Rapidly Detecting and Correcting Degradation of Military Supply Distribution Performance

Algorithms, Visualizations, and Case Studies

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About This Report

This report documents research and analysis conducted as part of a project entitled *Drivers of OCONUS Distribution Performance*, sponsored by the Office of the Deputy Chief of Staff, G-4 (Logistics), U.S. Army. The purpose of the project was to develop planning tools to better support rotational assignments and tools to rapidly detect and allow Army logistical leaders to respond to supply chain problems.

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Summary

Army units worldwide depend on a complex network of distribution centers, managed primarily by the Defense Logistics Agency, to support equipment readiness and sustainability. Rapid and reliable distribution support is especially important for Army forces deployed into theaters of operations. There are many factors that can cause performance changes affecting the distribution timeliness to the Army. Currently, distribution problems are detected manually and reactively by Army units once these problems start to affect equipment readiness.

The objectives of this work were to create the following:

- algorithms that monitor the distribution system and automatically detect distribution problems (or potential distribution problems) that might affect equipment readiness
- data visualizations that assist Army managers and analysts to determine the root causes and potential corrective actions related to the detections.

Both the algorithms and visualizations are applied to various metrics and to data subsets by customer location, ship mode, distribution center, and issue priority. To detect problems as early as possible, many metrics are further upstream in the distribution process and use open shipment data rather than data from completed shipments (i.e., closed shipments) as is common. Hence, the detections can occur earlier than detections that exclusively use closed shipment data (i.e., shipments that have been receipted by the customer) and omit open shipment data.

The major findings are the following:

- Current Army distribution metrics are lagging indicators of problems because they focus on requisition wait time (RWT), which requires the receipt of the shipment, and require manual monitoring to detect problems.
- In several historical case studies of distribution performance degradation, the detection algorithms and metrics could have automatically detected actual or potential distribution problems several months prior to when they were realized by the Army units.

The major recommendations are the following:

- Implement the detection algorithms and visualizations in an Army analytics platform for continued use and to inform corrective actions.
- Expand the metrics beyond RWT to include open shipment data in the analytics platform so that the algorithms can identify potential distribution problems earlier.

The Army’s Logistics Data Analysis Center, which has extensive experience and knowledge of distribution processes and data, is the Army organization best suited to operate and continually improve the tools. The best owners and users of the tools is less apparent, though Army Materiel Command is likely a good choice. The case studies involved changes in policy and processes and required working with stakeholders both within and outside the Army.
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CHAPTER ONE

Introduction

Army units worldwide depend on a network of distribution centers (DCs), managed primarily by the Defense Logistics Agency (DLA), to support equipment readiness and sustainability. Rapid and reliable distribution support is especially important for Army forces deployed into theaters of operations. In theater, Army supply support activities (SSAs) rely on DLA distribution for replenishment of repair parts and other materiel. In support of the Army units, DLA distribution operates DCs worldwide with both Army-managed items (AMIs) and DLA-managed items (also called non–Army-managed items [NAMIs]). The DCs are replenished by suppliers and repair activities. In this global and geographically dispersed network of suppliers and DLA DCs, an important aspect of equipment readiness is for the Army and DLA to provide adequate distribution support to Army SSAs.

There are many factors that can cause performance changes in the distribution support to Army SSAs, such as changes in DC sourcing preferences, changes in shipment mode policies, inventory level decisions, stockouts, personnel shortages to process shipments and receipts, and disruptions to commercial carriers that provide transportation. Moreover, rotating brigade combat teams and their equipment into theater from garrison can create receipt delays when equipment and/or personnel are in transit or in processing.

Distribution problems are typically detected manually and responded to reactively by Army units when those problems drive SSA zero balance rates up or reduce equipment readiness. Typically, Army units notify their theater sustainment command (TSC) to work with DLA to investigate and correct any problems. Identifying and correcting problems using this manual, ad hoc approach can take months. For example, in October 2018, DLA interpreted policy at that time as requiring them to use more surface shipping to Afghanistan customers, thereby increasing customer requisition wait time (RWT) significantly. It took months for the affected units to become fully aware of the change in support and report it (as was determined in previous RAND Corporation research;1 this is also covered as a case study in Chapter Four). As another example, early in Operation Iraqi Freedom, there were multiple distribution problems that increased workload in theater, dramatically increased RWT, and led to many requisitions not being receipted (hence, no RWT measurement), but it took months for the issues to be reported, diagnosed, and addressed (Robbins and Peltz, 2007).

With an expansive and complex distribution network, the Army needs automatic algorithms that actively monitor and detect distribution problems before those problems significantly affect equipment readiness in theater. Because distribution problems can significantly delay the receipt that completes RWT, the detection algorithms must apply to segments of the supply chain prior to receipt. Moreover, once potential problems are detected, distribution managers still must contend with a complex distribution system and large amounts of data. The Army needs effective and efficient data visualization tools to assist these managers in determining the root causes for poor distribution performance and in devising corrective actions.

The research objectives for this study were to create the following:

- algorithms that monitor the distribution system and automatically detect distribution problems (or potential problems) that might affect equipment readiness
- data visualizations that assist Army managers and analysts to determine the root causes and potential corrective actions related to the detections.

The methodology used to conduct this work was a combination of discussions with subject-matter experts and analysis of distribution data provided by DLA's Analytics Center of Excellence (ACE). The subject-matter experts were from Headquarters, Department of the Army, Office of Logistics (HQDA G-4), DLA, and the 21st Theater Sustainment Command.

The remainder of this document is organized as follows. Chapter Two presents the automatic detection algorithms, which consists of the algorithm mechanics and the data types and sources. Chapter Three presents an overview of the data visualization dashboards that can be used to rapidly identify potential root causes for what was detected. Chapter Four presents historical case studies in which the use of the detection algorithms and data visualization dashboards are demonstrated. Chapter Five contains conclusions and next steps on implementing and benefiting from the tools. Appendix A provides details of the data visualization dashboards and their functionality. Appendix B provides details about custom calculations and functionality in the data visualization dashboards. Appendix C groups countries into geographic regions for detections at the regional level. Appendix D provides a data dictionary for the primary data table used in this research.

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2 The methodology is described further in Chapter Two and Appendix D.
CHAPTER TWO

Automatic Detection Algorithms

This chapter presents an overview of the Army’s supply chain outside the continental United States (OCONUS), describes the algorithms for detecting changes in distribution performance, gives examples of data visualization dashboards that can be used to diagnose detections, and describes the source data used in the detection algorithm and data visualizations.

The algorithms and data sources used allow for early detection of potential distribution problems. In addition to monitoring shipment duration until customer receipt (a lagging indicator of problems), the algorithms monitor shipments (source, shipping mode, etc.) prior to customer receipt that provide leading indicators for potential problems. The Army has improved monitoring of global distribution using data visualization dashboards of RWT, but these efforts require manual review to detect problems, and the use of RWT suggests that there can be lags before RWT-based dashboards can be used to detect distribution problems.¹

Overview of the Army’s OCONUS Supply Chain

Figure 2.1 is an overview of the OCONUS Army supply chain. The intent of Figure 2.1 and the description that follows is not to be exhaustive of every possible path for filling OCONUS SSA requisitions. Rather, the intent is to highlight the key aspects of the distribution process and link them to the detections and associated data visualizations. With these links to the process map, it is easier to use the data visualization dashboards to do root cause analysis on the detections.

Orange marker 1 in Figure 2.1 denotes the flow of requisitions from the SSA. All requisitions, regardless of type, are passed to the LMP, which is the Army’s enterprise resource planning for managing national-level supply and depot-level repair.

SSA requisitions are processed differently for AMIs and for NAMIs, denoted by orange markers 2A and 2B, respectively. For AMI SSA requisitions (marker 2A), LMP goes through Army Materiel Command (AMC)’s source preference logic to select the DC with on-hand inventory to send a materiel release order (MRO) directing shipment to the SSA.² For AMIs, the DC is typically a DLA DC in the continental United States (CONUS) or an SSA operating a theater authorized stockage list (TASL) forward in theater (shown in Figure 2.1 as a foreign distribution point [FDP]). There are other options, but they tend to account for a small percentage of the shipments.

Continuing the description of Figure 2.1, SSA requisitions for NAMIs are first processed by the AJ2 module of LMP. (AJ2 is the Army ownership routing identifier code [RIC] for NAMIs.) LMP first checks

¹ For example, the Army Readiness Common Operating Picture displays only historical shipment durations after receipt from SSAs or other Army customers.

² Source preference logic here refers to the algorithm used to determine which DC to send an MRO if more than one DC has inventory on hand.
whether there are Army-owned NAMI assets that are available. If Army-owned assets are available, source preference logic in LMP is used to select the DC to receive the MRO.

If there are no Army-owned assets available, the requisition is passed to the appropriate source of supply (e.g., DLA, General Services Administration [GSA], other services). Once the requisition has been passed, the NAMI requisition follows a similar process (orange marker 2B in Figure 2.1), a DC with on-hand inventory is selected and is sent an MRO to ship to the SSA. DLA maintains FDPs (e.g., DLA Distribution Korea and DLA Distribution Europe) in theater that could be selected to receive the MRO if they have inventory on hand. The source preference logic for NAMIs is different from the logic for AMIs and varies depending on the source of supply (e.g., DLA, Air Force, Navy). All requisitions passed to GSA (and some passed to DLA) are filled via DVD. The passing of the requisition directly to the vendor is depicted by the short dashed line going back to “. . . Vendors.” DVD shipments for OCONUS SSAs are typically shipped to the CCP in CONUS serving the theater in question.

Once a DC has received an MRO, the requisitioned item is picked, packed, and shipped. The choice of shipment mode (orange marker 3) is critical and is based on several factors, such as the issue priority group (IPG) assigned to the requisition, the SSA (e.g., distribution standard system, air line of communication), Army policies, and shipment modes available at the DC. Figure 2.1 breaks out a few of the shipment mode

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3 There can be significant logic to define availability, which centers on whether the item is on hand and in local excess (e.g., item on hand > requirement objective + retention level) and appropriately positioned relative to the requisitioning SSA (e.g., in the same theater). Any item on hand in a TASL in theater is available because the TASL does not have direct support customers.

4 GSA no longer operates fulfillment centers.
options available. Most shipments from FDPs are shipped via scheduled truck to SSAs in the same theater. However, the Defense Distribution Depot Europe (DDDE) in Germany also supports U.S. Central Command and U.S. Africa Command, so SSAs in those theaters go through a more extensive shipment mode decision logic differentiating primarily between air (and type of air) and surface shipping.

The blue lines in Figure 2.1 (orange marker 4) depict the replenishment of DCs from vendor procurements or repair. Where replenishments are directed is referred to as stock positioning logic and typically operates off the critical path for SSA requisitions (or a backorder is likely to be incurred). Stock positioning decisions can occur at the time of the contract or when the vendor or repair facility signals a shipment is ready for delivery. Stock positioning logic drives which DCs have on-hand inventory (influencing the options available at orange markers 2A and 2B) and should be made in coordination with the source preference logic. The stock positioning logic is different for AMIs than it is for NAMIs.

FDPs are typically replenished from CONUS DCs using forward stock positioning logic. FDPs have two advantages. The replenishments to FDPs can be sent from CONUS DCs via surface transportation to reduce second-destination transportation (SDT) costs without exposing the SSAs in theater to the long lead times associated with surface shipping. Depending on the characteristics of the item (weight, cube, and price) and the quantities required in theater, these SDT savings can be significant. The second advantage for the FDP is reduced response time, particularly for situations in which airlift into theater is limited, either because of enemy action or competition from unit deployments. FDPs typically ship to the SSAs using scheduled trucks (or local deliveries if the FDP is colocated on the same installation as the SSA).

For shipments from CONUS DCs or DVD, the choice of shipment mode used to transport the materiel is the critical determinant of how fast and reliable the RWT will be. There are typically two types of transportation modes from CONUS: movement by air and movement by ship. Because of the importance of maintaining high equipment readiness, Army policy calls for most class IX shipments to go via air, which is more expensive but typically an order of magnitude faster than surface shipping (e.g., container ship). Only a small percentage of class IX requisitions are shipped via surface, typically items that are low priority and very heavy (e.g., over 10,000 pounds). Although these requisitions represent a small percentage of class IX shipments, they can account for a significant percentage of the weight shipped.

Within the air mode, there are three primary means of movement. For smaller (under 300 pounds) and otherwise eligible shipments, rapid and time-definite delivery is offered via commercial contracts with such shippers as FedEx and DHL under the U.S. Department of Defense NGDS program. NGDS is picked up at the DC by the carrier and delivered directly to the SSA (as depicted in Figure 2.1).

Not all NGDS-eligible shipments are sent via NGDS. These shipments (along with those that are not NGDS eligible) are transported by Air Mobility Command, which has two variants, depending on where shipments are consolidated onto air pallets: MILALOC (pallets built by DLA CCPs) and MILAIR (pallets built by AMC airfield locations).

MILALOC and surface shipments from CONUS flow through the CCP, which is typically colocated with the primary DLA DC serving that theater. From the CCP, shipments are routed to an airport of embarkation or surface port of embarkation. Once received at the APOD or SPOD, shipments are transferred to intratheater transportation and delivered to the SSA. In some theaters, the shipments from the APOD and/or SPOD will be sent to either the FDP or some other central receiving and shipping point to be consolidated onto trucks already scheduled to deliver to the SSAs (i.e., using a hub-and-spoke type system).

5 Sometimes FDPs are used as distribution hubs in theater, so shipments from CONUS arriving by air or surface will be shipped to the FDP, where they are cross-docked to the schedule trucks going to the SSAs. This is not depicted in Figure 2.1.

6 The Army uses classes of supply to categorize equipment; class IX refers to spare parts.
Overview of Automatic Detection Algorithms

We developed automatic detection algorithms that identify distribution changes with respect to several key metrics. The metrics were chosen because of their monitoring of both leading indicators of potential problems and indicators of existing problems. The metrics are as follows:

- proportion of shipments (e.g., proportion of total shipments that are from each DC or associated with each shipment mode)
- RWT (either average or 95th percentile)
- requisition to receipt segment durations.

The proportion of shipments and segment duration metrics are leading indicators of potential problems (i.e., the customer will likely experience distribution delays soon) whereas the RWT metrics are indicators of existing problems (i.e., the customer is currently realizing distribution delays). The metrics are tracked for detections over subsets of the data along such dimensions as DC, shipping mode, IPG, AMI or NAMI, or a combination thereof.

Figure 2.2 shows a hierarchy of the detection tiers and detection groups that display the different dimensions (data subsets) of each detection group. There are five dimensions used to filter the data for detection analysis: customer region or SSA, AMI or NAMI, DC, mode of shipment, and IPG. The tiers reflect the number of dimensions used to subset the data prior to detection analysis. For example, tier 1 (T1) contains detections at the customer region or SSA level; T2 contains detections by using two dimensions to subset the data. T2 detections are by region-DC, region-mode, and region-IPG. T3 detections are region-DC-mode, region-DC-IPG, and region-mode-IPG. T4 detections are by region-DC-IPG-mode.

FIGURE 2.2
Detection Tiers and Groups That Also Aid in Diagnostics

7 We refer to customer region or SSA as location.
For each tier, we have selected the most useful metric and dimensional permutations to detect performance changes. The selections were based on the business rules that drive the distribution process. For example, shipment mode often varies by IPG of the shipment (orange marker 3 in Figure 2.1). Proportion of shipments by DC is driven by source preference logic (orange markers 2A and 2B in Figure 2.1) and stock positioning of replenishments (dashed blue lines in Figure 2.1), both of which vary by AMI versus NAMI.

When the detection algorithms are applied, the initial focus should be in the highest tier with a detection.\(^8\) Any detections at a lower tier are connected via an arrow in Figure 2.2 to the higher-tier detection and provide drill-down diagnostics.

The detection groups are used to denote how the data is subset prior to detection and to assist with diagnostics (i.e., which box in Figure 2.2) within each tier. These groups detect by the following:

- location of the customer demand (T1)
- mode selection (T2M)
- DC (T2D)
- Mode-IPG (T3MI)
- DC-Mode (T3DM)
- DC-IPG (T3DI)
- DC-AMI/NAMI (T3DA)
- DC-IPG-Mode (T4DIM).

Within each detection group, the algorithm will detect changes in the proportion of shipments (P), average RWT, or 95th percentile of RWT. The algorithms also detect changes in RWT segment durations, which are segment subcomponents of the total RWT and divided as follows:

- document creation to MRO creation
- MRO to ship date
- ship date to installation receipt\(^9\)
- installation receipt to customer receipt.

The detection algorithm is based on statistical process control (SPC) using the Western Electric (WE) SPC rules (Western Electric Company, 1956) to detect changes in the metrics.\(^10\) Below are the three rules we used for detections:

- **WE1:** The metric in the most recent period is greater than the moving average of the metric plus three standard deviations of the metric.
- **WE2:** Two of the three most recent periods are greater than the moving average of the metric plus two standard deviations of the metric.
- **WE3:** Four of the five most recent periods are greater than the moving average of the metric plus one standard deviation of the metric.

\(^8\) The highest tier is the one with the lowest number, so T1 is a higher tier than T2.

\(^9\) Installation receipt is sometimes called a *tail date*.

\(^10\) WE rules typically feature a fourth rule (WE4) defined as: all of the eight most-recent months are greater than the moving average. We omitted this rule in our detections because it detects very slight shifts in the mean and, on deeper investigations of instances flagged by WE4 only, none of them appeared to be legitimate distribution problems.
The detections are applied on a rolling basis. The WE SPC rules are designed to detect different kinds of changes. WE1 is applied when there is a large sudden increase in the metrics in one period. WE2 detects a smaller shift than WE1 over a longer time frame (three periods). Similarly, WE3 detect smaller shifts in the metrics over an even longer time frame (e.g., trends).

The SPC can be run for periods of a week or a month. We apply these rules to 12 periods before the test window and to the test window itself. For example, for WE2, the test window is the three most recent periods; the average and standard deviations for WE2 are calculated using the 12 periods immediately before the three-period test window.

The algorithms group the detections into threads that go down the detection tree in Figure 2.2. These threads arrange detections that are related. The more dimensions that the data is subset into, the better chance there is of isolating the cause of the detection (e.g., the change in the value of the metric exceeding one of the three rules already discussed) and of allowing one to better diagnose the root cause (e.g., explain a higher-tier detection). For example, if an increase in RWT was detected for Afghanistan (T1), thread grouping will show whether that increase was caused by shifts in mode (T2M), DC sourcing (T2D), or additional dimensions isolated further down the tree.

To reduce the number of false or insignificant detections, we have implemented business rules that make detections ineligible because of small sample sizes associated with some subsets of the data. Within each detection group (i.e., each box in Figure 2.2), we deem the detection ineligible if the number of transactions (shipments, receipts) is less than 5 percent of the transactions in the detection group.11 For example, if shipments from DLA Distribution Depot in Red River, Texas (DDRT) constituted 3 percent of the total shipments to customers in Guam (T2D in Figure 2.2), a detection in proportion of shipments from DDRT to Guam is deemed ineligible. Similarly, if the MILAIR constituted 2 percent of the Kuwait receipts from DLA Distribution Navy Bahrain (DDNB) (T3DM in Figure 2.2), then an RWT change detection for MILAIR from DDNB to Kuwait is deemed ineligible for detection.

Source Data Description

The source data used for the algorithms and detections are from the DLA’s ACE.12 The data provided by ACE are the following:

- DLA issues and receipts: These are data from the DLA distribution depots and CCPs as recorded by DLA’s Distribution Standard System, which is DLA’s information system for warehouse operations.
- Logistics response time (LRT): These are data developed from transactions passing through DLA Transaction Services (DLATS).13
- Global Combat Support System (GCSS)-Army receipts: These data are from Army SSAs and dedicated and/or remote customers.

These data sets provide the transactional data of elements used in the detection algorithms. Those elements are the following:

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11 Small-volume detection groups have limited effects on customers, and the metrics within such a small population can vary widely because of their small sample size. We implemented the ineligibility rule of less than 5 percent because the rule reasonably omitted unnecessary detections from these small populations.

12 ACE was formerly known as the DLA Operations Research and Resource Analysis.

13 The formal term for DLATS is the Defense Automatic Addressing System.
Automatic Detection Algorithms

- customer and customer location (which arrange SSAs by region and can vary over time)
- DLA DC that issued the shipment (i.e., the DC that the MRO was sent to)
- mode of shipment (e.g., NGDS, surface, military air, MILALOC)
- time stamps that marked distribution segments (U.S. Department of Defense document creation, establish, MRO, ship, tail, receipt)
- IPG.

We arranged SSA locations by region (defined in Appendix C). The distribution data are combined with part catalog information to obtain source of supply (which denotes whether an item is Army or non-Army managed [mostly DLA managed]), unit price, and supply class. The data are rolled up into either weekly or monthly periods. Appendix D contains a list of variables used in the detections along with data sources.

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14 Source of supply is important because AMI and NAMI processes use different logic to direct MROs to DCs and to position stock when replenishing DCs.
Overview of the OCONUS Distribution Data Visualization Dashboards

Each detection in Chapter Two is an early warning flag for a potential degradation in distribution performance that might persist. To make it easier to diagnose causes for detections, we developed data visualization dashboards linked to the tiers and detection groups in Figure 2.2. The dashboards make it easier to both verify the detections and drill down into the causes for the detections. The dashboards have user controls that enable the graphed data to be rapidly filtered along the dimensions of the detection groups in Figure 2.2. The dashboards also have additional features to evaluate cost effectiveness and support for rotational units.

This chapter provides a brief overview of the visualization dashboards as a basis for understanding how the dashboards were used in the case studies that will be presented in Chapter Four. Appendixes A and B and previous RAND research provide more details about the dashboards’ design, calculations, and functionality.¹

OCONUS Distribution Detection Dashboards

Currently, the Army Readiness Common Operation Picture Supply Health RWT dashboards provide some visibility to OCONUS distribution performance by displaying RWT performance for each SSA. The Supply Health RWT dashboards, which focus on receipted shipments, are intended for use by commanders and accountable officers. Although very useful, these dashboards do not provide visibility on open shipments as they move through the distribution process. Also, these dashboards were not designed to support the detection algorithms described in Chapter Two; therefore, they do not provide the capability needed to diagnose detections.²

As a result, we created data visualization dashboards designed specifically for the metrics and detection groups in Figure 2.2. Moreover, the dashboards allow for more metrics (e.g., more than just RWT), more subsets of the data along the multiple dimensions of the detection groups, analysis of shipping cost per pound, and support for rotational units. Mastbaum et al. provided a detailed description of the dashboards; we summarize these here. Each of the five dashboards provides a different function:

- **Detections**: This dashboard displays the results of the detection algorithm described in Chapter Two.

² For example, the Supply Health RWT dashboards do not display the following information needed to diagnose the causes for detected changes:
  - proportion of shipments (e.g., associated with each DC and shipping mode)
  - segment durations of the customer wait time
  - time series of the proportion of shipments and segment durations.
- Cross-tabulations: This dashboard shows total ship cost, number of shipments, number receipts, cost per pound, ship weight, RWT, segment durations cross-tabulated by DC and mode.
- Proportion of shipments: This dashboard shows the time series of the proportion of shipments associated with different DCs and ship modes.
- RWT: This dashboard shows the time series of RWTs associated with different DCs and ship modes.
- Rotation shipments: This dashboard shows the time series of RWTs associated with different DCs and ship modes.
- Rotation shipments: This dashboard compares the proportion of DC mode usage experienced when on rotation with that experienced in garrison. The display provides usage diagnostic analysis for when regions or SSAs experience changes in distribution performance because of rotations. This dashboard also displays whether rotational and forward positioned units are receiving similar levels of support regardless of detection.

The following sections briefly describe the functionality provided by each dashboard. Chapter Four discusses our findings using visualizations drawn from these dashboards.

Detections Dashboard
This dashboard displays the results of the detection algorithm described in Chapter Two. The detections are grouped into threads down the detection tree in Figure 2.2. The detections show the metric of the detection (RWT, segment, proportion of shipments) and the dimensions (e.g., shipment mode, IPGs) of the data subsets for the detection (i.e., the detection tier and group). From this dashboard, the user can see all the detections for each period.

Cross-Tabulations Dashboard
The cross-tabulations dashboard shows heat-map views for proportion of shipments and for RWT and segment statistics. The shipments heat map dashboard displays a cross-tabulation (by DC and mode) of the number of shipments, ship weight, cubic volume, total ship cost, and cost per pound. Next to the heat map, we present the DC and mode totals. Underneath the heat map, we display time series for source-mode combinations. The RWT heat map dashboard functions similarly, except it is focused on RWT-related statistics.

Proportion of Shipments Dashboard
This dashboard allows the user to analyze the proportion of shipments to a location by DC and by mode over time. The mode chart additionally allows an analysis of shipments to a location from all DCs, or from a single DC. A table on the left-hand side of the dashboard shows the number of shipments to each customer, enabling the user to find high-volume customers quickly.

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3 Cross-tabulations refers to two dashboards. One is based on shipments and reports cost per pound. The other is based on receipts and reports RWT (and RWT segments).

4 Future work for this dashboard would entail reconciling the manner in which the detection outputs and the data used in the other dashboards are aggregated; this would allow the user to taken directly from this dashboard to another one and the latter to be automatically filtered with the relevant information from a specific detection.
RWT Dashboard
Like the Proportion of shipments dashboard, the RWT statistics dashboard has a time series by DC and a second time series chart by ship mode. This dashboard presents information about receipts. The dashboard allows the user to view time series on RWT or the requisition segments.

Rotation Shipments Dashboard
On this dashboard, we compare the proportion of shipments by DC and by mode between forward positioned units and those on rotation. This dashboard shows differences in distribution support between rotation and forward positioned units. This dashboard also contains time series plots of the proportions of sourced DCs and ship modes to identify trends in support.

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5 If shipments are not receipted yet but have completed the segment selected by the user, the transaction will be included in the analysis.
Case Studies of Distribution Degradation Detections, Visualizations, and Corrective Actions

This chapter describes the following three cases studies in which distribution degradation and underlying causes were identified using various tiers of algorithmic detections and/or visualizations:

1. increase in RWT in support of Army customers in Afghanistan starting in October 2018
2. changes in distribution to Army customers in Kuwait starting in October 2018
3. changes in RWT and distribution in support of Army customers in Guam that occurred in 2019.

RWT Increase for Customers in Afghanistan

The principal Army SSA based at Bagram, identified by RIC W2F and Department of Defense Automatic Address Code (DODAAC) W56GTN, supported hundreds of Army units throughout Afghanistan. Customer requisitions were filled either from the more than 12,000 items that the SSA kept stocked locally or by receipting shipments from the distribution system and issuing them to customers.

In this situation, when the support from DCs outside Afghanistan became less reliable (or even broke down in certain respects), readiness and combat capability were at risk. Decisions and changes in the distribution process further up the supply chain can have significant effects downstream among the warfighters dependent on reliable resupply. In this case, changes in how items were shipped to Afghanistan from one of the major DLA supporting DCs, the DDDE (located in Germersheim, Germany) had important ramifications for SSA W2F and its customers.

In March 2019, units located in Afghanistan noticed a sustained increase in their RWT (creating frequent zero-balance items on the authorized stockage lists [ASLs]). The problem was reported by the units to their TSC. In April 2019, RAND Arroyo analysis determined that the RWT increase was driven by shipments from DDDE. The increase was the result of a change in shipment mode logic based on requisition priority. The mode shift occurred in November 2018 after it was determined that NGDS could not be justified under current policy for low-priority requestions. Hence, DDDE shifted many of the IPG 2 and nearly all of the IPG 3 shipments from NGDS to surface mode to reduce shipping costs in November of 2018.1

By May 2019, HQDA G-4 (Logistics) was involved in sustained discussion and negotiation with DDDE and other actors (in DLA and the Air Mobility Command) to clarify the policy on shipment modes for low-priority class IX requisitions. These discussions finally led to new Army policy being issued in September 2019. It was only at that point, 11 months after the DDDE decision had taken effect, that DDDE returned to the pre-November 2018 means of supporting Army customers in Afghanistan.

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1 We computed the transportation costs from January 2018 through May 2020. The average cost for surface shipping was $1.26 per pound and the average NGDS cost was $2.08 per pound from DDDE.
So, in this case, it took six months before the issue was raised up the chain of command and root cause analysis was carried out. These distribution changes occurred prior to the implementation of the detection algorithms described in this report. However, running the detection algorithms on monthly historical data would have led to detection of an issue in the November 2018 data (meaning that the detection would have occurred in early December 2018). Running the detection algorithms weekly would have detected the issue as early as November 19, 2018. The algorithms provided the following detections for the W2F SSA:

0. October 2018–December 2018: Overall RWT increases because of a temporary increase in surface-mode durations from Defense Depot Susquehanna Pennsylvania (DDSP). This detection is labeled as “0” because it is unrelated to support from DDDE.²
1. November 2018–October 2019: The proportion of surface shipments from DDDE increases.

Figure 4.1 shows that the proportion of surface mode from DDDE increased significantly in November 2018 (detection #1). Figure 4.2 shows the time series of average RWT by overall sources (black average line) and by source, illustrating an overall (all DCs) average RWT increase from 35 days prior to detection to 50 days (detection #2) and a DDDE average RWT increase from 20 days prior to detection to 75 days (detection #3). None of the other DCs showed a significant increase in RWT; therefore, it can be concluded that the overall increase in RWT was being driven by DDDE.

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² Detection #0 was included in this list because an overall RWT increase and a DDSP RWT increase are obvious in Figure 4.2 and detected by the algorithms even though the increase was cause by DDSP and not by DDDE.
Moving down a tier, the algorithms also detected the mode shift to surface shipping was because of IPG 2 and IPG 3 shipments. Figure 4.3 shows the mode proportions over time for which IPG 2 had a surface-shipping mode proportion increase from approximately 15 percent to 20 percent and IPG 3 had a surface-shipping mode proportion increase from approximately 10 percent to 90 percent. For these IPGs, DDDE increased usage of surface shipping and decreased usage of NGDS.

There were many ripple effects across the supply chain from this seemingly innocuous change in shipment mode for low-priority shipments from one DC. First, prior to November 2018, IPG 3 requisitions dominated the DDDE class IX support to W2F, comprising almost 60 percent of all shipments (IPG 1 requisitions comprised about one-third of W2F requisitions filled by DDDE). IPG 3 requisitions play a dominant role in replenishing local ASLs maintained by W2F. The approximately 12,000 National Item Identification Numbers (NIINs)3 stocked by W2F are intended to rapidly satisfy maintenance demands. When equipment is non-mission capable, these customer demands will typically come to W2F as high-priority (i.e., IPG 1) requisitions, and with an immediate fill from the ASL (if stock is available), the customer will see a very short wait time, often receiving needed parts on the same day. The ASL is designed to hold enough inventory to cover the RWT needed for the lower-priority replenishment orders coming from the wholesale sources (such as DDDE). However, if the RWT for low-priority replenishments increases, the probability increases that the

3 Each NIIN identifies a particular type of material. For example, the engine for the M1 Abrams tank has a NIIN that identifies the engine.
ASL will go zero-balance. If the ASL goes zero-balance, the maintenance work order will have to wait for the parts to come into the SSA from the national level.

The second ripple effect is that, rather than the national-level supply receiving primarily low-priority ASL replenishment requestions (for a minimum lot size quantity), every high priority maintenance request will be passed through the SSA to the national-level supply (until there is stock on hand again at the SSA). This second effect is illustrated in Figure 4.4, which shows that the percentage of IPG 1 requisitions from W2F went up almost immediately following the shift to using surface shipping for IPG 3 requisitions. Although DLA changed the low-priority shipments to surface-shipping mode partly to reduce transportation costs, much of that savings
was negated by the dramatically increased proportion of IPG 1 requisitions, which qualify for NGDS. When analyzing the potential cost savings, this second-order effect of the shift in priority must be considered.

The third ripple effect was again related to the increase in the proportion of IPG 1 requisitions. The mode shift at DDDE to surface shipping caused a large spike in RWT for all class IX shipments to W2F, but that spike was short-lived, lasting about four months. The overall RWT for DDDE class IX to W2F fell closer to normal levels by March 2019, a few months after the switch in November 2018. Figure 4.5 demonstrates why this occurred. Because W2F tended to run out of inventory for parts typically replenished from DDDE, high-priority customer demands flowed directly back to the wholesale supply system as IPG 1 orders. Being high priority, they were shipped via NGDS, with RWTs under ten days; hence, the overall RWT went down as IPG 1 requisitions dominated the volume. This also illustrates why it is critical to have detections at the different tiers shown in Figure 2.2.4 If one were tracking only overall RWT without detections at the additional tiers, one might reach the mistaken conclusion that the disruption was temporary and all was well by March 2019.

The fourth ripple effect was on ASL performance metrics, which are tracked by the Army. If W2F stocks a part demanded by a customer, then the demand is defined as an accommodated demand, regardless of available inventory on the shelf. Of the accommodated parts (i.e., stocked by W2F), if the demand is filled by available inventory on the shelf, then it is considered a satisfied demand. Multiplying the accommodation rate by the satisfaction rate produces the W2F fill rate, which is interpreted as the proportion of all demands

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4 To compensate for the longer RWT, the SSAs might have eventually chosen to increase stock locally, thus increasing their cost to stock and manage the material.
that were fulfilled by inventory on the shelf. The impact of W2F running out of normally replenished stocks
can be seen in Figure 4.5. It shows the satisfaction rate for parts normally supplied by DDDE. The satisfaction
rate is a metric capturing how often a part stocked by an SSA has inventory immediately available to issue to a
customer when demanded. All the parts graphed were parts that W2F stocked and were typically replenished
from DDDE, so the accommodation tied to this subset of parts would have been 100 percent. The columns
list the volume of demands.

To capture the effect of the DDDE mode switch (which, obviously, did not affect all W2F customer
demands), we focus on parts stocked on W2F’s ASL for which there were at least 20 requisitions from W2F to
the wholesale system between 2018 and 2019 and for which at least 80 percent of W2F demand was filled from
DDDE in that same period. There are almost 700 class IX NIINs that met these qualifications.

Although the satisfaction rate might normally be quite variable, dependent on such factors as changes in
customer demands (note the variability in demands shown in the columns), it is normally above 80 percent
for an SSA, as can be seen in Figure 4.5 in the period before the November 2018 mode switch. The change
to surface shipments led to a rapid and dramatic impact on the satisfaction rate for these NIINs. By Febru-
ary 2019, the satisfaction rate had dropped from the 70–90 percent range to below 50 percent and stayed in
that range for almost all of 2019. Only after DDDE stopped downgrading IPG 3 shipments to surface mode, beginning in September 2019, do we see the satisfaction rate begin to return to previous levels.

Distribution Changes in Support of Customers in Kuwait

From January 2017 through September 2018, shipments for Kuwait customers primarily originated from

- DDSP (~33 percent of shipments)
- direct from vendors (~24 percent of shipments)
- DDDE (~20 percent of shipments)
- DLA Distribution San Joaquin, California (DDJC) (~7 percent of shipments)
- DDNB (~2 percent of shipments).

Starting in October 2018, DLA shifted its preference logic for selecting among DCs to choose DDNB before DDDE (orange marker 2B in Figure 2.1); 5 AMC did not shift its logic (orange marker 2A in Figure 2.1), so AMIs continued to originate from the TASL in Europe. Although the change was coordinated with the U.S. Army Central, the data visualization made it apparent that RWT from DDNB was consistently longer than DDDE (as discussed later and seen Figure 4.8). DLA also shifted its stock positioning logic (orange marker 4 in Figure 2.1), which increased the number of parts stocked at DDNB, resulting in increasing volume from DDNB to Army customers in Kuwait.

For support of Kuwait customers, the detection algorithms identified the following changes:


The monthly detection algorithms identified the October shift in early November 2018 after full data for October was available (detection # 1). The weekly detection algorithms identified the shift as early as October 21, 2018. Figure 4.6 shows the proportion of shipments from DDDE and DDNB DCs; it also shows that DLA’s logic for choosing DCs moved DDNB ahead of DDDE in October 2018.

The increased shipments from DDNB led to two detections (#2 and #3) of significant shifts in shipment mode (orange marker 3 in Figure 2.1). To offset the slow performance of the trucks from DDNB to Kuwait, higher-priority shipments initially were shifted from truck shipping to MILAIR (detection #2, see Figure 4.7). However, DDNB subsequently shifted most high-priority (IPG 1 and some IPG 2) shipments to NGDS (see Figure 4.7). DLA shifted the mode twice in attempts to avoid increased RWT for higher-priority shipments stemming from the long delays required to get customs clearance for trucks to transit Saudi Arabia (to get from DDNB to Army customers in Kuwait). The long custom delays were diagnosed using the data visualization shown in Figure 4.8 and showed up as long hold times at DDNB (time from the MRO to depot ship).

The shift to more shipments from DDNB and shipment mode shifts from DDNB increased the overall median RWT to Kuwait customers by two to five days. The shipments that shifted from DDDE to DDNB sourcing locations were the most affected, with DDNB’s median RWT being approximately ten to 15 days longer (Figure 4.9) than DDDE’s performance. This shift was more pronounced for the lower-priority shipments going via truck. The truck cost per pound ($0.08/lb) was lower than DDDE transportation costs ($0.49/lb). However,

5 DLA changed its DC preference logic for strategic reasons. Our discussions with DLA suggested a desire to send MROs to an FDP that was closer to theater and would not require surface shipments to transit the Straits of Hormuz.
FIGURE 4.6
Proportion of Shipments by DC to Customers in Kuwait

Detection #1: Proportion of shipments for DDNB increased

Source: RAND analysis of DLA ACE data.
Note: Source preferencing changed from preferring DDDE (in Germany) to preferring DDNB (in Bahrain) for Kuwait customers.

FIGURE 4.7
Proportion of DDNB Shipments to Kuwait Customers by Ship Mode

Detection #2: Proportion of DDNB shipments via MILAIR (teal line)
Detection #3: Proportion of DDNB shipments via NGDS (purple line)

Source: RAND analysis of DLA ACE data.
Note: Once DDNB was preferred, DDNB usage of MILAIR increased from October 2019 through June 2019 and usage of NGDS increased from July 2019 through March 2020.
these transportation savings were offset by the need to switch higher-priority shipments to NGDS because of the long custom clearance delays for the trucks. Further reducing any transportation savings was the fact that NGDS from DDNB to Kuwait (at $3.28/lb) was more expensive than NGDS from DDDE to Kuwait (at $2.05/lb).

Using the detections and data visualizations, the authors and HQDA G-4 were working with DLA distribution to address the longer times from DDNB. At that same time, in March 2020, Saudi Arabia stopped allowing ground shipments to transit from Bahrain to Kuwait because of the coronavirus disease 2019 pandemic. As a result, DLA switched its DC sourcing sequence to prefer DDSP over both DDDE and DDNB (see Figure 4.6, increase in red line beginning March 2020). DDSP median RWT performance is comparable with DDDE; DDSP RWT has been two to four days longer than DDDE.

**Distribution Changes in Support of Customers in Guam**

Our Guam case study exemplifies how the dashboards can be used directly to analyze customer support issues that originated prior to 2017. Given that we did not run the algorithms prior to 2017, the algorithms did not detect distribution system changes.

A Guam SSA reported that it was supporting air defense artillery units that were getting very long RWTs on some shipments. We were able to determine that, from before 2017 through April 2019, DLA Distribution Depot in South Korea (DDDK) surface shipments to Guam customers had 150 days RWT on average.

For customers in Guam, the DLA Distribution Depot in Guam (DDGM) is the default DC, so DLA looks for fulfillment at DDGM first. If DDGM cannot fill the requisition, DLA then checks for on-hand inventory

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6 We did not run the automatic detections on data prior to 2017, but this case study shows how the visualizations can be used directly to identify distribution problems and corrective actions.
at DDJC, DDDK, and then DDSP. Overall for Guam, DDJC fulfills approximately 10 percent of requisitions, DDDK fulfills approximately 8 percent, and DDSP fulfills approximately 15 percent.

Prior to March 2019, surface shipments to Guam took an average of 150 days or more from DDDK, whereas DDJC and DDSP took about 75 days on average. By tracking individual documents, we were able to determine this occurred because surface shipments from DDDK to Guam were routed via surface shipment from DDDK to the DDJC CCP (in California) and then shipped by surface from the DDJC CCP to Guam (so, the 150 days was predominantly the result of two long surface shipments). Figure 4.10 shows a time series of average RWT to Guam by DC.

There were two options to correct this problem. One was to move DDSP ahead of DDDK in the preference logic for customers in Guam. Under DLA’s logic, this would apply to all customers in Guam, not just Army customers. Because Guam is dominated by the other services, this would require coordination across the services. However, DDDK’s inventory is tailored to supporting Army customers on the Korean peninsula, so our analysis indicated that the impact on the other services, which get few fills from DDDK, would be minor. This change could have reduced IPG 3’s average RWT so that it was comparable to DDJC, and it would have avoided shipping cost because DDSP overall shipping costs per pound for each shipping mode were less than those of DDDK (see Table 4.1). The resulting shipping costs across all modes would be 30 percent lower from DDSP versus DDDK, though the savings are modest because of the relatively small number of shipments (see Table 4.2).  

From the visualizations of cost and cost per pound, we estimate that if DLA were to source from DDSP over DDDK, shipping cost would be 30 percent lower than the shipping cost of sourcing from DDDK from March through June 2020. Figure 4.10 shows that the DDSP ship cost per pound is less than that of DDDK for the three most-used ship modes. In total during this period, shipping cost from DDDK totaled $6,692. If DDSP were used to fulfill the demands fulfilled by DDDK, total cost is estimated to be $4,659 (down 30 percent from the $6,692). This provides yet another example in which shipping from a DC physically closer to the customer is not necessarily faster or cheaper because the available distribution channels can drive both responsiveness and cost.
FIGURE 4.10
Average RWT for IPG 3 Surface Shipments to Guam Customers by DC (Prior and Post Distribution Channel Change in March 2019)

<table>
<thead>
<tr>
<th>Date</th>
<th>DDDE</th>
<th>DDJC</th>
<th>DDSP</th>
<th>Average RWT over all DCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February 2018</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>August 2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>February 2019</td>
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<tr>
<td>August 2019</td>
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<td>November</td>
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</tr>
<tr>
<td>2019</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 2019</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 4.1
Average Cost per Pound for All Shipments to Guam Customers by DC, Overall IPGs January 2018–February 2019

<table>
<thead>
<tr>
<th>DC (Total # of Shipments)</th>
<th>Ship Modes (Total # of Shipments)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface (515)</td>
</tr>
<tr>
<td>DDSP (965)</td>
<td>$0.66</td>
</tr>
<tr>
<td>DDDK (523)</td>
<td>$1.03</td>
</tr>
</tbody>
</table>

TABLE 4.2
Dashboard Screenshot of Total Shipping Weight and Total Shipping Cost to Guam Customers, March–June 2020

<table>
<thead>
<tr>
<th>DC (Total # of Shipments)</th>
<th>Ship Modes (Total # of Shipments)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface (515)</td>
</tr>
<tr>
<td>DDJC (613)</td>
<td>5,476 lbs</td>
</tr>
<tr>
<td></td>
<td>$1,761</td>
</tr>
<tr>
<td>DDSP (588)</td>
<td>3,534 lbs</td>
</tr>
<tr>
<td></td>
<td>$5,135</td>
</tr>
<tr>
<td>DDDK (267)</td>
<td>988 lbs</td>
</tr>
<tr>
<td></td>
<td>$2,138</td>
</tr>
</tbody>
</table>

SOURCE: RAND analysis of DLA ACE data.
DLA chose a second option, which was to rework the surface distribution channel from DDDK to Guam. Starting in March 2019, DLA changed the distribution channel to send surface cargo from DDDK to DLA Distribution Depot in Okinawa Japan rather than through DDJC in CONUS, and then on to Guam. This change reduced average RWT from DDDK to approximately 81 days, about the same as that of DDJC and DDSP (Figure 4.10).
CHAPTER FIVE

Conclusion and Way Forward

Although the Army has improved monitoring of global distribution using data visualization dashboards of RWT, these efforts require manual review to detect problems. Furthermore, the use of RWT as the only metric for distribution performance suggests that there can be lags before distribution problems are reflected in the metric.

Our research developed automatic detection algorithms that actively monitor global distribution performance over multiple metrics across multiple dimensions to automatically flag potential distribution problems as they arise. The algorithms are designed to detect both potential and existing distribution problems to inform early corrective action. The research effort also developed data visualization dashboards related to the detections that can help Army distribution managers and stakeholders conduct root cause analysis and recommend potential corrective actions.

In this report, we demonstrate through case studies how the automatic algorithms and dashboards—had they been in place when the distribution problems were manifesting—could have avoided or mitigated past distribution performance degradation. The case studies show that, if the algorithms had been in place then, the shift to surface shipments from DDDE to Afghanistan customers in late 2018 would have been detected within weeks rather than after five months. This early detection could have then been corrected months prior to the units realizing the effects on equipment readiness. The case studies also show that, if detections had been operational, the increase in RWT to Kuwait customers that resulted from a shift in the source DC preferencing logic could have been mitigated or avoided in late 2018 and all of 2019. We also demonstrate how the visualizations can aid with problem diagnostics, as shown through the RWT analysis in the Guam case study from 2017 through 2019.

The tools developed in our research should be transitioned to the Army to enable the ability to rapidly detect, diagnose, and correct distribution problems. The Army’s Logistics Data Analysis Center (LDAC), which has extensive experience and knowledge of distribution processes and data, is the Army organization best suited to operate and continuously improve the tools. Who would be responsible for using the tools (i.e., those who receive and act on the detections using the data visualization dashboards) is less apparent. The case studies involved changes in policy and processes and required working with stakeholders both within and outside the Army. This research was sponsored by DA G-4, but DA G-4, as a headquarters element, lacks the bandwidth to do more than address policy issues that are raised by the detections. AMC Army Sustainment Command (ASC) is likely a very good organization to initiate corrective action because it has the advantage of housing many (but not all) of the organizations that need to be involved (i.e., LDAC; Air Clearance Authority; ASC-Supply Determination Branch, which sets the TASLs; and ASFBs). AMC could develop a cell in ASC or LDAC to provide central analytic support to distribution. That cell would then do the initial analysis on detections using the data visualization dashboards and would reach out to the appropriate Army Field Support Brigade, TSC, and other stakeholders (e.g., HQDA G-44S (Supply), DLA, the U.S. Transporta-
tion Command) for subject-matter expertise to quickly resolve any detections that could lead to distribution problems.\(^1\) Another possible place to initiate action is the supply and distribution cell within the TSC.

Distribution is a complex process with many stakeholders both inside and outside the Army. This process generates data across many different information systems. As the Army looks to leverage advances in data analytics like those described in this report, the Army will need to assign responsibilities and develop formal processes to correct distribution problems. Assigned responsibilities and well-honed processes will be particularly critical early in a deployment when there is increased uncertainty and acute competition for transportation, management and manpower, and materiel resources.

\(^1\) ASC-Supply Determination Branch provides a similar capability for central ASL reviews, allowing maintenance and supply managers to focus on using their subject-matter expertise to review results rather than focus on the mechanics of generating ASL recommendations.
APPENDIX A

OCONUS Distribution Visualization Dashboards
Details

This section presents the design and functionality of the visualization dashboards. The supported filter dimensions on all dashboards are listed here:

- **Name**: selects the underlying regional data to us for analysis (Pacific or Europe)
- **Service (svc)**: Air Force, Army, Marines, Navy
- **Location**: The region names in Appendix C
- **Customer**: SSAs identified by their DODAAC (AMI/NAMI: Air Force Materiel Command, AMI, NAMI, Navy, U.S. Marine Corps)
- **IPG**: 1, 2, 3
- **Supply class (supcl)**: 2-3p-4, 9
- **DC**: DLA DC (e.g. DDDK, DVD, other_CONUS,\(^1\) other_OCONUS\(^2\))
- **Mode**: ground, local, premair,\(^3\) etc.

With exception of “name,” the filters also have an “all” setting.

Detection

The detection dashboard (Figure A.1) presents the output of our detection algorithm, as described in Chapter Three. Only the most recent month of detections is displayed because detections can shift as new data come in.

Section A in Figure A.1 displays the information, organized by thread number (a location might have multiple detection chains in a single month) and starting tier. Sections B and C contain the filter settings for this dashboard. Section B has the settings for Name (Europe vs. Pacific) and eligibility, which has to do with rules for whether we rule out certain detections. Section C has filters that allow a user to focus on specific subsets of detections—for example, only detections involving a given DC or mode—and specific detection categories. Section D provides hyperlinks to our four detection-oriented dashboards. Right now, these are simple hyperlinks; the way that we represent “all” in our detection algorithm (for example, “mode = null” means all modes) does not correspond with how Tableau aggregates data into “all.” In future work, we hope to be able to get the detection output data aligned with how Tableau aggregates so that a user could instead

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\(^1\) Lists other CONUS-based distribution centers that are not listed individually by name.

\(^2\) Lists other OCONUS-based distribution centers that are not listed individually by name.

\(^3\) *Premium Air shipments* is another name for Next-Generation Delivery System.
be sent to the other dashboards with all of the filters for the detection that they were interested in already populated for them.

### Cross-Tabulations

These dashboards are the cross-tabulation dashboards described in Chapter Three.

Figure A.2 displays shipment-related metrics, and Figure A.3 displays receipt-related metrics. These were originally intended to be a single dashboard with the RWT-related information being a third cell in the heat map and the line chart having both shipment and RWT options. This proved infeasible for this round of work because of technical difficulties with having Tableau use two separate sets of dates on a single heat map.

Section A in Figure A.2 contains filters that control the entire dashboard. Section B contains the heat map. The top portion of each cell can be set to display number of shipments (N Val), shipment weight (Shipwt), or extended cube (Extcu); the bottom portion can be set to display Cost per Pound or Total Cost. The heat map shading can be independently set to any of those values. The N Val row and column totals are shown next to the distribution and mode names; the other row and column totals are displayed in section C. The controls for the heat map, which also have a minimum N Val cutoff, are in section D.

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4 *Extended cube* is defined as the volume measurement in cubic feet of the material including packaging.

5 The N Val slider controls all three tables, but the tables will not necessarily filter out the same rows for the same N Val threshold. For example, suppose that N Val is set to be at least 100, and DVD has N Val = 50 premair and N Val = 50 for surface. Those N Vals will not show on the heat map but will still factor into the DVD marginal total because the N Val for DVD
FIGURE A.2
Shipments Cross-Tabulation Dashboard

FIGURE A.3
RWT Cross-Tabulation Dashboard
Section E contains a line chart, which can be set to either a weekly or monthly display of the same metrics as the heat map. In section F, there is also a maximum (Max) N Val filter and filters to remove individual DCs and modes from consideration.6

The functioning of RWT cross-tabulation dashboard (Figure A.3) is mostly the same. The only differences are that each heat map cell contains only a single value; the heat map cells and coloring are a variety of RWT metrics (various percentiles, the RWT average, and segment averages); and the N Val and Max N Val filters are replaced with number of receipted shipments (N RWT) and Max N RWT filters.

**Proportion of Shipments**

The proportion of shipments dashboard (Figure A.4) focuses on the proportion of shipments to a location by DC (section B) and the mode distribution for individual location–DC combinations (section C). In both sections B and C, the lines represent proportions of shipments, and the area chart represents the total volume. The table on the left (section A) provides the list of DODAACs associated with the given location, sorted by shipment volume.

6 The maximum N Val filter graphs time series that have a maximum monthly record count above a user-specified threshold. This filter removes time series from the plot that have low record counts.
Section B also has a control for toggling the line charts between monthly and weekly time series. The remainder of the controls for this dashboard are in section D, which also has the color legends for the two time series. The name, svc, location, customer, date range, N_Val, Shipwt, Extcu, AMI/NAMI, IPG, and Supcl filters control both charts. The top chart has a Max N Val filter (like the one described in the cross-tabulations section) that filters at the DC level—this filter controls only which DCs are displayed on the top chart and does not affect the area chart nor the denominator for the proportion calculation. The lines will sum to 100 percent only for a given month or week if the Max N Val’s minimum value is set to 0; the intent is to de-clutter the chart by removing low-volume DCs. The final control changes the DC used in the location-DC combination forming the basis of the bottom chart.

RWT

The functionality of the RWT dashboard (Figure A.5) is largely similar to that of the Proportion of Shipments dashboard described in the previous section. That being the case, we will focus on the pieces of functionality that are distinct.

The DODAAC chart in section A is sorted by N RWT (receipts) instead of N Val (shipments). The line charts in sections B and C can display one of several RWT metrics, selectable using the control in section D. These are several RWT percentiles, N RWT, RWT average, and the averages for several of the shipping segments. Instead of the gray area chart showing shipping or receipt volumes, the line chart in section B has a black line showing the aggregate for the selected RWT metric for the given location; like the area chart on the proportion of shipments calculation, the Max N Val filter for this chart only removes DCs from being

FIGURE A.5

RWT Dashboard
displayed on the chart, it does not stop them from being factored into this aggregate line. This black line dis-
appears when N RWT is selected; the overall sum can be at least an order of magnitude greater than the sums
for the individual location–DC combinations, making the overall chart illegible because of skewing the axis.

Rotation Shipments

As described in Chapter Three, the unit rotation dashboard (Figure A.6) compares the proportion of DC and
mode usage experienced when on rotation with that usage in garrison, and it displays whether rotational and
forward positioned units are receiving similar levels of support regardless of detection.

Sections A–D display this information by DC, and sections F–I display the same information broken out
by mode. Section A is the color legend for sections B–D, and section F is the color legend for sections G–I.

In sections B, C, G, and H, the total volume of shipments is displayed above the individual proportion bar
charts; on C and H, the unit type, rotation number, and date range for shipments for that rotation number are

FIGURE A.6
Unit Rotation Shipments Dashboard

also displayed. The time series in sections D and I are controlled by their own Max N Val filters.

The controls in section E control all the charts in sections B–D and G–I, which consist of our typical
assortment of name, date range, svc, DC, AMI/NAMI IPG, Supcl, and mode. Here, the toggle for monthly or
weekly time series controls both line charts. There is also a DC Location toggle that can filter DCs by whether
they are in CONUS or OCONUS.
APPENDIX B

Documentation of Calculations in Tableau

All the underpinnings of the functionality of the Tableau workbook can be observed by opening the work-sheets underpinning the dashboards. However, some of this functionality required customization to implement, and this appendix will discuss how that customization was performed.

One of our development goals was to place information for shipment and RWT data on the same dash-boards. Limitations in Tableau regarding mixing two different date columns (moshp for the shipment data, and mod6s for the RWT data)\(^1\) forced us to develop separate ship and RWT dashboards. However, we chose to retain having Tableau connect to the same data table twice, once as ship and once as RWT. This decision was made to simplify organization and selection of ship-specific and RWT-specific Tableau calculations over the course of developing the dashboards.

Ship Heat Map

In the heat map at the top of the dashboard, the row and column totals were generated by doing Tableau level of detail (LoD) calculations to exclude mode and source, respectively, from the calculation. Because this results in Tableau simultaneously calculating the totals at different levels of aggregation, and because there is a filter (N Val) to exclude cases without a user-specific minimum number of shipments, these row and column totals will not reflect the individual cells in the row or column. For example, if the filter is set to require at least 100 shipments, and DVD has 50 premair shipments and 50 surface shipments, DVD-premair and DVD-surface will not show on the heat map, but those rows will still factor into the overall DVD calculation because the total number of shipments by the combined modes is at least 100. Therefore, the row totals always show the total number of shipments sent from a given source or mode, regardless of what the mini-mum number of shipments filter is set to.

The heat map toggle combines the options from the top toggle and bottom toggle, which are so named for where the corresponding measures appear in the individual heat map cells. This allows for the measure used to color the heat map to be set independently of the measures being displayed in the cell. These toggles are parameters used in correspondingly named calculated fields, which are what are displayed in the heat map cells.

The line chart at the bottom of the dashboard has a filter (Max N Val), which is calculated using:

\[
\text{WINDOW\_MAX(COUNT([Value]))}
\]

This determines whether each source-mode combination ever hits the user-specified minimum number of shipments to be plotted within the user-controlled timeframe being displayed. This was done because we wanted to filter out the low-volume source-mode combinations but filtering on N Val was resulting in incom-

---

\(^1\) Moshp indicates the month in which the shipment occurred; mod6s indicates the month in which the shipment was receipted by the customer.
plete line segments being plotted. For example, if the user-defined minimum is 100 shipments, and a given source-mode combination had 150 shipments in one month and 50 in every other month, only the month with 150 shipments would be plotted using a simple N Val filter; with the Max N Val filter, the 50-shipment months are also plotted.

**RWT Heat Map**

This dashboard is constructed similarly to the dashboard in the previous section. The only notable differences are that the counts of N Val (i.e., number of shipments) are replaced with counts of N RWT (i.e., the number of receipts) and that here the heat map toggle controls both the measure being displayed in the cells and the measure used to color the cells. N RWT (i.e., number of receipts) will be null if the shipment has not yet been received by the customer.

**Proportion of Shipments**

The top chart has another Max N Val filter as described in the section titled “Ship Heat Map.” As the minimum is increased and low-volume sources drop off the chart, the percent of total calculation is not re-run, and the area chart in the background will always display the total without anything being filtered out. For example, if a source is shown as accounting for 50 percent of shipments in a given month and a source representing 25 percent of shipments has been dropped off by the Max N Val filter, that 50 percent is 50 percent of the total, not 50 percent of what’s left after applying the Max N Val filter.

**RWT Statistics**

This dashboard is about RWT and not shipments, but it still has both the top and bottom charts controlled by Max N Val filters as described in previous sections. Here, the top chart has a black line representing the aggregate across all sources. As with the area chart in the previous section, this line is calculated before the Max N Val filter removes any rows from consideration. This black line is divided by a calculated field that is set to 1 when the RWT metric is set to anything other than N RWT, and is set to 0 when the RWT metric is set to N RWT. The divide by 0 causes the black line to disappear; without this adjustment, when the RWT metric is set to N Val, the black line is simply the sum of the other lines, which causes the chart to rescale so that the black line dominates the y axis.

**Shipping Percentages**

Several elements displayed on this chart required LoD calculations; the names are meant to be self-explanatory. Note that Source Location is a calculated field that categorizes sources as being either CONUS or OCONUS. These calculations were Sample Size Exclude Mode, Sample Size Exclude Source and Mode, Sample Size Exclude Source, and Sample Size Exclude Source and Source Location.

This dashboard also use the Max N Val filter on the rotation by source over time and rotation by mode over timeline charts.
This appendix defines how we grouped locations into regions. In the DLA distribution data, the “loc” field contains codes that specify SSA locations by country or U.S. state or territory. Table C.1 shows the locations (as specific by the “loc” variable) and our regional groupings used for this research.

**TABLE C.1**

**Country and U.S. State or Territory Groupings for this Analysis**

<table>
<thead>
<tr>
<th>Region Name</th>
<th>Locations Within the Region (Countries or U.S. States or Territories)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU Northeast</td>
<td>Poland, Lithuania, Ukraine, Estonia, Latvia, Georgia</td>
</tr>
<tr>
<td>EU Southeast</td>
<td>Balkans (all countries in former Yugoslavia are coded BK), Romania, Bulgaria, Turkey, Hungary, Cyprus, Greece</td>
</tr>
<tr>
<td>EU North</td>
<td>Germany, Netherlands, Belgium, Norway, Luxembourg, Denmark, France, Great Britain/United Kingdom</td>
</tr>
<tr>
<td>EU South</td>
<td>Italy, Spain, Portugal (can be Azores)</td>
</tr>
<tr>
<td>AF Africa</td>
<td>Djibouti or other unspecified African nation</td>
</tr>
<tr>
<td>CE Afghan</td>
<td>Afghanistan</td>
</tr>
<tr>
<td>CE Kuwait</td>
<td>Kuwait</td>
</tr>
<tr>
<td>CE Iraq</td>
<td>Iraq</td>
</tr>
<tr>
<td>CE Gulf</td>
<td>Bahrain, Qatar, United Arab Emirates, Oman, Jordan, Saudi Arabia</td>
</tr>
<tr>
<td>Alaska</td>
<td>Alaska</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Hawaii</td>
</tr>
<tr>
<td>Guam</td>
<td>Guam</td>
</tr>
<tr>
<td>Japan</td>
<td>Japan (excludes Okinawa)</td>
</tr>
<tr>
<td>Korea</td>
<td>South Korea</td>
</tr>
<tr>
<td>Okinawa</td>
<td>Okinawa</td>
</tr>
<tr>
<td>Other Pacific</td>
<td>Other locations in Pacific Command</td>
</tr>
</tbody>
</table>
APPENDIX D

Data Fields and Sources

The data we receive requires some processing to be used in our detection algorithms and data visualizations. Table D.1 gives the field names that we use in our data files and a description of what the field is and what data source it comes from and whether it is used in our detections and visualizations. If a field is derived from other fields, the names of those source fields are in the indented rows below the field name.

<table>
<thead>
<tr>
<th>Data Field</th>
<th>Description</th>
<th>Used in Detections</th>
<th>Used in Visualization</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>customer</td>
<td>customer shipto address (DODAAC)</td>
<td>x</td>
<td></td>
<td>Derived from LRT based on dodaac, suppad, and signal code</td>
</tr>
<tr>
<td>dodaac</td>
<td>requisitioning DODAAC (first 6 digits of document number)</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>suppad</td>
<td>supplemental address (a dodaac)</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>signal</td>
<td>signal code A–D = ship to requisitioner, else to suppad</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>regn &amp; locationa</td>
<td>customer region (OCONUS) and subregions (location)</td>
<td>x</td>
<td>x</td>
<td>DODAAF</td>
</tr>
<tr>
<td>loc</td>
<td>country code affiliated with customer</td>
<td></td>
<td></td>
<td>LRT, DODAAF</td>
</tr>
<tr>
<td>name (of theater groupings)</td>
<td>ELIC for EUCOM/ AFRICOM/CENTCOM, PAC for PACOM</td>
<td>x</td>
<td>x</td>
<td>DODAAF</td>
</tr>
<tr>
<td>SSA</td>
<td>RIC of customer dodaacs that are SSAs</td>
<td>x</td>
<td>x</td>
<td>DODAAF</td>
</tr>
<tr>
<td>rotation</td>
<td>theater rotation identifier</td>
<td></td>
<td>x</td>
<td>DODAAF</td>
</tr>
<tr>
<td>dates of rotations</td>
<td></td>
<td></td>
<td></td>
<td>DODAAF changes</td>
</tr>
<tr>
<td>svc</td>
<td>customer military service</td>
<td>x—used to filter for Army only</td>
<td>x</td>
<td>LRT</td>
</tr>
</tbody>
</table>
### Table D.1—Continued

<table>
<thead>
<tr>
<th>Data Field</th>
<th>Description</th>
<th>Used in Detections</th>
<th>Used in Visualization</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>OCONUS mode of shipment</td>
<td>x</td>
<td>x</td>
<td>LRT, DLA issues, SDDC data (GATES ITV), TRANSCOM AMC data (GATES)</td>
</tr>
<tr>
<td>lpg</td>
<td>IPG</td>
<td>x</td>
<td>x</td>
<td>LRT (grouping of priority codes)</td>
</tr>
<tr>
<td>var1 = priority source</td>
<td>issue priority 01–15</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>var1 = depric</td>
<td>depot RIC</td>
<td>x</td>
<td>x</td>
<td>LRT, DLA issues</td>
</tr>
<tr>
<td>NIIN characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMI/NAMI</td>
<td>AMI (RIC A* B*) or not</td>
<td>x</td>
<td>x</td>
<td>LRT, Federal Logistics Information System</td>
</tr>
<tr>
<td>var1 = icp</td>
<td>NIIN's inventory control point RIC</td>
<td>x</td>
<td>x</td>
<td>LRT</td>
</tr>
<tr>
<td>var2 = sosric</td>
<td>NIIN’s source of supply RIC</td>
<td></td>
<td></td>
<td>Catalog data</td>
</tr>
<tr>
<td>supply class</td>
<td>NIIN’s federal supply class, filtered to classes 2, 3p, 4, or 9</td>
<td>x</td>
<td>x</td>
<td>Catalog data</td>
</tr>
<tr>
<td>Dates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>docdt</td>
<td>requisition document date</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>estdt</td>
<td>requisition established date</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>mrodt</td>
<td>date of MRO</td>
<td></td>
<td></td>
<td>LRT, DLA issues</td>
</tr>
<tr>
<td>shipdt</td>
<td>date shipped from depot or source of fill</td>
<td>x</td>
<td>x</td>
<td>LRT, DLA issues</td>
</tr>
<tr>
<td>tail</td>
<td>tailgate or delivery date (~arrival on post)</td>
<td></td>
<td></td>
<td>LRT, DLA transportation data (GBL/MPH files), TRANSCOM data (GATES ITV)</td>
</tr>
<tr>
<td>d6s</td>
<td>date of customer receipt on a D6S/D6U/DRA</td>
<td>x</td>
<td>x</td>
<td>LRT, ILAP, DLA receipts</td>
</tr>
<tr>
<td>Data Field</td>
<td>Description</td>
<td>Used in Detections</td>
<td>Used in Visualization</td>
<td>Data Sources</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>--------------------</td>
<td>-----------------------</td>
<td>--------------</td>
</tr>
<tr>
<td><strong>Segments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>docest</td>
<td>days from docdt to estdt</td>
<td>x</td>
<td>x</td>
<td>Calculated</td>
</tr>
<tr>
<td>estmro</td>
<td>days from estdt to mrodt (ICP hold time) less back-order time</td>
<td>x</td>
<td>x</td>
<td>Derived from dates above</td>
</tr>
<tr>
<td>mroship</td>
<td>days from mrodt to shipdt (depot processing time)</td>
<td>x</td>
<td>x</td>
<td>Derived from dates above</td>
</tr>
<tr>
<td>ship6ds</td>
<td>days from depot ship to customer receipt</td>
<td>x</td>
<td>x</td>
<td>Derived from dates above</td>
</tr>
<tr>
<td>shiptail</td>
<td>days from depot ship to on-post-delivery (transit time)</td>
<td>x</td>
<td>x</td>
<td>Derived from dates above</td>
</tr>
<tr>
<td>tail6ds</td>
<td>days from on-post delivery to customer receipt</td>
<td>x</td>
<td>x</td>
<td>Derived from dates above</td>
</tr>
<tr>
<td>rwt</td>
<td>RWT = days from docdt to d6s</td>
<td>x</td>
<td>x</td>
<td>Derived from dates above</td>
</tr>
<tr>
<td><strong>Shipment data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_rwt</td>
<td>number of records with measurable RWT</td>
<td>x</td>
<td>x</td>
<td>Calculated</td>
</tr>
<tr>
<td>rwt</td>
<td>RWT is set to missing if over 365 days for surface shipping, 100 days for other modes</td>
<td></td>
<td></td>
<td>Calculated</td>
</tr>
<tr>
<td>n_value</td>
<td>number of records with extended value</td>
<td>x</td>
<td>x</td>
<td>Derived from below</td>
</tr>
<tr>
<td>uprice</td>
<td>unit price for the NIIN</td>
<td></td>
<td></td>
<td>Catalog data</td>
</tr>
<tr>
<td>sqty</td>
<td>quantity shipped</td>
<td></td>
<td></td>
<td>LRT, DLA issues</td>
</tr>
<tr>
<td>shipwt</td>
<td>TCN weight apportioned to document level</td>
<td>x</td>
<td></td>
<td>DLA transportation data for bills of lading and small packages (GBL/MPH), TRANSCOM data (GATES ITV from SDDC, GATES from AMC) for surface and military airlift</td>
</tr>
<tr>
<td>extcu</td>
<td>Extended cube</td>
<td>x</td>
<td></td>
<td>Catalog data for unit cube x sqty (LRT &amp; DLA issues), DLA and TRANSCOM transportation data</td>
</tr>
<tr>
<td>ucube</td>
<td>unit cube for the NIIN</td>
<td></td>
<td></td>
<td>Catalog data</td>
</tr>
<tr>
<td>cost</td>
<td>Total ship cost</td>
<td>x</td>
<td></td>
<td>Sum of below 3 costs</td>
</tr>
</tbody>
</table>
### Table D.1—Continued

<table>
<thead>
<tr>
<th>Data Field</th>
<th>Description</th>
<th>Used in</th>
<th>Used in</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>shipcost</td>
<td>2nd destination cost</td>
<td>DLA transportation data (GBL/MPH), Powertrack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>amccost</td>
<td>cost to ship overseas via Air Mobility Command (MILAIR/ MILALOC modes)</td>
<td>AMC air cargo rates (online)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surcost</td>
<td>cost to ship overseas via ocean carriers (surface shipping mode)</td>
<td>Surface liner rates (SDDC online)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES: AFRICOM = U.S. Africa Command; CENTCOM = U.S. Central Command; DODAAF = DoD Automated Address File; ICP = Inventory Control Point; ILAP = Integrated Logistics Analysis Program; POD = port of debarkation; POE = port of embarkation; SDDC = Surface Deployment and Distribution Command; TCN = Transportation Control Number; GBL/MPG = Government Bill of Lading/Manifest Print History; GATES = Global Air Transportation Execution System; ITV = In-Transit Visibility

* See Appendix C for region assignments.
Abbreviations

ACE  Analytics Center of Excellence
AMC  Army Materiel Command
AMI  Army-managed item
APOD airport of debarkation
ASC  Army Sustainment Command
ASL  authorized stockage list
CCP  container consolidation point
CONUS continental United States
DC  distribution center
DDDE Defense Distribution Depot Europe
DDDK DLA Distribution Depot in South Korea
DDGM DLA Distribution Depot in Guam
DDJC DLA Distribution San Joaquin, California
DDNB DLA Distribution Navy Bahrain
DDSP Defense Depot Susquehanna Pennsylvania
DLA  Defense Logistics Agency
DLATS DLA Transaction Services
DODAAC Department of Defense Activity Address Code
DODAF Department of Defense Architecture Framework
DVD direct vendor delivery
extcu extended cube
FDP  forward distribution point
G-4 Logistics
G-44S Supply
GCSS Global Combat Support System
GSA General Services Administration
HQDA Headquarters, Department of the Army
IPG issue priority group
LMP Logistics Modernization Program
LoD level of detail
LRT logistics response time
Max maximum
MILAIR military air
MILALOC military air line of communication
MRO materiel release order
NAMI non-Army-managed item
NGDS next-generation delivery system
NIIN National Item Identification Number
N RWT  number of receipted shipments
N Val  number of shipments
OCONUS outside the continental United States
RIC   ownership routing identifier code
RWT   requisition wait time
Shipwt ship weight
SDDC  Surface Deployment and Distribution Command
SPC   statistical process control
SPOD  sea port of debarkation
SSA   supply support activity
Supcl supply class
svc   Service
TASL  theater authorized stockage list
TSC   theater sustainment command
References
