 15.0 percent over the baseline. The greatest percentage savings were estimated for the Mechanicsburg depot, saving 14.0 percent ($369 thousand) with a 18-day standard and 19.5 percent ($514 thousand) with a 21-day standard. The lowest percentage savings were 6.5 percent and 11.4 percent for the Richmond depot.

Complete results, including costs by mode of transit, are shown in Table 5-1.

B. Total Shipments. The total number of shipments for all depots was 512,098 for the 15-day standard, 421,307 (17.7 percent less) for 18 days, and 374,108 (26.9 percent less) for 21 days. The reductions resulted from decreases in small parcel (UPS/USPS) shipments and mode B (LTL) shipments from each depot, while mode A (TL) shipments actually increased slightly. The shipment results are summarized in Table 5-2. The levels of consolidation are further illustrated by the weight shipped per mode of transit, shown in Table 5-3.

C. Shipping Unit Summaries. The total number of shipping units also decreased as the time standard increased. From a baseline total of 745,200 shipping units, the 18-day number dropped 10.7 percent to 665,263, and the 21-day total dropped 17.7 percent to 613,040. More detailed results are shown in Table 5-4. The decreases were driven by 11.6 and 18.9 percent declines in bin item shipping units, and by 8.0 percent and 13.9 percent drops in bulk item units, although the number of lines of each type did not change. The number of shipping units delivered by UPS and USPS decreased by 16.3 percent and 25.2 percent in the 18-day and 21-day results. The number of shipping units delivered as freight decreased by only 3.9 percent and 8.5 percent, because much of the materiel previously shipped as small parcels became freight shipping units when the time standard increased.

D. On-Time Performance

The on-time performance easily exceeded 90 percent in each simulation scenario. In fact, the average on-time performance per depot was 97.4 percent for the 15-day standard, 98.3 percent for the 18-day standard and 99.2 percent for the 21-day standard. Several scenarios showed the depot achieving the 90 percent goal a day or more early. The frequency of this observation increased whenever the time standard increased.
Table 5-1
SIMULATED IPG III TRANSPORTATION COSTS  SIX MONTHS

<table>
<thead>
<tr>
<th>Depot</th>
<th>Scenario</th>
<th>Transportation Charges ($ Thousands)</th>
<th>Percent Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Truckload</td>
<td>LTL</td>
</tr>
<tr>
<td>Mech</td>
<td>15 days</td>
<td>608.49</td>
<td>1,823.61</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>668.11</td>
<td>1,442.29</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>697.80</td>
<td>1,287.36</td>
</tr>
<tr>
<td>Tracy</td>
<td>15 days</td>
<td>618.36</td>
<td>1,321.34</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>674.62</td>
<td>1,110.05</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>692.86</td>
<td>980.59</td>
</tr>
<tr>
<td>Colum</td>
<td>15 days</td>
<td>106.96</td>
<td>758.29</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>117.03</td>
<td>691.99</td>
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<tr>
<td></td>
<td>21 days</td>
<td>126.00</td>
<td>646.08</td>
</tr>
<tr>
<td>Memp</td>
<td>15 days</td>
<td>2,508.08</td>
<td>2,341.47</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>2,581.70</td>
<td>1,866.68</td>
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<tr>
<td></td>
<td>21 days</td>
<td>2,605.45</td>
<td>1,637.94</td>
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<tr>
<td>Rich</td>
<td>15 days</td>
<td>879.34</td>
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<tr>
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<td>21 days</td>
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<td>1,144.27</td>
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<td>1,540.29</td>
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<td></td>
<td>21 days</td>
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<td>Combined</td>
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<td></td>
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<td>Depot</td>
<td>Scenario</td>
<td>Number of Shipments by Mode</td>
<td>Percent Decrease</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>-----------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TL</td>
<td>LTL</td>
</tr>
<tr>
<td>Mech</td>
<td>15 days</td>
<td>1,160</td>
<td>21,325</td>
</tr>
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<td></td>
<td>18 days</td>
<td>1,255</td>
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<td>11,805</td>
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<td>21 days</td>
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<td>7,237</td>
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</tr>
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<td></td>
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<td>58,063</td>
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<td>Depot</td>
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<td>11.573</td>
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<td>25.633</td>
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<td>27.160</td>
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<td>183.238</td>
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<td></td>
<td>21 days</td>
<td>190.850</td>
<td>57.936</td>
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## Table 5-4

### SIMULATED IPG III SHIPPING UNITS - SIX MONTHS

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<tr>
<th>Depot</th>
<th>Scenario</th>
<th>By Warehouse Type</th>
<th>By Transit Type</th>
<th>Total</th>
<th>Percent Decrease</th>
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<td></td>
<td></td>
<td>Bin</td>
<td>Mail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mech</td>
<td>15 days</td>
<td>97,889</td>
<td>72,303</td>
<td>132,812</td>
<td>0.00%</td>
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<td></td>
<td>18 days</td>
<td>83,928</td>
<td>57,752</td>
<td>114,798</td>
<td>13.56%</td>
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<td></td>
<td>21 days</td>
<td>77,107</td>
<td>51,559</td>
<td>105,973</td>
<td>20.21%</td>
</tr>
<tr>
<td>Tracy</td>
<td>15 days</td>
<td>78,329</td>
<td>54,772</td>
<td>101,627</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>70,138</td>
<td>46,794</td>
<td>91,932</td>
<td>9.78%</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>64,189</td>
<td>41,951</td>
<td>84,138</td>
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</tr>
<tr>
<td>Colum</td>
<td>15 days</td>
<td>72,108</td>
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</tr>
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<td>18 days</td>
<td>62,837</td>
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<td>73,956</td>
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</tr>
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<td>21 days</td>
<td>57,463</td>
<td>41,055</td>
<td>68,518</td>
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</tr>
<tr>
<td>Memp</td>
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</tr>
<tr>
<td></td>
<td>18 days</td>
<td>126,156</td>
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<td>175,096</td>
<td>10.25%</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>115,876</td>
<td>69,770</td>
<td>161,646</td>
<td>17.22%</td>
</tr>
<tr>
<td>Rich</td>
<td>15 days</td>
<td>89,014</td>
<td>66,592</td>
<td>118,606</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>82,237</td>
<td>59,695</td>
<td>101,932</td>
<td>11.94%</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>76,984</td>
<td>55,024</td>
<td>92,008</td>
<td>12.78%</td>
</tr>
<tr>
<td>Ogden</td>
<td>15 days</td>
<td>89,286</td>
<td>68,512</td>
<td>112,298</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>77,502</td>
<td>56,144</td>
<td>93,646</td>
<td>11.94%</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>69,392</td>
<td>48,448</td>
<td>87,840</td>
<td>20.43%</td>
</tr>
<tr>
<td>Combined</td>
<td>15 days</td>
<td>568,670</td>
<td>411,468</td>
<td>745,138</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>18 days</td>
<td>502,798</td>
<td>344,542</td>
<td>647,340</td>
<td>10.73%</td>
</tr>
<tr>
<td></td>
<td>21 days</td>
<td>461,011</td>
<td>307,807</td>
<td>624,818</td>
<td>17.73%</td>
</tr>
</tbody>
</table>
Complete results, including the cumulative percentages of units delivered three days, two days, and one day early, are shown in Table 5-5. For example, in the Mechanicsburg 15-day scenario, 69.0 percent were delivered by 12 days, 81.4 percent by 13 days, 90.3 percent by 14 days, and 95.5 percent by 15 days.

E. Average Transit Times. The average transit time per shipment decreased slightly but consistently as the time standard increased, as summarized in Table 5-6. The slightness of the differences between time standards is explained by the fact that the random variable transit time's mean value for a particular mode, depot, and destination state was constant for all time standards, and by the fact that the high number of small parcel shipments (roughly 80% of the total) dominated the computed average. The decreases which did occur resulted primarily from the slight increases in the fraction of total shipments which went by the fastest mode: full truckloads. The high variance of each transit time reported should inhibit drawing further conclusions from the transit time results.

Table 5-5

<table>
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<tr>
<th>Depot</th>
<th>Time Standard (TS)</th>
<th>TS-3</th>
<th>TS-2</th>
<th>TS-1</th>
<th>TS</th>
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</thead>
<tbody>
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<td>.814</td>
<td>.903</td>
<td>.955</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>.809</td>
<td>.894</td>
<td>.946</td>
<td>.978</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>.874</td>
<td>.928</td>
<td>.964</td>
<td>.985</td>
</tr>
<tr>
<td>Tracy</td>
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<td>.660</td>
<td>.854</td>
<td>.960</td>
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<td>18</td>
<td>.802</td>
<td>.897</td>
<td>.951</td>
<td>.984</td>
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<td></td>
<td>21</td>
<td>.878</td>
<td>.940</td>
<td>.982</td>
<td>.998</td>
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<tr>
<td>Columbus</td>
<td>15</td>
<td>.652</td>
<td>.840</td>
<td>.946</td>
<td>.986</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>.810</td>
<td>.903</td>
<td>.958</td>
<td>.985</td>
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<tr>
<td></td>
<td>21</td>
<td>.862</td>
<td>.932</td>
<td>.976</td>
<td>.994</td>
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<tr>
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<td>.858</td>
<td>.923</td>
<td>.962</td>
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<tr>
<td></td>
<td>18</td>
<td>.838</td>
<td>.909</td>
<td>.955</td>
<td>.979</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>.895</td>
<td>.943</td>
<td>.971</td>
<td>.987</td>
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<tr>
<td>Richmond</td>
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<td>.934</td>
<td>.983</td>
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<tr>
<td></td>
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<td>.802</td>
<td>.900</td>
<td>.964</td>
<td>.993</td>
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<tr>
<td></td>
<td>21</td>
<td>.870</td>
<td>.939</td>
<td>.981</td>
<td>.997</td>
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<tr>
<td>Ogden</td>
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<td>.907</td>
<td>.965</td>
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<td></td>
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<td>.795</td>
<td>.893</td>
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<td>.982</td>
</tr>
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<td></td>
<td>21</td>
<td>.876</td>
<td>.937</td>
<td>.973</td>
<td>.991</td>
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<tr>
<td>TOTAL</td>
<td>15</td>
<td>.677</td>
<td>.832</td>
<td>.928</td>
<td>.974</td>
</tr>
<tr>
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<td>18</td>
<td>.709</td>
<td>.899</td>
<td>.954</td>
<td>.983</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>.876</td>
<td>.937</td>
<td>.974</td>
<td>.992</td>
</tr>
</tbody>
</table>
Table 5-6
AVERAGE TRANSIT DAYS PER SHIPMENT

<table>
<thead>
<tr>
<th>DEPOT</th>
<th>TS</th>
<th>TL</th>
<th>LTL</th>
<th>UPS/USPS</th>
<th>OVERALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanicsburg</td>
<td>15</td>
<td>3.99</td>
<td>6.59</td>
<td>6.50</td>
<td>6.49</td>
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<td>3.79</td>
<td>6.52</td>
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<td>21</td>
<td>3.86</td>
<td>6.57</td>
<td>6.41</td>
<td>6.39</td>
</tr>
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<td>3.69</td>
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<td>6.25</td>
<td>6.19</td>
</tr>
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<td>6.14</td>
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<td>6.17</td>
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<td>21</td>
<td>3.66</td>
<td>6.18</td>
<td>6.26</td>
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<td>15</td>
<td>3.76</td>
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<td>5.74</td>
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<td>5.47</td>
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<td>5.74</td>
<td>5.27</td>
<td>5.31</td>
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<td>3.61</td>
<td>6.18</td>
<td>6.05</td>
<td>6.02</td>
</tr>
</tbody>
</table>

F. Bank Cycle Durations

The overall average number of days per bank cycle increased from 3.47 days for the 15-day standard to 6.75 days for the 18-day standard. The corresponding total bank cycles for all bank areas numbered 6981 for a 15-day standard, dropping to 3576 bank cycles for 18 days and 2498 cycles for 21 days. More complete results are shown in Table 5-7.
<table>
<thead>
<tr>
<th>DEPOT</th>
<th>TS</th>
<th>Lowest Area Average</th>
<th>Highest Area Average</th>
<th>Average For All Areas</th>
<th>Total Cycles All Areas</th>
<th>% Drop In Number</th>
</tr>
</thead>
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<tr>
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<td>0</td>
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<td>6.65</td>
<td>589</td>
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<tr>
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<td>1114</td>
<td>0</td>
</tr>
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<td></td>
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<td>5.24</td>
<td>9.75</td>
<td>7.38</td>
<td>629</td>
<td>43.54</td>
</tr>
<tr>
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<td>13.73</td>
<td>10.51</td>
<td>456</td>
<td>59.07</td>
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<tr>
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<td>2.89</td>
<td>1243</td>
<td>0</td>
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<td>10.00</td>
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<td>592</td>
<td>52.37</td>
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<tr>
<td></td>
<td>21</td>
<td>6.90</td>
<td>13.73</td>
<td>9.52</td>
<td>390</td>
<td>68.62</td>
</tr>
<tr>
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<td>7.00</td>
<td>3.47</td>
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<td>13.73</td>
<td>9.78</td>
<td>2498</td>
<td>64.22</td>
</tr>
</tbody>
</table>

G. A Key Effect. Two points explain the slight but consistent increases in on-time performance with longer time standards. First, the increased use of fast, reliable TL shipments virtually guarantees on-time delivery of some materiel which might be late under lower time standards. More significant is a subtle benefit of increased bank times. The average age of MROs in a bank is about one-half the bank time. As a result, increasing the time standard (and thus the average bank duration) by a certain amount increases the average age of dropped MROs by only one-half that amount. The additional timeliness cushion is carried on through the processing and transit operations. This speculation was confirmed by computation of median delivery times for the 18-day and 21-day time standards. The three additional bank days added from 1.04 to 1.61 days to the median delivery time. The overall average delay was only 1.38 days.
H. Remarks

Some of the preceding results should be used cautiously due to limiting assumptions in the model. For example, the computed on-time performance is undoubtedly high in each case because actual warehouses will occasionally process an item too late for shipment in the intended cycle, but this was not permitted in the model; furthermore, validation cases showed that actual depots probably ship more by small parcels and less by faster TL shipments than the model estimated.

Another example: the number of shipping units estimated in the model is an ideal minimum, because bin item consolidation was not constrained by warehouse location, and the same holds for bulk items. The assumptions are consistent between scenarios, however, so the relative (percentage) differences in shipping units may be meaningful even if the magnitudes are conservative.

The bank time results are also probably high predictions of those achievable in reality. Actual depots appear to hold items at the freight terminal longer than the model assumes. This may be due in part to early partial drops of an area's MROs needed to level daily processing workloads. Again, the banking logic is ideal but consistent across all scenarios.

These examples merely confirm that the model's output is useful only if interpreted in light of the model's assumptions. In general, the model assumed that all depots performed near a theoretical optimal level of efficiency for the particular time standard. The better a depot performs, the less room it has for improvement; therefore, the model's estimated benefits of increasing the time standard are probably conservative. In other words, an estimated savings of $5 million is more likely to be low than to be high.

The most reliable insights possible from the model are probably in the effect that bank times have on both numbers of shipments and total transportation charges. The relative reductions in numbers of cycles for different scenarios closely parallels the relative reductions in shipments and costs presented earlier. For example, Mechanicsburg experienced the largest percentage drops in all three measures of comparison, while Richmond experienced the least change in all three measures. The degree and implications of this correlation are discussed in the next chapter.
VI. ANALYTIC METHODOLOGY AND INSIGHTS

A. Motivation

The simulation experiment produced the desired output measures for each case, but was augmented by theoretical analysis for several reasons. The simulation results can be said to answer the "How Much?", but don't necessarily answer the "How?" or "Why?" questions. The more events modeled per run, the more difficult it can be to isolate key events. Inspecting different output quantities such as cost and numbers of shipments yields some clues about their relationships, but does not spell out the key effects of bank time durations. For example, why does an 18-day standard save 9.6 percent of the 15-day transportation costs, while extending the time standard another three days to 21 saved only an additional 5.4 percent (15% over the 15-day standard)?

There are inherent limits to simulation analysis. The run time for one of the 18 cases averaged 150 CPU minutes. The cases run for each depot represented only three time standards in a larger set of interest ranging from 12 to 24 days, but computer resource constraints prohibited explicitly running each alternative. Furthermore, each scenario to some degree represented an ideal depiction of the system. The output numbers may be as useful as support of general insights as they are as predictors of "real-world" performance.

General insights were sought in the form of mathematical answers to two basic questions:

1. What increases consolidation, and by how much? Given a certain number of shipments with one time standard, how much does this number change for a different time standard? What other factors affect consolidation?

2. How much money does increased consolidation save? Given a percentage change in the number of shipments, by what percentage do the total transportation charges change?

The analytic approach consisted of four steps. First, the impacts of key variables on numbers of shipments were explored to derive a useful formula for estimating numbers of shipments. Second, a transportation cost estimating formula was derived based on the number of shipments and the total weight shipped. Third, the shipment and cost results were combined to estimate transportation charges from the average cycle time. Finally, the formula parameters were derived from simulation results to estimate results for all time standards of interest.

B. Number of Shipments

1. Expected Value Results

Consider the requisitions received by a depot from customers at a single installation, or DCR, over some number of days $T$. Suppose that the expected number of units, or requisitions, over $T$ is $N_e$, and the expected total weight to be shipped is $W_e$. Then the average weight per unit is:
\[ A_e = \frac{W_e}{N_e} \]

The expected number of shipments was estimated for different combinations of \( W_e \), \( A_e \) and the number of days per cycle by making two assumptions. The first is that the unit size is a constant of size:

\[ A = A_e \text{ pounds} \]

The impact of this assumption is discussed later.

Second, units were assumed to arrive at the depot according to a Poisson Process. This is equivalent to specifying that the time until the next arrival is always independent of the time since the last, or that the number of units received in a given time period is not influenced by the number received in the previous time period.

The resulting expected number of shipments is:

\[
E(S) = \left( \frac{T}{t} \right) \sum_{k=1}^{\infty} \text{Int} \left( 1 + \frac{A(k-1)}{M} \right) u^k e^{-u} / k! 
\]

where:

\[ t = \text{constant number of days per shipping cycle (bank time)}, \]
\[ u = \text{expected units per cycle} \]
\[ = \frac{N_e t}{T} \]

and:

\[ M = \text{maximum weight per shipment}. \]

The 'Int' function yields the largest integer less than or equal to the argument.

The above estimate can be approximated by computer because the terms in the infinite sum converge to zero, permitting estimation from a finite number of computed terms.

It should be noted that the above result minimizes the number of shipments received by the DCR. An actual DCR may experience more shipments because shipping units under ten pounds to different activities (DODAACs) will usually not be combined, and those under fifty pounds will not be combined unless the DCR has already qualified for freight. The primary benefits of consolidation appear from the simulation results to come from combining small freight into larger freight shipments; the estimate may be a fairly accurate measure of consolidation for material in this category. If one wished to estimate all categories of shipments, independent estimates for small mail shipments could be added in. The intent of the expected-value approach, however, was merely to rank certain consolidation effects.
2. Observations

The impacts of key variables on the expected number of shipments is discussed in increasing order of significance.

a. Unit Size

For a particular level of DCR total weight, the number and arrival rate of units change as the inverse of the unit size (average weight). The impact of this change is most pronounced for a DCR receiving a small total weight over a large number of cycles. There are almost as many shipments as units, because two units seldom arrive during the same cycle. The number of shipments begins to stabilize for longer cycle duration and/or more total weight, because the total expected weight per cycle becomes large enough to be relatively independent of the number of units. These relationships are illustrated by Figure 6-1a for a small-demand DCR and Figure 6-1b for a roughly normal-demand DCP.

The impact of unit size is further reduced by the fact that an increase in bank times reduces the number of shipments by about the same percentage regardless of the number of units.

b. Total Weight Received

As the total weight shipped to a DCR over a set period of time is increased, there are two points (weight levels) determining its impact on the number of shipments. The first is the point at which enough total units are received that at least one unit arrives during each cycle. Before this level, the weight has a large impact because little consolidation is occurring; therefore, the number of shipments increases directly with the number of units. The weight value of this level is a function of unit size and cycle duration. For unit sizes between 40 and 400 pounds and cycles from two to ten days, the level is between 100,000 and 200,000 pounds per year to the DCR.

Once this first key level of DCR activity is passed, the average shipment weight increases but the expected number of shipments does not. Significant increases in shipment numbers do not begin again until a second level is reached. This is the point at which the expected weight received during a cycle exceeds the maximum shipment weight, inducing multiple shipments per cycle with regularity. The location of this point is primarily a function of cycle duration. For example, it occurred at about seven million pounds per year for a two-day cycle, but at 3.5 million pounds for a four-day cycle. The relationship of weight to shipments is illustrated in Figure 6-2.

The apparent fact that a DCR's weight can increase substantially without appreciably increasing the number of shipments conflicts with an intuitive assumption about consolidation opportunities. Suppose two DCRs were combined into one for shipping purposes. If their combined weight is large enough but does not exceed some threshold annual amount, one could
Figure 6-1 (a and b). EXPECTED SHIPMENTS VS. UNIT SIZE

a. 

b. 

BANK CYCLE
BANK CYCLE
BANK CYCLE
Figure 6-2. EXPECTED SHIPMENTS VS. DCR WEIGHT

- 1 Day
- 2 Days
- 3 Days
- 4 Days
- 7 Days
- 15 Days
reasonably expect to reduce their total number of shipments by one-half. The purpose of this point is not to explore the feasibility or desirability of such aggregations, but rather to illustrate a general economy of scale.

c. Cycle Duration

The number of days per shipping cycle significantly impacted the number of shipments. In most cases, especially those with total weight between 100,000 and 800,000 pounds per year, there was about one shipment per cycle; at least one unit was received, but the weight per cycle seldom exceeded the maximum shipment weight. The number of shipments decreases directly as the number of cycles does, as shown in Figure 6-3a. This trend begins to disappear when sufficient weight is shipped per cycle that multiple shipments are made in each cycle, as illustrated in Figure 6-3b.

Note that increasing the cycle time does not always decrease the number of shipments. For example, when the cycle duration increased from two to three days, the number of shipments to a 6.4-million-pound-DCR increased from 183 to 243. This can be explained by noting that the average weight per cycle was 35,068 pounds for a two-day cycle, but was 52,601 for a three-day cycle. In the former, most of the 182.5 cycles experienced a single large shipment because the weight seldom exceeded 40,000 pounds; in the latter, most of the 121.7 cycles experienced a second shipment with the extra weight over the maximum truck size. The other fluctuations in the curves in Figure 6-3 are also caused by such relationships between the weight per cycle and the maximum shipment weight.

3. Time Standard

The previous section and the simulation results suggest that the single variable which was consistently correlated with the number of shipments is the number of cycles the shipped materiel is divided into. This inference was confirmed by a hypothesis test of rank correlations.

Consider the percentage change in some simulation measure of comparison from the 15-day standard to an 18-day or 21-day standard for the same depot. These changes in two measures - number of shipments and number of bank cycles - are listed for all 12 alternative cases in Table 6-1.
Figure 6-3 (a and b). EXPECTED SHIPMENTS VS. CYCLE TIME

(a) CYPS with Annual Weight Under 100K lbs

- 6250 lbs
- 12.5K lbs
- 25K lbs
- 50K lbs
- 100K lbs

(b) CYPS with Annual Weight Over 100K lbs

- 800K lbs
- 1.6M lbs
- 3.2M lbs
- 6.4M lbs
- 12.8M lbs
- 25.6M lbs
Table 6-1
ALTERNATIVE SCENARIOS RANKED BY SHIPMENT AND CYCLE REDUCTIONS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>% Shipment Reductions From 15-Day Standard</th>
<th>Rank</th>
<th>% Drop In Cycles From 15-Day Standard</th>
<th>Rank</th>
<th>Difference D_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mech. 21</td>
<td>31.78</td>
<td>1</td>
<td>70.79</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ogden 21</td>
<td>30.17</td>
<td>2</td>
<td>68.62</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Memp. 21</td>
<td>27.26</td>
<td>3</td>
<td>66.75</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Colu. 21</td>
<td>27.02</td>
<td>4</td>
<td>58.21</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Tracy 21</td>
<td>24.99</td>
<td>5</td>
<td>58.26</td>
<td>5</td>
<td>-2</td>
</tr>
<tr>
<td>Mech. 18</td>
<td>22.85</td>
<td>6</td>
<td>58.57</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Rich. 21</td>
<td>19.34</td>
<td>7</td>
<td>59.07</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Ogden 18</td>
<td>18.78</td>
<td>8</td>
<td>52.37</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Memp. 18</td>
<td>18.35</td>
<td>9</td>
<td>51.88</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Colu. 18</td>
<td>17.91</td>
<td>10</td>
<td>43.20</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Tracy 18</td>
<td>15.59</td>
<td>11</td>
<td>39.88</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Rich. 18</td>
<td>11.54</td>
<td>12</td>
<td>43.54</td>
<td>12</td>
<td>2</td>
</tr>
</tbody>
</table>

The test considered whether or not the two ranks for a scenario were related or "associated". The null and alternative hypotheses were, respectively:

H_0: There is not association between ranks;
H_1: There is a direct association between ranks.

Given the difference D_i between the two ranks for case i, i = 1,..., 12, the test statistic is Spearman's Coefficient of rank correlation.

\[
P = 1 - 6 \sum \frac{D_i^2}{n(n^2-1)}
\]

\[
= 1 - 6(14)/(12(143)) = .95105
\]

The critical value for a one-sided test at .95 significance level for n = 12 cases is .503. That is, we reject the null hypothesis in favor of the alternate hypothesis with 95 percent confidence if R > .503. Therefore, because R = .95105, we concluded that the reductions in numbers of shipments were directly associated with the reductions in numbers of cycles. In fact, the level of significance of the test statistic was greater than .999.

The number of cycles is a direct result of the cycle duration, which is determined for each DCF by the time standard.

Let t_s be the number of days in the time standard, and t_1 be the planned combined processing and transit time for a particular DCF. Then the bank, or cycle, duration is:

\[
t = t_s - t_1
\]
Then the number of shipping cycles over a period of time $T$ is:

$$c = T/t = T/t_S - t_1$$

This result reveals why one three-day increase (e.g. 15 to 18 days) in time standard results in more consolidation than another (e.g. 18 to 21 days). Let $C_{15}$, $C_{18}$, and $C_{21}$, be the number of cycles under the respective time standards, and let $t_{15}$, $t_{18}$, and $t_{21}$, be the respective bank time. If $t_1 = 11$ days, then:

$$t_{15} = 15 - 11 = 4,$$
$$t_{18} = 18 - 11 = 7,$$ and
$$t_{21} = 21 - 11 = 10.$$ 

Then over a period $T = 180$ days,

$$C_{15} = 180/4 = 45 \text{ cycles},$$
$$C_{18} = 180/7 = 25.71 \text{ cycles},$$ and
$$C_{21} = 180/10 = 18 \text{ cycles}.$$ 

Note that the decrease from the 15 to 18 day standard was about 19.3 cycles (42.8%) while the decrease from the 18 to 21 day standard was only 7.7 cycles (an additional 17%). This decline is in the rate of decrease in number of cycles paralleled that observed for the number of shipments. The apparent correlation motivated the form of a shipment estimating function derived from the simulation output, in a manner described in the next section.

It should be noted that the time standard increase from 15 to 18 days increased the average bank time by more than three days in the simulation results. The average bank time for all depots increased by 3.28 days from 3.47 to 6.75. Inspection of detailed results for individual areas suggested a probable cause: areas which would ideally bank for three to five days, which are common for the 15-day standard, were often dropped earlier because drops on the weekend were prohibited in the model. On the other hand, areas which ideally bank for six to eight days, which are common in the 18-day scenarios, avoided weekend problems because each cycle usually extended past the weekend regardless of the weekday it began on.

4. General Estimating Formula

A general formula was derived to estimate the number of shipments from a single variable related to the time standard. The apparent logical choice for that variable was either the total number of cycles or the overall average bank time. Bank times were more directly related to time standards, so the chosen general formula was

$$\hat{S} = S_0 t^{-c}$$

37
where:

\( \hat{S} \) = estimated number of shipments,

\( t \) = average bank time in days,

\( S_0 \) = constant parameter, and

\( C \) = constant parameter.

The simulation results for two time standards provided two equations which could be solved for the two unknowns, \( S_0 \) and \( C \). The solutions are:

\[ C = \log \left( \frac{S_1}{S_2} \right) / \log \left( \frac{t_2}{t_1} \right), \]

and

\[ S_0 = e^{\left( \log S_1 + C \log t_1 \right)}, \]

where \( S_i \) and \( t_i \) are the shipments and average bank time from simulation case \( i \).

The utility of this function was tested against the results for two depots, Richmond and Tracy. Four additional simulation cases were run - two for each depot: one for a 12-day standard and another for a 24-day standard. The 15-day and 21-day results were used to derive \( S_0 \) and \( C \) and then estimates the \( S_i \) value for each of the other time standards on the basis of the simulated bank time \( t_i \). The estimated and actual (simulation) numbers of shipments are compared in Table 6-2.

The only case with significant error was the Tracy 12-day scenario. This may be due to the sensitivity of the formula to bank times close to one. The estimating function is quite "steep" for small values of \( t \), so small errors in \( t \) make a big difference in shipment number estimates.

### Table 6-2

<table>
<thead>
<tr>
<th>Scenario</th>
<th>( S_0 )</th>
<th>( C )</th>
<th>( t_i )</th>
<th>No. of Shipments Simulation</th>
<th>No. of Shipments Predicted</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tracy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 days</td>
<td>104974</td>
<td>.3162</td>
<td>1.36</td>
<td>88743</td>
<td>95248</td>
<td>7.33</td>
</tr>
<tr>
<td>15 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>4.10</td>
<td>67194</td>
<td>67194</td>
<td>0</td>
</tr>
<tr>
<td>18 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>7.02</td>
<td>56720</td>
<td>56687</td>
<td>.058</td>
</tr>
<tr>
<td>21 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>10.14</td>
<td>50465</td>
<td>50465</td>
<td>0</td>
</tr>
<tr>
<td>24 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>13.86</td>
<td>45564</td>
<td>45717</td>
<td>.335</td>
</tr>
<tr>
<td><strong>Richmond</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 days</td>
<td>115672</td>
<td>.2331</td>
<td>1.72</td>
<td>102168</td>
<td>101938</td>
<td>.225</td>
</tr>
<tr>
<td>15 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>4.18</td>
<td>82880</td>
<td>82880</td>
<td>0</td>
</tr>
<tr>
<td>18 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>7.38</td>
<td>73318</td>
<td>72596</td>
<td>.985</td>
</tr>
<tr>
<td>21 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>10.51</td>
<td>66853</td>
<td>66853</td>
<td>0</td>
</tr>
<tr>
<td>24 days</td>
<td>&quot;</td>
<td>&quot;</td>
<td>13.63</td>
<td>67691</td>
<td>62023</td>
<td>.371</td>
</tr>
</tbody>
</table>
C. **Total Transportation Charges**

1. **Approximate Shipment Cost Function**

The transportation charges incurred by a depot to deliver a single shipment are primarily a function of the mode and distance of transit, the size of the shipment, and the contractual agreement with the carrier. A general cost estimating function was sought which would be reasonably accurate when applied to large numbers of shipments by all modes, depots, and customers combined. Such a function was derived from statistical analysis of shipments to the depot to its customers in a single state. The result was confirmed to be accurate for other cases, and is illustrated in Figure 6-4.

Each point plotted on this "scattergram" corresponds to one DCR; the coordinates are the natural logarithms of the total weight and total transportation charges from all the installations MROs filled by the Tracy depot over a six month period. Results for other depots are similar. The approximately linear nature of the graph supports an equation of the form

\[ \log(C(x)) = \log B + a \log x, \]

where \( C(x) \) is the cost of delivering a single shipment of weight \( x \) pounds. The equivalent result in non-logarithmic form leads to a function for the estimated cost \( C(x) \):

\[ C(x) = Bx^a \]

where \( a \) and \( B \) are constants such that:

\[ 0 < a < 1, \text{ and } B > 0. \]

Note that the cost per pound, or rate \( r(x) \), for the shipment is:

\[ r(x) = \frac{C(x)}{x} = Bx^{a-1}. \]

Consider two shipments of weight \( x_1 \) and \( x_2 \). If \( x_2 > x_1 \), then:

\[ \frac{r(x_2)}{r(x_1)} = \frac{Bx_2^{a-1}}{Bx_1^{a-1}} = \left(\frac{x_2}{x_1}\right)^{a-1} = \left(\frac{x_1}{x_2}\right)^{1-a} < 1 \]

This result is less than one because \( 0 < 1 - a < 1 \) and \( 0 < x_1/x_2 < 1 \). Thus \( r(x_2) < r(x_1) \), confirming that larger shipments tend to receive discounts in the cost per pound. Note that if \( a = 1 \), then the cost per pound is constant, \( r(x) = B \), for any shipment.

2. **Comparing Levels of Consolidation**

Let \( T(S,N) \) be the estimated total cost of shipping \( N \) pounds in \( S \) different shipments, and assume each shipment is of size \( x = N/S \) pounds. Then:
Figure 6-4. LOGARITHMIC SCATTERGRAM OF TRACY DCR COSTS AND WEIGHTS
\[ T(S,N) = SC(N/S) = SB(N/S)^a = BS^{1-a} N^a \]

It can be shown that assuming equal shipment sizes makes this result an upper bound for alternate forms of \( T(S,N) \) based on \( C(x) \).

Now consider two scenarios. In one, \( S_1 \) shipments are used; in the other, \( S_2 < S_1 \) are used. The ratio of the cost is:

\[ R_{21} = \frac{T(S_2,N)}{T(S_1,N)} \]

\[ = BS_2^{1-a} N^a / (BS_1^{1-a} N^a) \]

\[ = (S_2/S_1)^{1-a} \]

Note that \( R_{21} \) depends only on \( a \) and the ratio \( S_2/S_1 \). For example, suppose \( a = .7 \) and \( S_2/S_1 = .5 \). Then:

\[ R_{21} = (.5)^{1-.7} = (.5)^{.3} = .8123. \]

This result implies that cutting the number of shipments in half reduces the cost by \( 1-.8123 = .1877 \), or by 18.77 percent.

3. Estimating \( a \) and \( B \)

The two cost function parameters can be estimated a number of ways. Approximate least squares techniques include linear regression of the logarithm from the cost function using a large number of actual shipments:

\[ \log y = \log \hat{B} + \hat{a} \log x + E, \text{ or} \]

\[ y = \text{actual cost of shipment} \]
\[ x = \text{weight of shipment} \]
\[ \hat{B} = \text{estimate of } B \]
\[ \hat{a} = \text{estimate of } a \]
\[ E = \text{predicted minus actual cost (error of prediction)} \]

Performing this regression for different depots yielded \( a \) values ranging from .45 to .75. The estimates for \( B \), which affects the magnitude but not the ratio of cost estimates for different scenarios, ranged more substantially from depot to depot. This is because \( B \) can be considered the scaling parameter, while \( a \) is the shape parameter. Most actual cost functions yield about the same percentage discounts, or cost breaks, for a given increase in weight; hence they have the same shape, and we may be able to estimate a universal \( \hat{a} \) for application to any or all depots. A value for \( \hat{a} \) could then be derived for a particular case.

The primary purpose for estimating \( a \) and \( B \) was to generalize the simulation results and permit their extension to other scenarios. Therefore, the cost function parameters were derived, not by statistical techniques, but
directly from the simulation results. Let $S_i$ and $T_i$ be the total shipments and estimated cost for simulation scenario $i$. If scenario 1 is the combination of results for the 15-day time standard and scenario 2 is the combined results for the 18-day time standard, then:

\[
S_1 = 512,098, \quad T_1 = \$15,711.37K, \\
S_2 = 421,307, \quad T_2 = \$14,208.02K.
\]

First estimate $\hat{\alpha}$ from the ratio formula:

\[
\hat{\alpha} = 1 - \log \left( \frac{T_1}{T_2} \right) / \log \left( \frac{S_1}{S_2} \right)
\]

\[
= .48462.
\]

This result is consistent with statistical results. Either scenario's result $T_i$ can be used to estimate $B$: From:

\[
T(S,N) = BS_1 - aN\hat{\alpha}
\]

we get:

\[
\hat{B} = T_1 S_1^{-\hat{\alpha}} N^{-\hat{\alpha}}
\]

where $N$ = total pounds shipped from all depots.

\[
= 251,496,233
\]

Using $i = 1$ (15-days)

\[
\hat{B} = 1.52286
\]

4. Extrapolation or Interpolation

The utility of the above results can be checked by attempting to duplicate the results of the third scenario: the 21-day standard. Knowing the number of shipments $S_3$ yields:

\[
T_3 = BS_3^{-\hat{\alpha}} N^{-\hat{\alpha}} = \$13,364.01K.
\]

This result is within .056 percent of the simulation result $T_3 = \$13,356.59K$.

Thus we have a means of quickly estimating the cost of a wide range of levels of consolidation.

If we had instead used the results of scenarios 1 and 3 to estimate the results of scenario 2, we would have had slightly different parameter values:
\[ \hat{a} = 0.48284, \text{ and} \]
\[ \hat{B} = 1.53976. \]

The estimated cost in scenario 2 becomes:
\[ T_2 = 14,203.10K. \]

This result is only .035 percent off the simulation result \( T_2 = 14,208.02K \). This was slightly closer because interpolation tends to be more accurate than extrapolation, although both results are quite accurate.

D. Combined Shipment and Cost Formula

The transportation cost formula derived in the last section was
\[ T(S,N) = BS^{1-a}N^a. \]

In general, the number of shipments \( S \) is an unknown for a particular scenario. The value of \( S \) was estimated previously from the average bank time \( t \) by the formula
\[ \hat{S} = S_0 t^{-c}. \]

Substituting this result into the cost formula yields a new formula:
\[ T = B S_0^{1-a} N^a t^{-c(1-a)} \]
\[ = b t^{-d}, \]

where
\[ b = B S_0^{1-a} N^a, \text{ and} \]
\[ d = c(1-a). \]

The appropriateness of relating the total cost to the average bank time was confirmed by another hypothesis test of rank correlations. The Spearman's Coefficient of rank correlations between the percent drops in number of cycles from the baseline case and the percent cost savings was
\[ R = .86014 \]

This \( R \) value is significant at better than the .999 level, confirming the direct association of bank cycle reductions and cost savings.

The values of all the key parameters could be estimated from only two simulation cases, because each of the three equations has only two unknown parameters.
E. Combined Analytic and Simulation Results

The key parameters in the equations derived to estimate the number of shipments and the transportation charges were derived from two cases. One was the 15-day totals from all six depots combined, and the other was the combined 21-day results. The outputs used are summarized in Table 6-3.

Table 6-3

<table>
<thead>
<tr>
<th>CASES USED TO ESTIMATE ANALYTIC PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

The resulting estimated number of shipments for any average bank time is

$$S = S_0 t^{-c}$$

$$= 746581 t^{-0.3030072}$$

The parameters were computed as follows:

$$c = \log \left( \frac{S_1}{S_2} \right) / \log \left( \frac{t_2}{t_1} \right)$$

$$= \log \left( \frac{512098}{374108} \right) / \log \left( \frac{9.78}{3.47} \right)$$

$$= 0.3030072,$$ and

$$S_0 = S_1 t_1^c$$

$$= 512098 \times 3.47^{0.3030072}$$

$$= 746581$$

The total transportation charges were estimated by

$$T = b t^{-d}$$

$$= 19.09352 t^{-0.1567044}$$

The parameter computations:

$$d = \log \left( \frac{T_1}{T_2} \right) / \log \left( \frac{t_2}{t_1} \right)$$

$$= \log \left( \frac{15.71137}{13.35659} \right) / \log \left( \frac{9.78}{3.47} \right)$$

$$= 0.1567044,$$

$$b = T_1 t_1^d$$
These parameter values are useful only for the combined results of all six depots for the six months considered, but appropriate alternate parameters could be computed for individual depots in a similar fashion, and one could probably scale the results accurately for different periods of time.

Use of these equations for a particular scenario requires some knowledge of the expected average bank time. Overall average bank times were provided by simulation cases for the three primary time standards (15, 18 and 21 days). In addition, results for two depots for 12-day and 24-day standards were available; individual area bank times were inspected to establish educated guesses about the overall average for the six depots in both time standard cases. The resulting set of five overall average bank times was 1.3, 3.47, 6.75, 9.78 and 13.19 days for the 12, 15, 18, 21 and 24 day standards, respectively. Piecewise linear estimates were created for the remaining time standards' bank times. Then the number of shipments and total transportation charges were estimated for all integer time standards from 12 to 24 days. In addition, estimates were computed for each bank time from 1 to 13 days. These results are tabulated in Table 6-4.

Table 6-4
FINAL COMBINED RESULTS FOR SIX MONTHS

<table>
<thead>
<tr>
<th>Integer Time Standards</th>
<th>Integer Bank Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS Bank Days</td>
<td>Number of Shipments</td>
</tr>
<tr>
<td>12 1.3</td>
<td>689527</td>
</tr>
<tr>
<td>13 2.02</td>
<td>603328</td>
</tr>
<tr>
<td>14 2.75</td>
<td>549485</td>
</tr>
<tr>
<td>15 3.47</td>
<td>512098</td>
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<td>22 10.92</td>
<td>361816</td>
</tr>
<tr>
<td>23 12.05</td>
<td>351190</td>
</tr>
<tr>
<td>24 13.19</td>
<td>34692</td>
</tr>
</tbody>
</table>

These results are displayed graphically in Figures 6-5 and 6-6.
Figure 6-5. ESTIMATED TOTAL CHARGES

Figure 6-6. ESTIMATED NUMBER OF SHIPMENTS
VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Bank Times

MRO bank times significantly affect levels of consolidation and the resulting transportation costs.

The greatest potential benefits tend to come from extending bank times which are currently shortest.

2. An 18-Day Time Standard

Based on an extrapolation of the six month simulation results to yearly benefits, an 18-day IPG 3 time standard would reduce current transportation charges alone by over $3 million (9.6%) per year.

Shipments could be reduced by over 180,000 per year, or about 17.7 percent. Reliance on mode A (TL) shipments would increase, while both LTL and small parcel shipments would decrease substantially.

Total shipping units could be reduced at all warehouses, and at the mail and freight terminals as well. Total reductions would exceed 160,000 per year, or about 10.7%.

3. A 21-Day Time Standard

All of the estimated benefits of an 18-day time standard were exceeded by a 21-day standard, although the gains from 18 to 21 days were smaller than the gains from 15 to 18 days.

Again, based on an extrapolation of six month simulation results to yearly benefits, transportation costs would decrease by at least $4.7 million per year (about 15%).

Shipments would decrease by over 276,000 (about 27%) per year.

Total shipping units would decline by about 17.7 percent, or by over 260,000 units.

4. On-Time Performance

Increasing the time standard would make it easier to deliver material within the time standard. Furthermore, the increase in customer pipeline time per requisition would probably be less than half the number of days the time standard increases by. In fact, many of the supplies would probably be delivered as soon as or sooner than currently, due to increased use of fast TL shipments.

5. Other Benefits

Cost savings in several areas were not estimated, although these total savings may actually exceed those in transportation charges. Such areas to:
a. Reduced GBL costs from decreased numbers of shipments.
b. Reduced packing materials due to decreased number of shipping units.
c. Reduced numbers of drop cycles.
d. Reduced overtime due to increased bank times and resulting workload planning flexibility.
e. Reduced need for weekend processing.

6. Possible Disadvantages

At least one real consideration must be weighed against the benefits of increasing the IPG 3 time standard.

If military customers who are accustomed to certain pipeline times perceive that an increased time standard will add unacceptable delivery delays, they may upgrade many of their requisitions from IPG 3 to IPG 2. This could actually offset most or all of the cost savings, if care is not taken to maintain accurate customer perceptions of depot responsiveness.

B. Recommendations

DLA should establish the maximum IPG 3 time standard that satisfies the timeliness needs of military customers and meets other DLA objectives. If no concerns outside the scope of this analysis prohibit such a change, we recommend establishment of a 21-day standard.

DLA depots should concentrate on extending the shortest current bank times, even if the time standard is not increased. Furthermore, consolidation through bank time duration should be preferred to extending transportation hold times to gain consolidation.
Appendix A

SLAM Model Code
EFFECT OF CHANGING DEPOT ON-TIME PERFORMANCE STANDARD

SLAM SIMULATION MODEL FOR PROJECT #5001

THIS MODEL SIMULATES A DEPOT'S MRO PROCESS, FROM RECEIPT THROUGH 'BANKING', DROPPING, WAREHOUSE PROCESSING, TRANSPORTATION HANDLING, AND SHIPMENT. CHOICE OF ALTERNATIVE IPG3_TIME_STANDARD DETERMINES THE BANK TIMES FOR EACH AREA'S MRO'S.

CAPT. R.C. RIECKS  DLA-LO(DORO) AV 695-4045

THE MASTER FORTRAN PROGRAM 'MAIN' IS 'GOR.RIECKS.ASM(SLAMFOR)' AND THE JCL IS IN 'GOR.RIECKS.JCL(SLAM)'.

RESOURCE TYPE 'TRK?' IS TRUCKS GOING TO AREA? WHICH WILL BE FREED IN EVENT SUBROUTINE 4 AND MADE AVAILABLE TO SHIPMENTS AT 'AWAIT' NODE 53 A SET NUMBER OF DAYS AFTER THAT AREA'S MROS ARE DROPPED.

RESOURCE/TRK(0),53,54/TRK(1),53,54/TRK(2),53,54/TRK(3),53,54/TRK(4),53,54;
RESOURCE/TRK(0),53,54/TRK(1),53,54/TRK(2),53,54/TRK(3),53,54/TRK(4),53,54;
RESOURCE/TRK(0),53,54/TRK(1),53,54/TRK(2),53,54/TRK(3),53,54/TRK(4),53,54;
RESOURCE/TRK(0),53,54/TRK(1),53,54/TRK(2),53,54/TRK(3),53,54/TRK(4),53,54;
RESOURCE/TRK(0),53,54/TRK(1),53,54/TRK(2),53,54/TRK(3),53,54/TRK(4),53,54;
GATE 'DRP?', INITIALLY CLOSED, WILL BE OPEN AT CERTAIN SCHEDULED DAYS TO SIMULATE DROPS, ALLOWING ALL MROS COLLECTED AT 'AWAIT' NODE FOR AREA. 2 TO PROCEED ON TO WAREHOUSE

GATE/DRP4, CLOSE, 1, 2, 3.
GATE/DRP4, CLOSE, 2, 3, 4.
GATE/DRP4, CLOSE, 3, 4, 5.
GATE/DRP4, CLOSE, 4, 5, 6.
GATE/DRP4, CLOSE, 5, 6, 7.
GATE/DRP4, CLOSE, 6, 7, 8.
GATE/DRP4, CLOSE, 7, 8, 9.
GATE/DRP4, CLOSE, 8, 9, 10.
GATE/DRP4, CLOSE, 9, 10, 11.
GATE/DRP4, CLOSE, 10, 11, 12.
GATE/DRP4, CLOSE, 11, 12, 13.
GATE/DRP4, CLOSE, 12, 13, 14.
GATE/DRP4, CLOSE, 13, 14, 15.
GATE/DRP4, CLOSE, 14, 15, 16.
GATE/DRPN>CLOSE, 14,40;
GATE/DRPQ>CLOSE, 15,41;
GATE/DRPQ>CLOSE, 16,42;
GATE/DRPQ>CLOSE, 17,43;
GATE/DRPQ>CLOSE, 18,44;
GATE/DRPQ>CLOSE, 19,45;
GATE/DRPQ>CLOSE, 20,46;
GATE/DRPQ>CLOSE, 21,47;
GATE/DRPQ>CLOSE, 22,48;
GATE/DRPQ>CLOSE, 23,49;
GATE/DRPQ>CLOSE, 24,50;
GATE/DRPQ>CLOSE, 25,51;

TIME IS IN HOURS.
CLOCK STARTS AT USER SPECIFIED DAY
MRUS ARRIVED BY ACTUAL DAY RECEIVED.

EACH ENTITY IS CHARACTERIZED BY RECORD READ FROM EXTERNAL MRU FILE
GENERATE FIRST MRU LINE
FIRST CREATE:
ACTIVITY,, MRUS:
ACTIVITY,, 24,;
DAYS EVENT,, 6;
ACTIVITY,, 24,, T.NOW,LT,5000,,DAYS;
ACTIVITY:
TERM:

USE EVENT SUBROUTINE 3 TO READ RECORD FROM EXTERNAL MRU FILE,
ASSIGNING THE FOLLOWING ATTRIBUTE VALUES:
1: MARK TIME OF ENTITY (FROM CREATE NOUE *MRUS*;
2: GEOGRAPHICAL AREA CODE (FORMERLY A-Z, NOW 1-26)
3: SPLC GROUP [ST 2 DIGITS]
4: OCR (DESTINATION CROSS REFERENCE CODE)
5: SHIPPING UNIT NUMBER
6: PARCEL POST ZONE
7: WEIGHT IN POUNDS
8: VOLUME IN TENTHS OF CUBIC FEET
9: BIN/BULK INDICATOR (1=BIN,2=BULK)
10: TIME TILL NEXT MRU ARRIVAL (ZERO OR MULTIPLE OF 24 HOURS)

MRUS EVENT,, 3;
ACTIVITY,, ATRIB110, ATRIB110, LT, 500, MRUS;

BRANCH ACCORDING TO MRU ITEM TYPE BEFORE BRANCHING BY AREA
EACH AREA HAS TWO BANKS - ONE FOR SMALL (BIN) ITEMS AND ONE FOR
LARGE (BULK). BOTH BANKS WILL DPDP AT SAME TIME ACCORDING TO
SCHEDULE CONTROLLED BY AREA'S GATE.

ACTIVITY,, ATRIB19, EQ, 1, SMALL;
ACTIVITY,, ATRIB19, EQ, 2, LARGE;

USE ARRIVAL OF FIRST MRU FOR EACH AREA TO ACTIVATE
DROP-SCHEDULING NETWORK

ACTIVITY/1, USERF1(I), ATRIB12, EQ, 1, AND, NNACT(I), EQ, 0;
ACTIVITY/2, USERF1(I), ATRIB12, EQ, 2, AND, NNACT(2), EQ, 0;
ACTIVITY/3, USERF1(I), ATRIB12, EQ, 3, AND, NNACT(3), EQ, 0;
ACTIVITY/4, USERF1(I), ATRIB12, EQ, 4, AND, NNACT(4), EQ, 0;
ACTIVITY/5, USERF1(I), ATRIB12, EQ, 5, AND, NNACT(5), EQ, 0;
ACTIVITY, ATRIB(2), EQ. 16, OPNP;
ACTIVITY, ATRIB(2), EQ. 17, OPNC;
ACTIVITY, ATRIB(2), EQ. 18, OPNR;
ACTIVITY, ATRIB(2), EQ. 19, OPNS;
ACTIVITY, ATRIB(2), EQ. 20, OPNT;
ACTIVITY, ATRIB(2), EQ. 21, OPNU;
ACTIVITY, ATRIB(2), EQ. 22, OPNV;
ACTIVITY, ATRIB(2), EQ. 23, OPNH;
ACTIVITY, ATRIB(2), EQ. 24, OPNX;
ACTIVITY, ATRIB(2), EQ. 25, OPNY;

OPEN AREA GATE TO ALLOW SHIPPING UNITS TO LEAVE BANK.
CLOSE AGAIN AFTER SUFFICIENT DELAY.

OPNA OPEN, DRPA;
ACTIVITY, UNFRM(1..9,5);

CLSA CLOSE, DRPA;
ACTIVITY, ATRIB(L3), SHIP;

OPNB OPEN, DRPB;
ACTIVITY, UNFRM(1..9,5);

CLSB CLOSE, DRPB;
ACTIVITY, ATRIB(L3), SHIP;

OPNC OPEN, DRPC;
ACTIVITY, UNFRM(1..9,5);

CLSC CLOSE, DRPC;
ACTIVITY, ATRIB(L3), SHIP;

OPND OPEN, DRPD;
ACTIVITY, UNFRM(1..9,5);

CLSD CLOSE, DRPD;
ACTIVITY, ATRIB(L3), SHIP;

OPNE OPEN, DRPE;
ACTIVITY, UNFRM(1..9,5);

CLSE CLOSE, DRPE;
ACTIVITY, ATRIB(L3), SHIP;

OPNF OPEN, DRPF;
ACTIVITY, UNFRM(1..9,5);

CLSF CLOSE, DRPF;
ACTIVITY, ATRIB(L3), SHIP;

OPNG OPEN, DRPG;
ACTIVITY, UNFRM(1..9,5);

CLSG CLOSE, DRPG;
ACTIVITY, ATRIB(L3), SHIP;

OPNH OPEN, DRPH;
ACTIVITY, UNFRM(1..9,5);

CLSH CLOSE, DRPH;
ACTIVITY, ATRIB(L3), SHIP;

OPNI OPEN, DRPI;
ACTIVITY, UNFRM(1..9,5);

CLSI CLOSE, DRPI;
ACTIVITY, ATRIB(L3), SHIP;

OPNJ OPEN, DRPJ;
ACTIVITY, UNFRM(1..9,5);

CLSJ CLOSE, DRPJ;
ACTIVITY, ATRIB(L3), SHIP;

OPNK OPEN, DRPK;
ACTIVITY, ATRIB(L3), SHIP;

CLSK CLOSE, DRPK;
ACTIVITY, ATRIB(L3), SHIP;

OPNL OPEN, DRPL;
ACTIVITY, UNFRM(1..9,5);

CLSL CLOSE, DRPL;
ARTRI(13) HOURS AFTER DROP, CALL SUBROUTINE EVENT 4 TO COMBINE SHIPPING UNITS INTO FREIGHT UNITS AND FREE TRUCK RESOURCE(S) FOR THIS AREA.

SHIP EVENT 4: ACTIVITY;
TRES ACTIVIY; ARTRI(2) / ARTRI(13);
END OF DROP-SCHEDULING NETWORK - RETURN TO MRO NETWORK

MROS HAVE BEEN SORTED BY SIZE. NOW BRANCH BY AREA TO BANK NODES.

SMALL GCUN:

- ACTIVITY, ATRIB(2).EQ.1, DR1A;
- ACTIVITY, ATRIB(2).EQ.2, DR1B;
- ACTIVITY, ATRIB(2).EQ.3, DR1C;
- ACTIVITY, ATRIB(2).EQ.4, DR1D;
- ACTIVITY, ATRIB(2).EQ.5, DR1E;
- ACTIVITY, ATRIB(2).EQ.6, DR1F;
- ACTIVITY, ATRIB(2).EQ.7, DR1G;
- ACTIVITY, ATRIB(2).EQ.8, DR1H;
- ACTIVITY, ATRIB(2).EQ.9, DR1I;
- ACTIVITY, ATRIB(2).EQ.10, DR1J;
- ACTIVITY, ATRIB(2).EQ.11, DR1K;
- ACTIVITY, ATRIB(2).EQ.12, DR1L;
- ACTIVITY, ATRIB(2).EQ.13, DR1M;
- ACTIVITY, ATRIB(2).EQ.14, DR1N;
- ACTIVITY, ATRIB(2).EQ.15, DR1O;
- ACTIVITY, ATRIB(2).EQ.16, DR1P;
- ACTIVITY, ATRIB(2).EQ.17, DR1Q;
- ACTIVITY, ATRIB(2).EQ.18, DR1R;
- ACTIVITY, ATRIB(2).EQ.19, DR1S;
- ACTIVITY, ATRIB(2).EQ.20, DR1T;
- ACTIVITY, ATRIB(2).EQ.21, DR1U;
- ACTIVITY, ATRIB(2).EQ.22, DR1V;
- ACTIVITY, ATRIB(2).EQ.23, DR1W;
- ACTIVITY, ATRIB(2).EQ.24, DR1X;
- ACTIVITY, ATRIB(2).EQ.25, DR1Y;

LARGE GCUN:

- ACTIVITY, ATRIB(2).EQ.1, DR2A;
- ACTIVITY, ATRIB(2).EQ.2, DR2B;
- ACTIVITY, ATRIB(2).EQ.3, DR2C;
- ACTIVITY, ATRIB(2).EQ.4, DR2D;
- ACTIVITY, ATRIB(2).EQ.5, DR2E;
- ACTIVITY, ATRIB(2).EQ.6, DR2F;
- ACTIVITY, ATRIB(2).EQ.7, DR2G;
- ACTIVITY, ATRIB(2).EQ.8, DR2H;
- ACTIVITY, ATRIB(2).EQ.9, DR2I;
- ACTIVITY, ATRIB(2).EQ.10, DR2J;
- ACTIVITY, ATRIB(2).EQ.11, DR2K;
- ACTIVITY, ATRIB(2).EQ.12, DR2L;
- ACTIVITY, ATRIB(2).EQ.13, DR2M;
- ACTIVITY, ATRIB(2).EQ.14, DR2N;
- ACTIVITY, ATRIB(2).EQ.15, DR2O;
- ACTIVITY, ATRIB(2).EQ.16, DR2P;
- ACTIVITY, ATRIB(2).EQ.17, DR2Q;
- ACTIVITY, ATRIB(2).EQ.18, DR2R;
- ACTIVITY, ATRIB(2).EQ.19, DR2S;
- ACTIVITY, ATRIB(2).EQ.20, DR2T;
- ACTIVITY, ATRIB(2).EQ.21, DR2U;
- ACTIVITY, ATRIB(2).EQ.22, DR2V;
- ACTIVITY, ATRIB(2).EQ.23, DR2W;
- ACTIVITY, ATRIB(2).EQ.24, DR2X;
- ACTIVITY, ATRIB(2).EQ.25, DR2Y;

COLLECT MROS IN BANKS - 2 FOR EACH AREA
DROP AS A SHIPPING UNIT REQUEST
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR1A</td>
<td>AVOID(1), DRPA; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1B</td>
<td>AVOID(2), DRPB; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1C</td>
<td>AVOID(3), DRPC; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1D</td>
<td>AVOID(4), DRPD; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1E</td>
<td>AVOID(5), DRPE; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1F</td>
<td>AVOID(6), DRPF; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1G</td>
<td>AVOID(7), DRPG; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1H</td>
<td>AVOID(8), DRPH; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1I</td>
<td>AVOID(9), DRPI; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1J</td>
<td>AVOID(10), DRPJ; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1K</td>
<td>AVOID(11), DRPK; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1L</td>
<td>AVOID(12), DRPL; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1M</td>
<td>AVOID(13), DRPM; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1N</td>
<td>AVOID(14), DRPN; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1O</td>
<td>AVOID(15), DRPO; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1P</td>
<td>AVOID(16), DRPP; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1Q</td>
<td>AVOID(17), DRPQ; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1R</td>
<td>AVOID(18), DRPR; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1S</td>
<td>AVOID(19), DRPS; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1T</td>
<td>AVOID(20), DRPT; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1U</td>
<td>AVOID(21), DRPU; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1V</td>
<td>AVOID(22), DRPV; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1W</td>
<td>AVOID(23), DRPW; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1X</td>
<td>AVOID(24), DRPX; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR1Y</td>
<td>AVOID(25), DRPY; ACTIVITY, WRHS;</td>
</tr>
<tr>
<td>DR2A</td>
<td>AVOID(26), DRPA; ACTIVITY, WRHL;</td>
</tr>
<tr>
<td>DR2B</td>
<td>AVOID(27), DRPB; ACTIVITY, WRHL;</td>
</tr>
<tr>
<td>DR2C</td>
<td>AVOID(28), DRPC; ACTIVITY, WRHL;</td>
</tr>
<tr>
<td>DR2D</td>
<td>AVOID(29), DRPD; ACTIVITY, WRHL;</td>
</tr>
<tr>
<td>DR2E</td>
<td>AVOID(30), DRPE; ACTIVITY, WRHL;</td>
</tr>
</tbody>
</table>
PROCESS UNIT AT SMALL-ITEM WAREHOUSE

MAIL SHIPPING UNIT 10 POUNDS OR LESS BY UPS OR USPS

IF OVER 10 POUNDS, MAIL IF NO OTHER DCR SHIPPING UNIT IS FREIGHT. SEND TO FREIGHT TERMINAL IF ONE OR MORE UNITS ARE FREIGHT. ATR181(10) IS THE INDICATOR VARIABLE.
MORF GOUN;

ACTIVITY, ATKL(10), EQ, 0, MAIL;

ACTIVITY, ATRIB(10), EQ, 1, FRGT;

: ALL UNITS AT WAREHOUSE 2 ARE FREIGHT

: WRHL GOUN;

: WHL2 GOUN;

ACTIVITY/27, USERF(2);

: WHL3 GOUN;

ACTIVITY/28, ATRIB(7), LT, 10000, FRGT;

: ACTIVITY/29, ATRIB(7), GE, 10000, FRGT;

: MALL GOUN;

ACTIVITY/30;

: MAIL2 EVENT, 5;

ACTIVITY/32, ATRIB(13);

: DSTF COLCT, INT(1), TIME TO DELIVER, 12/264/24.;

: ACTIVITY;

: MTRM TERMINATE;

: FR1 GOUN;

ACTIVITY/31;

: FR2 AWAIT(51), ATRIB(2);

: ACTIVITY/33;

: FR3 AWAIT(54), ATRIB(2);

: ACTIVITY/34, ATRIB(13);

: DSTF COLCT, INT(1), TIME TO DELIVER, 12/264/24.;

: ACTIVITY;

: FRM TERMINATE;

: END;

: INIT, 0, 9000;

: F11;
Appendix B

SLAM Model FORTRAN Program
**Program Main**

```plaintext
; INITIALIZE NS100000000
COMMON V:OPT, S, T:OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OPT, OP
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
*** FINISH SHIPMENT: DETERMINE IF NEXT SHIPMENT

*** NEXT SHIPMENT: DETERMINE IF NEXT SHIPMENT

*** UPDATE PERFORMANCE DISTRIBUTION STATISTICS

*** STORE ATTRIBUTES FOR THIS SHIPMENT: GO BACK TO BEGIN ANOTHER

*** LOOK FOR OTHER SHIPPING UNITS ELIGIBLE FOR SAME SHIPMENT

*** KEEP NUMBER OF TRUCK RESOURCE NEEDED
**UNTIL DAY$1 = 4**

**DO 201 DAY$1 = 4**

**END**
C SCHEDULE Tie MATERIALIZE, INT COSTS
C
C ALEN COST
C ALEN COST
C
C TIE MATERIALIZE, INT COSTS
C
C IF (TIE, INT) IF = 1
C IF (TIE, INT) IF = 1
C
C IF (TIE, INT) IF = 1
C IF (TIE, INT) IF = 1
C
C CONTINUE
C CONTINUE
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C RETURN
C RETURN
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Appendix C

Sample Simulation Output Case
TRACY 15 DAYS

SHIPPING UNIT SUMMARIES BY DAY OF WEEK

UNITS COMPLETED PER DAY, BY WAREHOUSE TYPE

<table>
<thead>
<tr>
<th>WAREHOUSE</th>
<th>MON</th>
<th>TUE</th>
<th>WED</th>
<th>THU</th>
<th>FRI</th>
<th>SAT</th>
<th>SUN</th>
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UNITS DROPPED EACH DAY, BY WAREHOUSE TYPE

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UNITS PREPARED EACH DAY, BY TRANSIT TYPE

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UNITS HELD OVER AT FREIGHT TERMINAL AT END OF DAY

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C-2
### TREACY 15 DAYS

#### DROP CYCLE DURATIONS BY CUSTOMER AREA

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TOTAL DROPS = 1126

AVG. BANK DAYS = 4.10

"LOW" IS THE SHORTEST BANK TIME FOR GIVEN AREA.
TOTAL WEIGHT (Pounds) SHIPPED BY MODE:
MODE A (1000 LBS OR MORE) : 23736946
MODE B (LTL - < 10000 LBS) : 11046778
MODE C (CUR 5 (UPS OR JSPS)) : 508138

TOTAL IPS3 WEIGHT CONSIDERED : 35291762
TOTAL READ IN : 35291762
## TRACY 15 DAYS

### TRANSF. COST SUMMARY BY MODE AND CUSTOMER AREA

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<th>MODE G/5</th>
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| 26   | 618958.44 | 1321335.00 | 131906.63 | 2121599.00 |

**$/CUT:** 2.61 11.96 35.80 6.01

**ALL TOTALS ARE IN DOLLARS**

Area No. 26 is the total or overall results on this and subsequent tables.
**TRACY 15 DAYS**

**NUMBER OF SHIPMENTS BY MODE AND CUSTOMER AREA**

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