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**WEAPON SYSTEM SUPPLY
PERFORMANCE ANALYZER**

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Supply Performance VSL Computations Inventory Analysis		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes a new management tool being made available to the Army Materiel Readiness Commands (MRC). The tool is referred to as the Weapon System Supply Performance Analyzer (SPA) and enables the MRC's to set their safety levels by weapon system grouping within the guidelines of DoDI 4140.39. The SPA makes estimates of supply performance (stock availability and customer waiting time) compared to costs (commitment authority and safety level investment).		

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TABLE OF CONTENTS

	<u>Page</u>
TABLE OF CONTENTS.....	1
REPORT	
1. Background.....	2
2. DoDI 4140.39 Management Concept.....	3
3. CCSS Supply Performance Analyzer.....	4
4. Weapons System SPA.....	5
5. Running the Weapon System SPA.....	6
6. Improvements in the Weapon System SPA.....	9
7. Future Enhancements to the Weapon System SPA.....	10
APPENDIX - WEAPON SYSTEM SPA ESTIMATION OF SUPPLY PERFORMANCE AND COMMITMENT AUTHORITY.....	11
REFERENCES.....	14
DISTRIBUTION.....	15

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1. Background

When the Army implemented Dept of Defense Instruction (DoDI) 4140.39, two computer programs were developed for the Commodity Command Standard System (CCSS). One program, called the VSL/EOQ Module, computes safety levels and other quantities in accordance with the policies of DoDI 4140.39. A key input to the VSL/EOQ module is the shortage cost parameter which represents the cost ascribed by management to having one requisition on backorder for one year. The shortage cost is referred to as implied since its value is established by management's selection of either cost or performance goals.

The other program implemented in CCSS is called the Supply Performance Analyzer (SPA). Its function is to produce the relationship between the shortage cost parameter and measures of interest to management like safety level investment, commitment authority, stock availability, and customer waiting time. To do this, the SPA merely runs different values of the shortage cost through the VSL/EOQ module and estimates the impact of the resulting levels on costs and supply performance. Management is able to review these statistics in several formats and make its decisions.

The above, of course, is all too brief and should be more understandable with later narrative. However, the important point to be made now is that the CCSS SPA has not been used by the Materiel Readiness Commands (MRCs) and partly for that reason is not a viable management tool. This report will describe a new SPA which is available to the MRCs, although off line from the CCSS, and which is more convenient to use and provides more and better developed information. We call this the Weapon System SPA because its primary difference from the CCSS SPA is its ability to produce cost and supply performance for items within specified weapons systems.

The Weapon System SPA will be incorporated in CCSS when and if it becomes a routinely used product. It is anticipated that the users of the product will request a good many new features as they begin to use it. Because of resource constraints at Automated Logistics Mgt Systems Activity (ALMSA), it is impractical to develop a management tool like this within CCSS. The time required to make adjustments is prohibitive. Consequently, we have opted for the off-line approach where we retain direct control of the programming until the system is fully developed and debugged.

2. DoDI 4140.39 Management Concept

There are several ways to explain the concepts of DoDI 4140.39. Essentially, as the Army has implemented it, the objective of VSL/EOQ computation is to find the set of least cost levels which achieve a specified goal for average delay due to backorders at the MRC for a specified catalog of stocked items. Currently, these catalogs are selected at each MRC as the group of Army Stock Fund (ASF) secondary items, and the group of Procurement Appropriation for the Army (PAA) secondary items. The DoDI, however, is flexible and, among other ways, permits catalogs to be constructed on a weapon system basis. It is this feature which led to the work described in this report.

Let G identify a group of items. Then, the objective of VSL/EOQ is mathematically expressed as the problem

$$(1) \quad \min_{SL, Q} \quad \sum_{i \in G} C_h (SL_i + PLTD_i + Q_i/2) + C_p \frac{Q_i}{AYD_i}$$

subject to the constraint that

$$\frac{\sum_{i \in G} B_i(SL_i, Q_i)/S_i}{\sum_{i \in G} AYD_i/S_i} = W_0$$

where

SL_i = safety level for item i ; $i = 1 \dots N$

Q_i = order quantity for item i ; $i = 1 \dots N$

$SL = (SL_1, SL_2, \dots, SL_N)$

$Q = (Q_1, Q_2, \dots, Q_N)$

C_h = holding cost rate per year

C_p = cost to procure

AYD_i = average yearly demand for item i ; $i = 1 \dots N$

$PLTD_i$ = forecasted demand during the procurement lead time for item i ; $i = 1 \dots N$

S_i = average requisition size for item i

$B_i(SL_i, Q_i)$ = average time weighted units on backorder for item i when SL_i and Q_i are its supply levels.

To solve problem (1) the Generalize Lagrange Multipliers Method (GLMM) is used (see reference [2]). When GLMM is applied, problem (1) is transformed to

$$(2) \quad \sum_{i \in G} \min_{SL_i, Q_i} C_h(SL_i + PLTD_i + Q_i/2) + C_p \frac{Q_i}{AYD_i} + \lambda(B_i(SL_i, Q_i)/S_i)$$

such that

$$\sum_{i \in G} B_i(SL_i, Q_i) = (W_0) \left(\sum_{i \in G} AYD_i / S_i \right)$$

For a given value of λ , it is a fairly simple matter to find the values of SL_i and Q_i which minimize costs. However, the burden of this approach is to find the value of λ which yields SL_i 's and Q_i 's which achieve the constraint. Note that λ is effectively applied as a cost to the average time weighted requisitions on backorder and for that reason λ is also referred to as the shortage cost parameter. To reemphasize, it is referred to as implied because it is selected only as it relates to the costs and performance it yields.

3. CCSS Supply Performance Analyzer

This section will describe the important aspects of the CCSS SPA as they relate to the Weapon System SPA. It was stated earlier that the CCSS SPA was not a viable tool. There are some perplexing problems which show up sporadically and which have never been explained, let alone corrected, primarily because the SPA was never used by management. Fortunately, however, the data base which the SPA uses is fine. The problems are somewhere in the logic which processes that data.

A major objective of the CCSS SPA is to be consistent with corresponding measures produced by the Budget Stratification System (STRAT). In order to do this, the STRAT summarizes and screens its data and produces an input file for the SPA. The following is an abridged list of the elements in the input file.

SPA INPUT FILE

- (1) STRAT Group Key (7 positions)
- (2) Financial Inventory Accounting (FIA) Code (5 positions)
- (3) Forecasted AMD Used in VSL/EOQ at the beginning of the Apportionment Year (AY), Budget Year (BY) and Budget Year plus 1.
- (4) Unit Price
- (5) Procurement Lead Time
- (6) Cost to Procure for BOA, Purchase Order, and Contract
- (7) Delivery Cycle
- (8) Cost to Hold Rate
- (9) Repair Lead Time
- (10) Unserviceable Return Rate
- (11) Average Requisition Size
- (12) Reorder Point less Safety Level at beginning AY, BY and BY + 1
- (13) Reorder Cycle at beginning BY and BY + 1
- (14) Total Assets at beginning AY
- (15) Net demand (demands-returns) during the AY and during the BY separately.

The above data elements basically allow the SPA to compute safety levels as a function of the shortage cost parameter, and estimate stock availability, average delay in filling requisitions due to backorder, and commitment authority in the AY and in the BY. Estimates of supply performance, i.e. stock availability and average delay, are produced analytically through the VSL/EOQ Module using the same fundamental model on which SL computations are based. Because the model assumes somewhat of an idealized world, the projections of supply performance tend to be a bit better than the actual real world values. Commitment authority (CA) is estimated by assuming that supply levels do not change significantly within a given year, and that demands and returns occur for one unit at a time. The ultimate judgement of the CA estimate is how well it compares to the estimate produced by the STRAT. It does quite well.

For a more thorough explanation of the CCSS SPA see reference [4].

4. Weapons System SPA

There are many similarities in logic between the CCSS SPA and the Weapon System SPA and, in fact, the Weapon System SPA, although not run on the CCSS computers, uses the CCSS SPA data base. From the user's point of view, however, there are basic differences.

The Weapon System SPA is written in FORTRAN and is set up to be run on a CDC 6500 or 6600 computer with the NOS/BE operating system. Of course, with minor changes it could be run on virtually any machine capable of running FORTRAN programs including the CCSS computers. It is run in two phases. The first phase is a batch mode process and is virtually the same as the CCSS SPA except that Weapon System catalogs can be separately analyzed. All of the statistics for the selected shortage costs for the specified catalogs are printed and, in addition, are written to a disk file. The second phase is run in a time sharing mode and enables an analyst or decision maker to manipulate the results produced in the first phase which were stored on disk. The value of the second phase is that the user can see the impact of shortage costs other than those preselected values run through phase one; can find the effect of meeting performance goals; and can merge the results for several groups. This will become clearer in the next section.

5. Running the Weapon System SPA

In order to run phase one, the user must specify the weapon system/fund groups to be analyzed along with up to five shortage costs for each group. The groups are identified from the fourth and fifth positions of the FIA code which define the weapon system, and from the second position of the FIA code which defines the fund. The user then must input the appropriate 3 digit code for the group of interest. In the program, this code is matched against the corresponding three positions in the group key which appears for each item on the data base. All of the MRC's build their group keys so that they contain the second, fourth and fifth positions of the FIA code. In principle, the program could key on any of several digits in the group key so that there is no real limit to how groups could be defined. Presently, the program is limited to handle at most 30 groups, but extending it to at least 100 is not a problem. There are, however, questions as to whether there would be benefits from expanding the number of groups, especially if the decision maker is interested in trading off resources among groups. Since this has to be a manual effort, the decision maker would have to assimilate the information from all groups and it is doubtful that more than 10 groups could be handled at one time. A hierarchical approach could be used to handle a large number of groups in some cases. In this mode of operation the decision maker would review aggregated groups and make tradeoffs among the aggregates. Then the aggregate groups could be reviewed separately to determine the resource allocation to the individual elements.

For each group, the following table is produced by the first phase of the Weapon System SPA.

		APPORTIONMENT YEAR				BUDGET YEAR					
		SL\$	CA\$	AVAIL DAYS	LAM	SL	SL\$	CA\$	AVAIL DAYS		
		(000)	(000)	WAIT		MOS	(000)	(000)	WAIT		
1	1	9240	121582	.801	60.7	100	.6	9289	163017	.763	74.5
						300	1.9	31245	181246	.836	50.5
						475	2.9	48227	195779	.861	41.8
						600	3.5	58947	205152	.873	38.6
						750	4.2	70526	213387	.883	34.5
2	1	30897	117253	.843	48.3	100	.6	9289	147446	.755	77.8
						300	1.9	31245	165672	.831	52.1
						475	2.9	48229	180118	.857	43.1
						600	3.5	58947	189671	.869	39.2
						750	4.2	70526	197595	.879	35.6
3	1	47533	152226	.865	40.7	100	.6	9289	133020	.765	72.1
						300	1.9	31245	150630	.830	52.4
						475	2.9	48229	165634	.856	45.6
						600	3.5	58947	174661	.868	39.5
						750	4.2	70526	182792	.878	35.9
4	1	58038	159068	.876	36.9	100	.6	9289	126823	.776	67.7
						300	1.9	31245	143759	.831	51.7
						475	2.9	48229	158729	.856	44.8
						600	3.5	58947	168028	.868	39.5
						750	4.2	70526	176186	.878	36.0
5	1	67448	167715	.886	33.8	100	.6	9289	119372	.784	64.7
						300	1.9	31245	135848	.832	51.7
						475	2.9	48229	150484	.856	48.2
						600	3.5	58947	159020	.867	39.8
						750	4.2	70526	167734	.878	36.7

Basically, there are two sets of information for each group. One set consists of estimates for the AY, the other set of estimates for the BY. There is a line of results for each shortage cost (LAM in the above table) which shows the resulting safety level months and dollars, the commitment authority, the stock availability, and the wait due to backorders in filling requisitions. Since the AY decisions will have an effect in the BY, the BY results are shown as conditional on the AY value of shortage cost. For example, in the above table, if the AY value of shortage cost is \$475, and the BY value is \$600, then the AY SL \$ is 47,593,000 while the BY SL \$ is 58,947,000. Likewise, CA \$ are 152,226,000 in the AY, and 174,661,000 in the BY. Note that if the AY shortage cost were \$600, instead of \$475, then the CA \$ in the AY is 159,068,000 and the BY CA \$ is reduced from 174,661,000 to 168,028,000. The specific procedures for producing the estimates are in the appendix.

When the first phase has been completed satisfactorily, the second phase can be run at any time. The primary input to the second phase is the table shown above for each group of items analyzed. As noted earlier, the table is put on a disk file so that the second phase can be run in a time sharing mode.

The fundamental design objective for this phase of the Weapon System SPA was that the program be easily used by someone not accustomed to working with computers. Consequently, once the program is started by the user, all subsequent responses by the user are prompted by the program. The program prompts, essentially, as follows:

- (a) Informs the user which groups have been analyzed.
- (b) Tells the user what functions the program can perform and tells how to select each function.
- (c) When a function is selected, prompts the user for the information required to perform the function.

There are three functions performed in this phase. The most important function is the one which finds the shortage cost parameters which meet management goals for a specific group. When performing this function the program first asks the user to specify how the AY shortage cost is to be determined. It may be preset (selected previously), or it may be set to achieve a target on either SL dollars, commitment authority, stock availability or delay in filling requisitions. The targeted values must lie within the range of shortage costs analyzed. Once the AY shortage cost has been set, the program allows the user to do the same things for the BY. Because the BY depends on the AY decision, the program will not allow the BY shortage cost to be set until a value for the AY shortage cost is picked.

Another main function of the SPA allows the user to aggregate the statistics from several groups into one. This is valuable for the hierarchical scheme of analysis mentioned earlier. When the aggregated group is formed the program asks the user if he wants to pick shortage costs for the aggregate group. If yes, the program effectively performs the first function described above.

The last function is not that important, but, for convenience, it allows the user to print out the table of results for any specified group while at the terminal.

6. Improvements in the Weapon System SPA

In addition to being easier to use, the Weapon System SPA has some improved techniques for estimating supply performance over the CCSS version. Earlier it was mentioned that the CCSS SPA uses the analytical techniques which are fundamental to VSL/EOQ computation. So too does the Weapon System SPA, but it builds upon those techniques in an attempt to produce more realistic performance estimates.

There are several assumptions made by the present model for computing VSL's and EOQ's. Two critical assumptions are that the procurement lead time (PLT) can be forecasted exactly, and that reorder points are always hit exactly, i.e. there is no reorder point undershoot. Of course, these assumptions are unrealistic and they have been relaxed in the Weapon System SPA. In the appendix, we show the methodology. Here, we will only note that the Weapon System SPA estimates of supply performance are more pessimistic than the corresponding estimates in the CCSS SPA. For example, on a series of tests on some Communications-Electronics Command (CECOM) weapon system groups it was found that the improved methodology for estimating stock availability gave results that were about six percentage points less in the 85% availability range. In other words, when the improved techniques predict 85% stock availability, the CCSS SPA would predict about 91% availability. Similar results were obtained when the improved estimate for backorder delay was compared with its counterpart in the CCSS SPA. For example, a group of Missile Command (MICOM) items on 30 day average delay in the CCSS SPA is on the order of 42 days in the Weapon System SPA.

These results are particularly encouraging since the estimates need to be credible before there can be DARCOM acceptance of the approach. It is no secret that the CCSS SPA suffered because there was little trust in its performance estimates. The estimates of the Weapon System SPA, on the other hand, are within the normal range of actual MRC performance measures as collected through Military Supply Transportation Evaluation Procedures (MILSTEP). Although there is no way the SPA statistics will exactly match the corresponding MILSTEP statistics, there is, nevertheless, the need for the SPA estimates for each of the weapon system to be within the neighborhood of the MILSTEP values, and to be relatively consistent. By relatively consistent we mean that if weapon system A is estimated to have XX better supply performance than system B, then the MILSTEP statistics should also show A about XX better than B.

7. Future Enhancements to the Weapon System SPA

An important recommendation of the OSD Stockage Policy Analysis Study [1] is that the primary supply measure be the average delay in filling a requisition at the MRC irrespective of whether the requisition is for a demand based stockage item, a non-demand based item, or a non-stocked item. This recommendation will almost certainly be adopted by DoD and will be reflected in the update of DoDI 4140.39 which is due shortly. This measure will require that the range and depth decisions be integrated, whereas today they are separate. To integrate the decisions as envisioned by DoD will require the adoption of an economic model for range which is consistent with the model for depth. Moreover, the SPA will need to look at the impact of range on supply performance in addition to depth as it does now. The data base provided to the SPA will, therefore, need to be expanded so that it has access to all items which are candidates for stockage by the MRC.

APPENDIX

WEAPON SYSTEM SPA ESTIMATION OF SUPPLY PERFORMANCE AND COMMITMENT AUTHORITY

I. Supply Performance Estimates

The estimates of stock availability and backorder delay are based on the work in [3], which describes a method for approximating the impact of reorder point undershoot. An (s,S) continuous review inventory system constitutes a regenerative process where regenerations occur each time an order is placed. Consequently, average measures of the system can be obtained from corresponding measures in each regeneration cycle. See Ross [5], page 95.

Let Z denote the undershoot, $Z = 0, 1, \dots$, and $P(Z)$ its probability function. If we let $U(X,Y)$ denote the expected number of units from an order of size Y when placed from an asset position X which are used to fill backorders when the order arrives, then the fill rate

$$FR(R,Q) = 1. - \sum_{Z=0}^{\infty} U(R-Z, Q+Z) P(Z)/(Q+Z)$$

where

R = reorder point

Q = reorder quantity

Z = expected value of the undershoot

In the SPA, $FR(R,Q)$ is approximated by

$$FR(R,Q) = 1. - \frac{1}{Q+E(Z)} \{ \Pr[Z < R] U(R-Z_1, Q+Z_1) \\ + \Pr [Z > R] U(R-Z_2, Q+Z_2) \}$$

where

$$Z_1 = E(Z|Z < R)$$

$$Z_2 = E(Z|Z > R)$$

$U(X,Y)$ is computed using conventional steady state analysis of an R,Q inventory system assuming that demand size is always one unit.

If $\alpha(X,Y)$ is the steady state fill rate for a continuous review inventory system experiencing random demands for one unit each with reorder point X and reorder quantity Y , then $U(X,Y) = (Y) \alpha(X,Y)$.

For time weighted units on backorder there is an analogous result in which $U(X,Y)$ is replaced by its time weighted analog.

II. Commitment Authority Estimates

For a given year let

A_0 = asset position at the beginning of the year.

ND = net demands during the year.

R_E = reorder point at end of year.

Q_E = reorder quantity at end of year.

A_E = assets at end of year.

In the Budget Strat simulation it is always true that $R_E < A_E \leq R_E + Q_E$ for any item bought. As an approximation to the STRAT we set $CA = (n)(Q_E)$ where n is chosen such that $A_E = A_0 - ND + (n)(Q_E)$ is within the above limits. The goodness of this approximation depends upon how much levels change within a given year. If levels remain constant, the relationship agrees with the STRAT value exactly. Empirical testing has indicated that the approximation is quite good.

III. Aggregating the Estimates Over the Group

Let G represent the set of all items in group G . The SPA estimates the CA for the group as

$$CA_G = \sum_{i \in G} CA_i \text{ where } CA_i \text{ is the commitment authority for item } i.$$

The performance estimates, as described earlier, are estimates of long term average performance. Since the SPA reviews SL policies which may be quite different in the AY and in the BY, we focus on the items which are expected to be bought in the year of interest when aggregating performance.

Let $\delta_i = 1$ for item i if the item is simulated as needing a buy in a given year, and $\delta_i = 0$ otherwise. Then the estimated stock availability for group G is

$$SA = \sum_{i \in G} (\delta_i)(FR_i)(REQ_i) / \sum_{i \in G} (\delta_i)(REQ_i)$$

where

FR_i = estimated fill rate for item i

REQ_i = estimated number of requisitions for item i in the given year

Effectively, then the aggregation takes place across items which are bought and may be interpreted as the target stock availability for procurement actions within the given year. Again, there is a similar procedure for time weighted requisitions on backorder which is converted to average delay due to backorder by using the well know $L = \lambda W$ queueing theorem.

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1 Commander, USDRC Automated Logistics Mgt Systems Activity, P.O. Box 1578, St. Louis, MO 63188

1 Commander, Materiel Readiness Support Activity, Lexington, KY 40507

1 Director, Army Management Engineering Training Agency, Rock Island Arsenal, Rock Island, IL 61299

1 Defense Logistics Agcy, ATTN: DLA-LO, Cameron Sta, Alexandria, VA 22314

1 Dep Chf of Staff (I&L), HQ USMC-LMP-2, ATTN: LTC Sonneborn, Jr., Wash., DC 20380

1 HQ, Dept of the Army, (DASG-HCL-P), Wash., DC 20314

1 Logistics Studies Office, DRXMC-LSO, ALMC, Ft. Lee, VA 23801

1 Procurement Research Office, DRXMC-PRO, ALMC, Ft. Lee, VA 23801

1 Dept of Industrial Engr. & Engr. Management, Stanford University, Stanford, CA 94305

1 Commander, US Army Communications Command, ATTN: Dr. Forry, CC-LOG-LEO, Ft. Huachuca, AZ 85613

1 Prof Harvey M. Wagner, Dean, School of Business Adm, University of North Carolina, Chapel Hill, NC 27514

1 DARCOM Intern Training Center, Red River Army Depot, Texarkana, Tx 75501

1 Prof Leroy B. Schwarz, Dept of Management, Purdue University, Krannert Bldg, West Lafayette, Indiana 47907

1 US Army Training & Doctrine Command, Ft. Monroe, VA 23651

1 Operations & Inventory Analysis Office, NAVSUP (Code 04A) Dept of Navy, Wash., DC 20376

1 US Army Research Office, ATTN: Robert Launer, Math. Div., P.O. Box 12211, Research Triangle Park, NC 27709

1 Prof William P. Pierskalla, 3641 Locust Walk CE, Philadelphia, PA 19104

1 US Army Materiel Systems Analysis Activity, ATTN: DRXSY-MP, Aberdeen Proving Ground, MD 21005

Air Force Logistics Management Center, Gunter Air Force Station, AL 36144

1 ATTN: AFLMC/LGY

1 ATTN: AFLMC/XRP, Bldg. 205

1 Engineer Studies Center, 6500 Brooks Lane, Wash., DC 20315

1 US Army Materiel Systems Analysis Activity, ATTN: Mr. Herbert Cohen, DRXSY-MP, Aberdeen Proving Ground, MD 21105

1 Commander, US Army Missile Cmd, ATTN: Ray Dotson, DRSMI-DS, Redstone Arsenal, AL 35898

1 Prof Barney Bissinger, The Pennsylvania State University, Middletown, PA 17057

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