OPERATIONS ANALYSIS OFFICE

VECTOR:

AN ANALYTIC TOOL FOR PLANNING AND PREDICTING AIRCRAFT SPARES SUPPORT

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A computer program which we call "Vector" can estimate how the number mission-capable aircraft in a flying unit responds to changes in flying program, stock levels, the repair process, and so forth. Even though Vector and Dyna-METRIC both are based upon the same sophisticated mathematics, blind acceptance of the output from such black box models weakens any argument as to whether the models have been correctly applied. This report takes the reader through a careful, step-by-step interpretation of the output of Vector and relates the output conclusions to the input data and to the built-in assumptions of the mathematics.

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VECTOR:

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July 1982

FOREWORD

A computer program which we call "Vector" can estimate how the number of mission-capable aircraft in a flying unit responds to changes in flying program, stock levels, the repair process, and so forth. Even though PACAF's Vector and Rand's Dyna-METRIC both are based upon the same sophisticated mathematics, blind acceptance of the output from such black box models weakens any argument as to whether the models have been correctly applied. This report takes the reader through a careful, step-by-step interpretation of the output of Vector and relates the output conclusions to the input data and to the built-in assumptions of the mathematics.

AN ANALYTIC TOOL FOR PLANNING AND PREDICTING AIRCRAFT SPARES SUPPORT

In recent years a new generation of supply oriented analytic programs that predict a flying unit's ability to generate wartime sorties has evolved. These programs are different in at least two significant ways from the previous generations:

a. Their theory has bridged the gap from the steady state logistics of peacetime to the dynamic logistics processes of wartime.

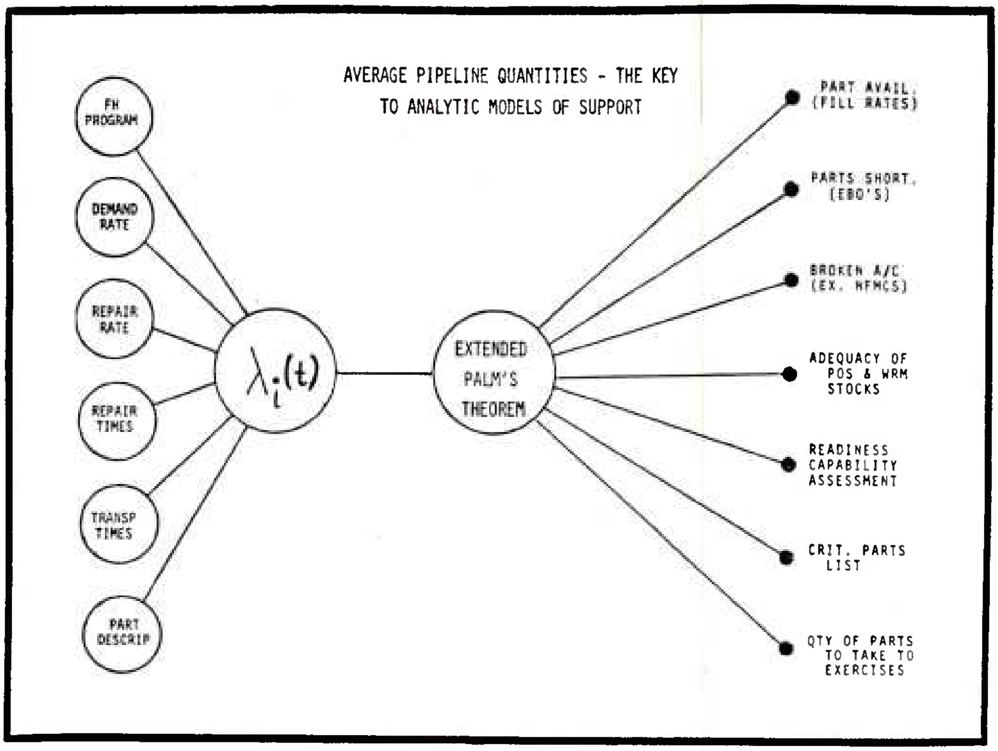
b. Their performance measures have shortened the gap from non-combat measures like "fill rate" and "expected backorders (EBOs)" to the number of broken aircraft (due to missing parts) and the number of sorties that can be generated per day.

This paper describes the underlying methodology of one such new generation program - the PACAF/OA Vector Model.

Vector computes the estimated pipeline quantity and the probability of one or more backorders for each part on a given day. Combining these probabilities for all parts and assuming 100% cannibalization, the program computes the expected number of aircraft down due to parts shortages.

Data from an actual Vector run are used to illustrate this process and to show how the results may be used to quantify the impact of spares shortages and repair delays. Vector does not, however, attempt to estimate the number of sorties that can be generated.

CHART 1: AVERAGE PIPELINE QUANTITIES

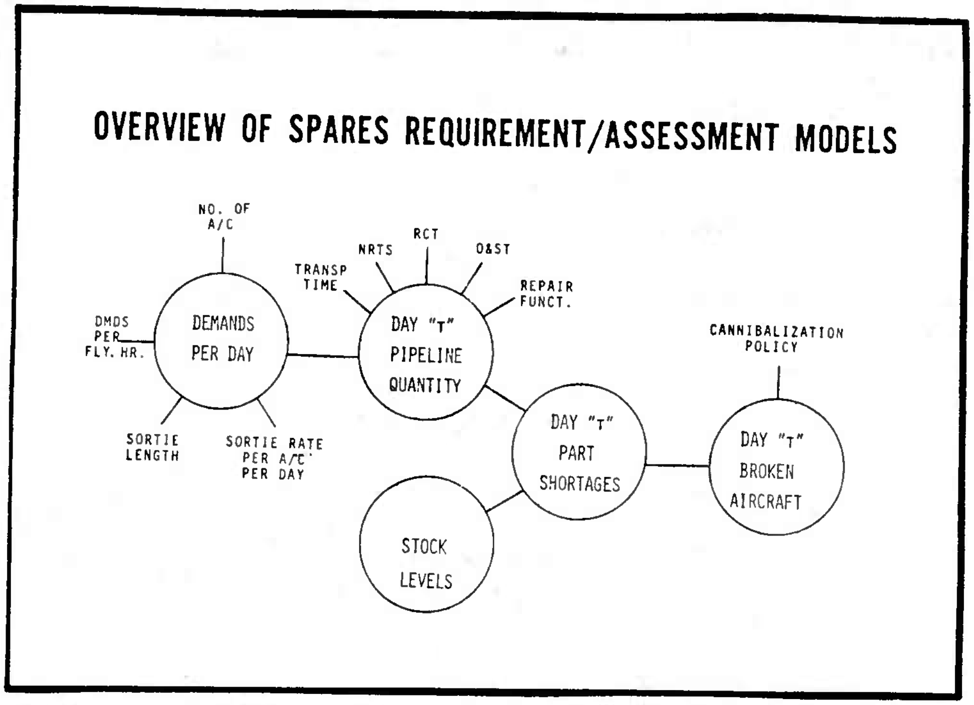


This Vector program reduces, on a component-by-component basis, each part's raw input factors into a single, information-packed, statistically rich variable, $\lambda_i(t)$, which is the average number in the repair and transportation pipeline on day "t" for part "i". More commonly, we say it is the average resupply pipeline quantity for part "i" on day "t".

Palm's Theorem as extended to a dynamic wartime environment (non-steady state) allows us to assert the form of probability distribution for the individual component $\lambda_i(t)$. That is we can compute the probability of actually finding "0", "1", "2", . . . etc., in the resupply pipeline on day "t".

Finally, each component's probability distribution is compared to the component's supportable stock to determine the shortages we can expect to see. From the combination of shortages over all components, we can now provide quantitative measures of the supply system performance.

CHART 2: VECTOR PROGRAM OVERVIEW



Now let us look in more detail at how the Vector program processes data. For a given part the product of the four factors surrounding the first balloon gives demands for the day being considered. This number may change from day-to-day because among the four factors only demands per flying hour is assumed to remain constant during wartime.

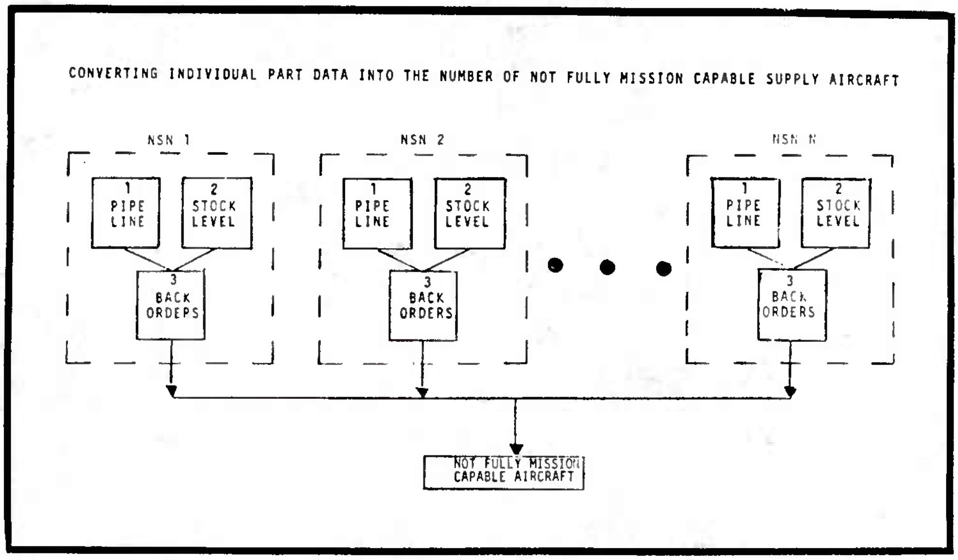
The demands per day from day "t" and days prior to day "t" interact with the five factors surrounding the second balloon to yield the day "t" average pipeline quantity, $\lambda_i(t)$, for the part "i". This is the expected quantity of a particular part that is being repaired at the base, at a centralized intermediate repair (CIRF), or at a depot.

Next the Poisson probability distribution of the pipeline quantity is computed with $\lambda_i(t)$ as the mean.

Adjusting for stock determines the part shortage for component "i" on day "t". This process is repeated for each component. As the last step, the Vector program will compact all the EBOs into the minimum number of aircraft by assuming a 100% maintenance cannibalization policy. Although this tells you the minimum number of broken aircraft, it says nothing about the amount of effort it took to consolidate (cannibalize) the EBOs.

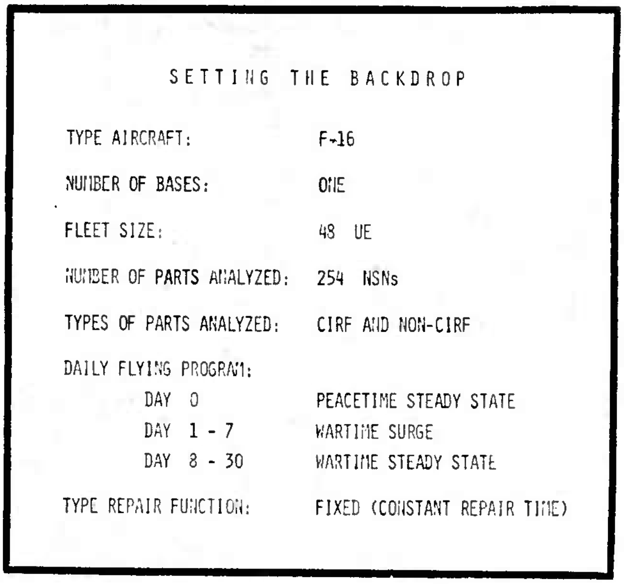
Each part shortage is a backorder; and with no cannibalization, each shortage will cause a NMCS aircraft. However, by cannibalizing this can be considerably reduced. The calculations in the program represent a 100% cannibalization policy, that is, consolidating the total number of backorders over all parts on the fewest number of aircraft. The program, however, does not indicate the amount of work involved in doing this consolidation. In cases of poor spares stockage, the maintenance manpower required could be beyond the capability of the unit.

CHART 3: CONVERTING PART DATA INTO NFMC AIRCRAFT



To review the process for each part on any given day, the program compares the estimated pipeline quantity with the stock level and computes the probability of one or more backorders. Combining these probabilities for all parts and assuming 100% cannibalization, the program computes the expected number of aircraft down because of part shortages. These part shortages are due to a combination of delays in repair or transportation as reflected in the pipeline quantity and inadequate stock as reflected in the stock level.

CHART 4: SETTING THE BACKDROP



SETTING THE BACKDROP

TYPE AIRCRAFT:	F-16
NUMBER OF BASES:	ONE
FLEET SIZE:	48 UE
NUMBER OF PARTS ANALYZED:	254 NSNs
TYPES OF PARTS ANALYZED:	CIRF AND NON-CIRF
DAILY FLYING PROGRAM:	
DAY 0	PEACETIME STEADY STATE
DAY 1 - 7	WARTIME SURGE
DAY 8 - 30	WARTIME STEADY STATE
TYPE REPAIR FUNCTION:	FIXED (CONSTANT REPAIR TIME)

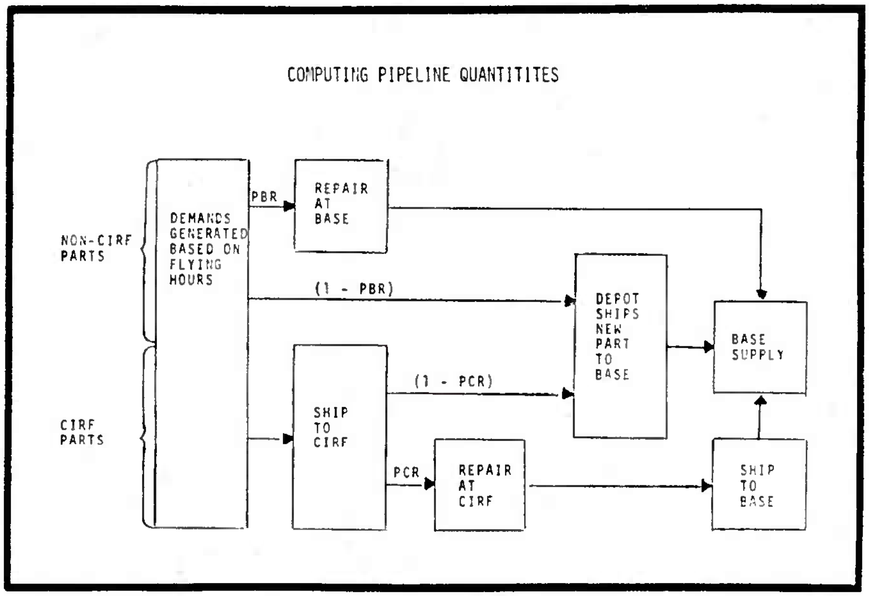
Now let us look at an actual Vector computer run to evaluate the readiness capability of a single base F-16 wing.

Two hundred fifty-four (254) individual (unique) parts were evaluated. Some were CIRF managed parts and some were not. These parts were all line replaceable units (LRUs).

In this run the flying program changed from a peacetime rate to a wartime surge for seven days and then dropped to a wartime steady-state level for the remainder of the 30-day period.

The Vector program as written utilizes deterministic, constant repair-time pipelines, although it is easy for the user to substitute his own favorite repair time distribution subroutine which needs to be described only as a table function.

CHART 5: COMPUTING PIPELINE QUANTITIES



These are the typical resupply routes for CIRF managed and non-CIRF managed parts. Although the calculations are done using the total pipeline quantity for a given part on a given day, the Vector program also prints out the individual base, CIRF, and depot portions of the total pipeline quantities.

During peacetime the total pipeline quantities, $\lambda_i(t)$, are more or less in steady state. That is, on the average they do not change day-to-day and the number of demands going into the resupply pipeline equals the number coming out. When war starts, the pipeline quantities become dynamic. The average pipeline quantities build quickly during the initial surge period.

CHART 6: PIPELINE MATRIX

PIPELINE MATRIX
TOTAL PIPELINE QUANTITY (AVERAGE)

PART NO.	DAY = 0	2	4	6	8	10	12	14	...	30
.										
.										
.										
25	0.8	1.1	1.5	1.8	2.0	2.1	2.2	2.3	...	1.7
38•	0.4	0.5	0.7	0.8	0.9	0.8	0.8	0.8	...	1.0
58	3.6	6.3	8.9	11.5	13.1	13.7	11.8	9.9	...	7.1
149•	1.1	1.3	1.6	1.8	2.0	2.0	2.1	2.2	...	2.6
175•	$\boxed{5.1}$	6.3	7.5	8.7	9.4	9.7	10.0	10.1	...	11.9
208•	2.4	3.4	4.4	5.5	6.1	6.3	5.9	5.4	...	5.2
.										
.										
.										

•PROBLEM PART.

This chart shows a matrix of pipeline quantities for a small group of parts on separate days as reflected across the top of the matrix. For example, the average pipeline quantity for part no. 175 on day "0" of the war (peacetime) is "5.1". Notice it builds steadily when the war starts, to a peak of "11.9" on day 30. Part no. 149 also shows monotonically rising average pipeline quantities. These parts are repaired predominantly at the depot and incur a thirty-day O&ST. Thus for thirty days, their pipelines are emptying at the peacetime rate but increasing at the wartime rate.

Contrast that pattern with part no. 58 and part no. 208. The former is a non-CIRF part repaired at the base in ten days. The latter is a CIRF part repaired at the CIRF in four days; however, it takes six additional days to get it to and from the CIRF. So after ten days both parts' pipelines are emptying at the high surge rate but building at the lower wartime steady-state rate.

The asterisks identify for you those parts the Vector program subsequently identified as problem parts (high EBOs). The $\lambda_i(t)$, themselves, will not tell you these are problem parts. You need to know the parts stock level also. Larger pipeline quantities are not bad if you have enough stock.

CHART 7a: PIPELINE PROBABILITY MATRIX

PIPELINE PROBABILITY MATRIX

PROBABILITY OF "K" OR FEWER PARTS IN TOTAL PIPELINE ON DAY ZERO

PART NO.	K = 0	1	2	3	4	5	...
.							
.							
.							
25	0.45	0.81	0.95	0.99	1.00		...
38*	0.66	0.94	0.99	1.00			...
58	0.03	0.12	0.29	0.51	0.70	0.84	...
149*	0.35	0.71	0.91	0.98	1.00		...
175*	0.01	0.04	0.12	0.25	0.42	0.60	...
203*	0.09	0.31	0.57	0.78	0.90	0.96	...
.							
.							
.							

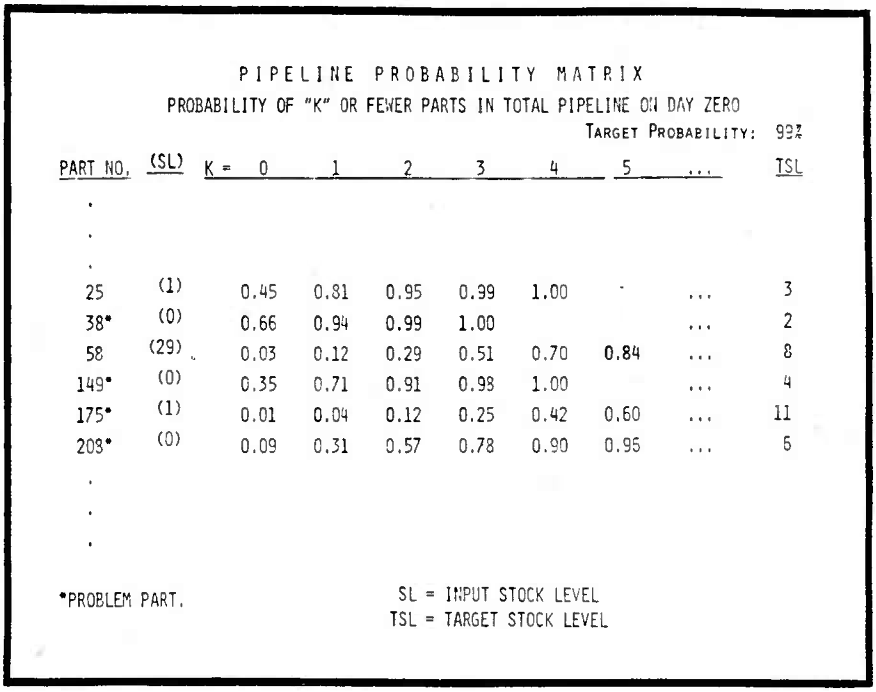
*PROBLEM PART.

Even though the average pipeline quantity on day zero for part no. 175 is predicted to be 5.1, there is some chance (probability) that it could be only 1.0. There is also the probability that it could be 2.0, or 3.0, etc. The Vector program uses the extended Palm's Theorem and standard statistical techniques to compute these point probabilities around each $\lambda_i(t)$. It then adds these point probabilities successively to form cumulative probabilities. That is what you see on this chart. Vector prints a probability matrix like this for each day you request.

Notice two things about cumulative probabilities. They are always rising (at least non-decreasing); and if you carry them out far enough, they reach 1.00. The subtitle says, "Probability of 'k' or fewer parts in the pipeline"; thus, part no. 175 has a probability of 0.25 that there would be three or less (k=3) parts in the pipeline even though the predicted average is 5.1.

The probabilities in this matrix give us an easy "first cut" at what our stock levels should be. The next chart shows how.

CHART 7b: PIPELINE PROBABILITY MATRIX (FLIP)



PIPELINE PROBABILITY MATRIX

PROBABILITY OF "K" OR FEWER PARTS IN TOTAL PIPELINE ON DAY ZERO

TARGET PROBABILITY: 99%

PART NO.	(SL)	K = 0	1	2	3	4	5	...	TSL
.									
.									
.									
25	(1)	0.45	0.81	0.95	0.99	1.00		...	3
38*	(0)	0.66	0.94	0.99	1.00			...	2
58	(29)	0.03	0.12	0.29	0.51	0.70	0.84	...	8
149*	(0)	0.35	0.71	0.91	0.98	1.00		...	4
175*	(1)	0.01	0.04	0.12	0.25	0.42	0.60	...	11
208*	(0)	0.09	0.31	0.57	0.78	0.90	0.96	...	6
.									
.									
.									

*PROBLEM PART.

SL = INPUT STOCK LEVEL
TSL = TARGET STOCK LEVEL

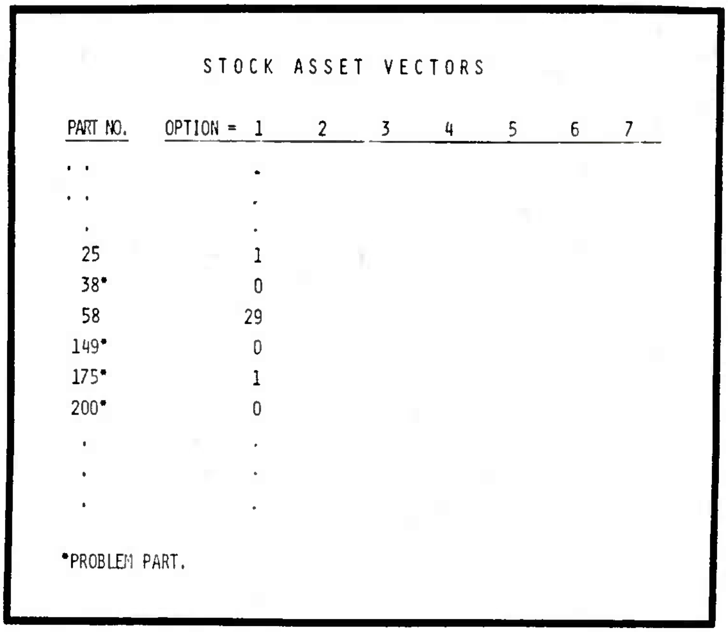
Pick a target probability representing how confident you want to be that you will have ample stock for each part when you need it. We selected 99% for this run. This means that if we buy to this level, 99 times out of 100, we would have a part when needed. If we stocked each LRU to a 99% target probability, however, we would expect backorders on two or three items at any given time. That could equate to two or three broken aircraft.

To determine what your target stock level (TSL) should be, find the cumulative probability element for each that at least equals the target probability. Then go straight up the chart to find the value of "k" that corresponds. This is your TSL. They are listed in the right column. For part no. 149, k=3 gives a probability of only 0.98. Therefore, we need to take k=4 to ensure a probability of at least 0.99--our target probability. If we had carried the table out far enough, you would see that TSL=11 for part no. 175.

To get a look at our supply status we have added the input stock levels for each part. They are under the column labeled "SL". By comparing SL with TSL, part-by-part, you get some initial evidence where your part shortages are located.

Do not let the apparent overage for part no. 58 confuse you. The input stock levels (SL) for this computer run were composed of both peacetime operating stock (POS) and base level self-sufficiency spares (BLSS). Recall that this matrix was for day zero only and that the TSL for day zero is "8". Vector program output for day five and day ten of the war showed TSLs of "18" and "22", respectively.

CHART 8: STOCK ASSET VECTORS



STOCK ASSET VECTORS

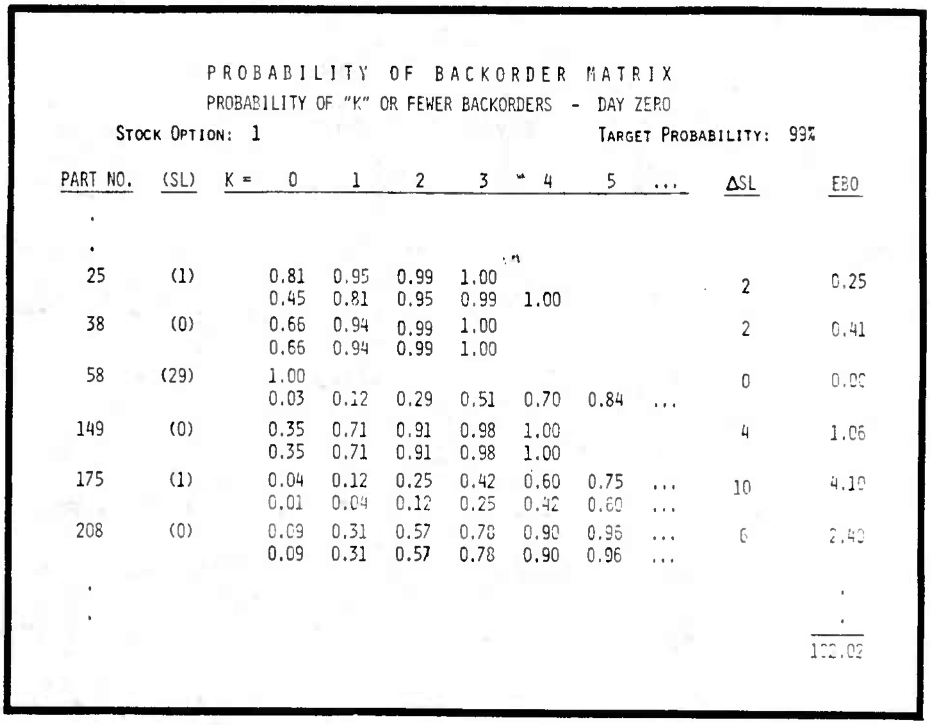
PART NO.	OPTION = 1	2	3	4	5	6	7
. .	.						
. .	.						
.	.						
25	1						
38*	0						
58	29						
149*	0						
175*	1						
200*	0						
.	.						
.	.						
.	.						

*PROBLEM PART.

A matrix of stock level options is input into Vector. We have filled in only the stock option used in this run. The program allows for up to 10 stock options to be stored in the computer. This facilitates analyzing several stock positions quickly since each run can be made using various stock options. We use different stock levels primarily to compare authorized levels versus on-hand or to evaluate the input of future deliveries.

Stock levels are not the same as on-hand quantities. In addition to the number on the shelf, they also include reparable assets in the various pipelines. The total pipeline requirement must be filled from the stock levels represented in one of these stock options. The discrepancies between that requirement and the assigned stock assets we have to fill the requirement may be backorders causing broken aircraft. Vector computes a precise value for expected backorders (EBOs).

CHART 9a: PROBABILITY OF BACKORDER MATRIX



PROBABILITY OF BACKORDER MATRIX

PROBABILITY OF "K" OR FEWER BACKORDERS - DAY ZERO

STOCK OPTION: 1 TARGET PROBABILITY: 99%

PART NO.	(SL)	K = 0	1	2	3	4	5	...	ΔSL	EBO
.										
.										
25	(1)	0.81	0.95	0.99	1.00				2	0.25
		0.45	0.81	0.95	0.99	1.00				
38	(0)	0.66	0.94	0.99	1.00				2	0.41
		0.66	0.94	0.99	1.00					
58	(29)	1.00							0	0.00
		0.03	0.12	0.29	0.51	0.70	0.84	...		
149	(0)	0.35	0.71	0.91	0.98	1.00			4	1.06
		0.35	0.71	0.91	0.98	1.00				
175	(1)	0.04	0.12	0.25	0.42	0.60	0.75	...	10	4.10
		0.01	0.04	0.12	0.25	0.42	0.60	...		
208	(0)	0.09	0.31	0.57	0.78	0.90	0.96	...	6	2.40
		0.09	0.31	0.57	0.78	0.90	0.96	...		
.										.
.										.
										[illegible]

This next matrix is very similar to the last one. The difference is we have adjusted the pipeline probabilities to reflect a stock level to go from the probability of parts in the pipeline to the probability of backorders. Note that the heading on this matrix is slightly different and that the stock option is now listed. Each matrix still represents a single day of the war. Ignore the SL, ΔSL, and EBO columns for a few moments while we concentrate on the probability elements.

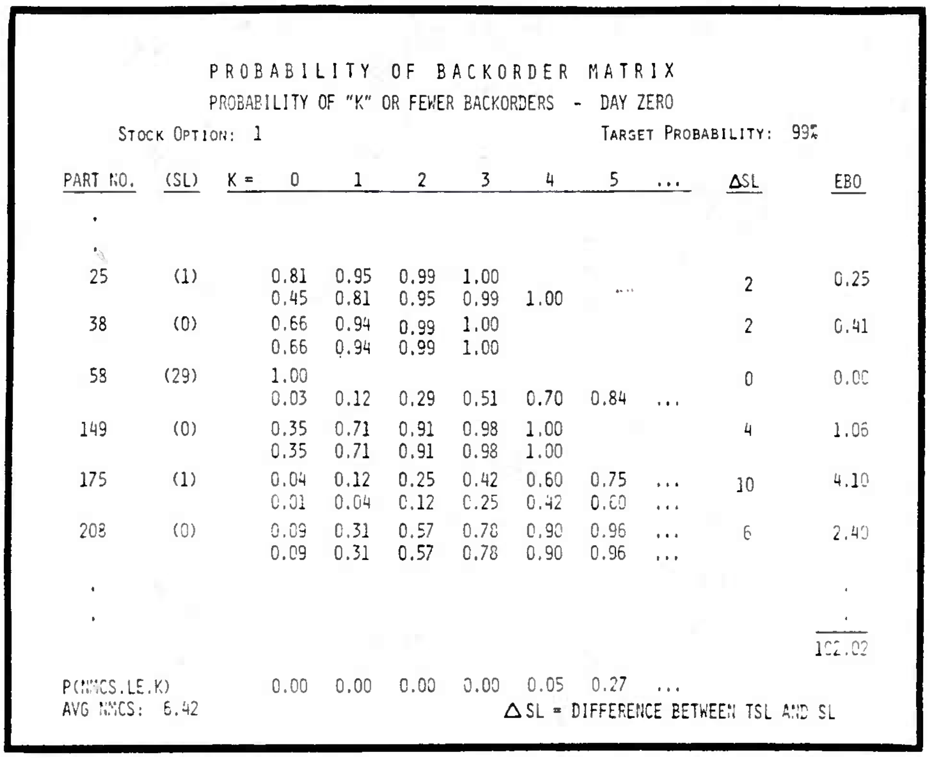
Vector prints one line of backorder probabilities for each part number. We have placed the probabilities from the last matrix beneath in row two of each part to show the relationship between them. It should be apparent that the two rows are identical but one has been shifted. The number of no. 175. The bottom row shows a 0.42 probability that there will a day zero pipeline requirement of four or fewer. Part no. 175's stock level is "1". Therefore, if you look in the upper row, one column to the left, you will see the same 0.42 probability. This time it represents the probability of three or fewer backorders on day zero. Notice that the rows for parts with zero stock levels remain unshifted (part nos. 38, 149, and 208).

From the probabilities of backorders, the average or expected backorders is computed. Vector does this. The results in the far right column labeled "EBO". At the bottom of the column is the total EBOs over the F-16 fleet based on all 254 parts.

So far we have two measures to rate our supply system performance. The first is the difference between SL and TSL (ΔSL) given an arbitrarily selected target probability. This is the additional stock required to achieve your target. Any positive value for ΔSL means you will probably have backorders, however, it doesn't indicate the magnitude except that larger SLs will probably have a greater number of backorders. The second measure is EBOs. Let it be emphasized that target probability and TSL have nothing to do with computing EBOs. All you need to get EBOs are pipeline probabilities and stock levels.

The backorder probabilities on this matrix allow us to compute another performance measure for the supply system. This time, however, the measure is for the whole fleet instead of part-by-part. The next chart illustrates how.

CHART 9b: PROBABILITY OF BACKORDER MATRIX (FLIP)



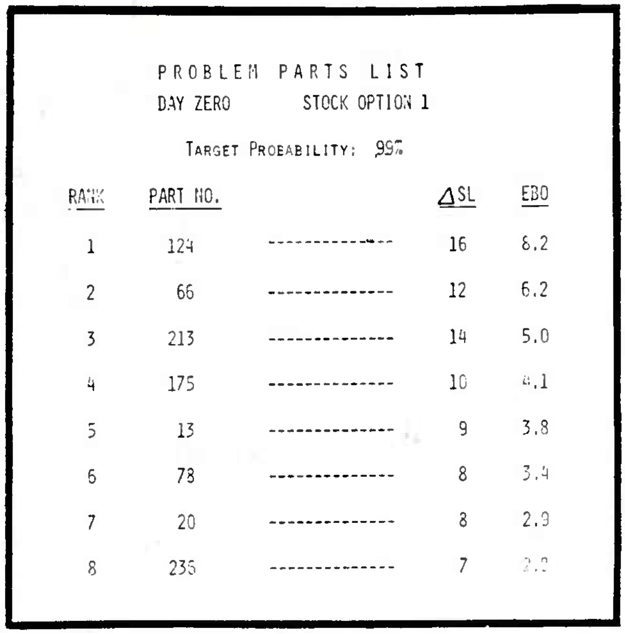
```
                    PROBABILITY OF BACKORDER MATRIX
               PROBABILITY OF "K" OR FEWER BACKORDERS  -  DAY ZERO
      STOCK OPTION:  1                                  TARGET PROBABILITY:  99%

PART NO.   (SL)   K =   0     1     2     3     4     5    ...     ΔSL       EBO
   .
   .
   25      (1)        0.81  0.95  0.99  1.00                          2        0.25
                      0.45  0.81  0.95  0.99  1.00        ...
   38      (0)        0.66  0.94  0.99  1.00                          2        0.41
                      0.66  0.94  0.99  1.00
   58      (29)       1.00                                            0        0.00
                      0.03  0.12  0.29  0.51  0.70  0.84  ...
  149      (0)        0.35  0.71  0.91  0.98  1.00                    4        1.06
                      0.35  0.71  0.91  0.98  1.00
  175      (1)        0.04  0.12  0.25  0.42  0.60  0.75  ...        10        4.10
                      0.01  0.04  0.12  0.25  0.42  0.60  ...
  208      (0)        0.09  0.31  0.57  0.78  0.90  0.96  ...         6        2.40
                      0.09  0.31  0.57  0.78  0.90  0.96  ...
   .                                                                            .
   .                                                                            .
                                                                             ------
                                                                             102.02

P(NMCS.LE.K)          0.00  0.00  0.00  0.00  0.05  0.27  ...
AVG NMCS:  6.42                            ΔSL = DIFFERENCE BETWEEN TSL AND SL
```

Assuming a 100% cannibalization policy, we can take the product of the individual part probabilities to get the probability of having less than or equal to "k" aircraft not fully mission capable, (NFMC). Actually, we can only multiply straight down if the quantity per aircraft (QPA) is "1" for each part. However, if some are other than "1" we still multiply down but shift to the right the appropriate number when encountering a part with QPA greater than "1".

The weighted average of these products is the average (expected) NFMC aircraft for the fleet. For this run the expected number of NFMC aircraft was 6.4. Remember this is peacetime. One of these matrices can be printed for each day of the war. However, Vector only prints the output days you request.

The next six charts take the Vector output and display the data in various ways. All the data comes at least indirectly from this matrix.

CHART 10: PROBLEM PARTS LIST

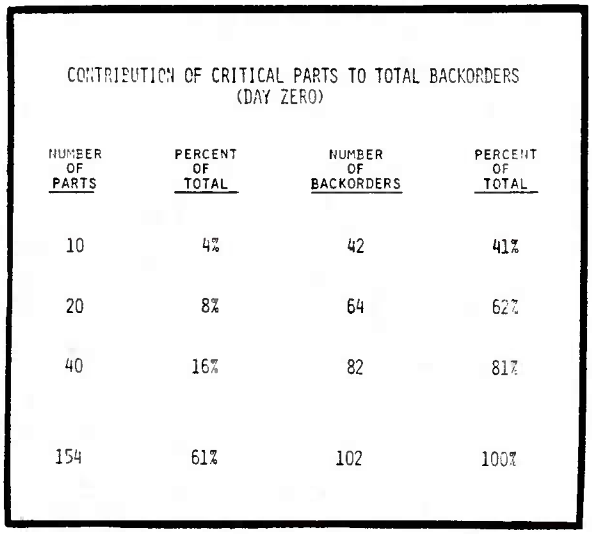


```
              PROBLEM PARTS LIST
              DAY ZERO        STOCK OPTION 1

                  TARGET PROBABILITY: .99%

RANK     PART NO.                         ΔSL      EBO

  1        124      --------------         16      8.2
  2         66      --------------         12      6.2
  3        213      --------------         14      5.0
  4        175      --------------         10      4.1
  5         13      --------------          9      3.8
  6         78      --------------          8      3.4
  7         20      --------------          8      2.9
  8        235      --------------          7      2.2
```

Most of the new analytic programs print out a critical parts list similar to this one. This chart shows parts ranked according to EBOs. You should notice the high correlation in ranking to the other performance measure, ΔSL. This list pertains only to day zero, stock option 1, and a 99% target probability. If any of these three factors change, the rank ordering may change. Also let it be emphasized again that target probability only applies to the ΔSL. It is independent from calculating EBOs.

Observe how quickly the performance measures decline. It is true of many systems that a handful of the elements requires the majority of management's attention (Parado's 80-20 law). The next chart shows how much the critical items degraded the total system.

CHART 11: CONTRIBUTION OF CRITICAL PARTS



CONTRIBUTION OF CRITICAL PARTS TO TOTAL BACKORDERS
(DAY ZERO)

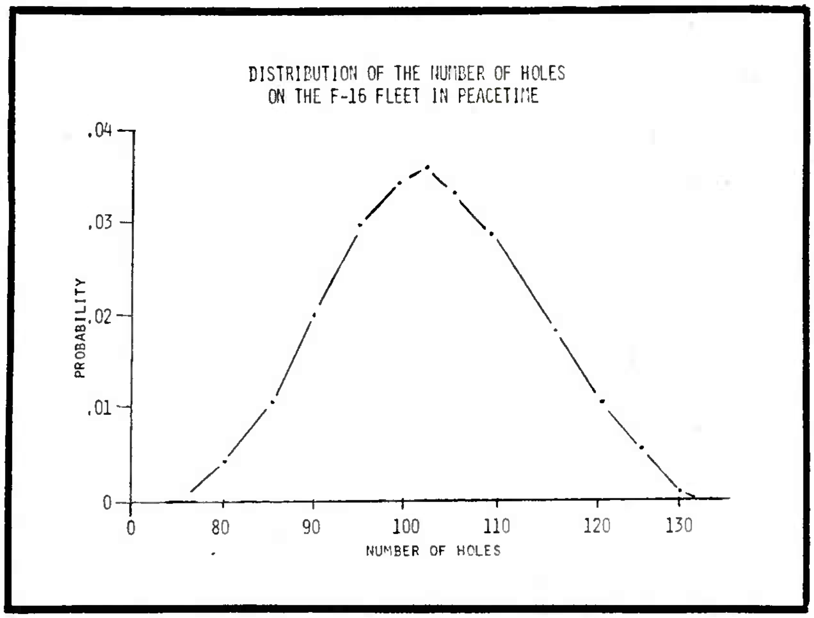
NUMBER OF PARTS	PERCENT OF TOTAL	NUMBER OF BACKORDERS	PERCENT OF TOTAL
10	4%	42	41%
20	8%	64	62%
40	16%	82	81%
154	61%	102	100%

This summary represents day zero performance under stock option 1. For this analysis of an F-16 Wing, 40 of the 254 parts (LRUs) accounted for 82 out of 102 backorders. That is, 16% of the parts caused 81% of the trouble.

Since 154 parts caused essentially all the backorders (102), there were 100 parts that had no backorders. Thus we have 40 "bad actors" causing 81% of the backorders, 114 fairly "well behaved" parts causing the remaining 20% of the backorders and 100 that are no problem at all.

So far we have concentrated on looking at individual EBOs. The next chart shows the EBO status over the entire F-16 Wing.

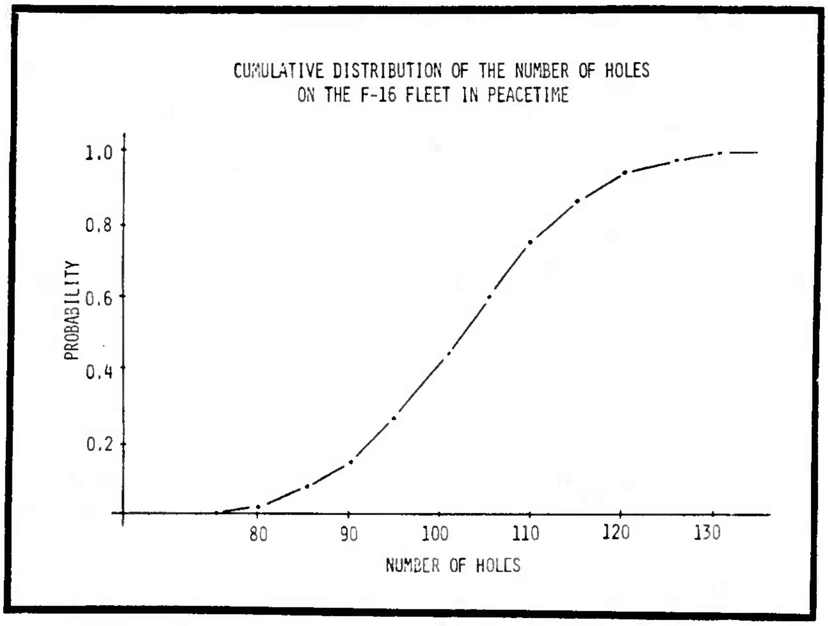
CHART 12: DISTRIBUTION OF BACKORDERS



This chart is a point probability distribution of the total number of EBOs (holes) over the F-16 Wing during peacetime. The highest probability is for about "102" backorders which is the total of all the EBOs. Nevertheless, there is a slight chance (probability) that the total EBOs would be only 80. Similarly there is a slight chance that the total EBOs would be 130. This chart then graphically bounds expected performance. Notice that the probability for any specific value is quite small.

Often it is helpful to look at the cumulative probability distribution rather than the point probabilities. Here is how they look.

CHART 13: CUMULATIVE DISTRIBUTION OF BACKORDERS

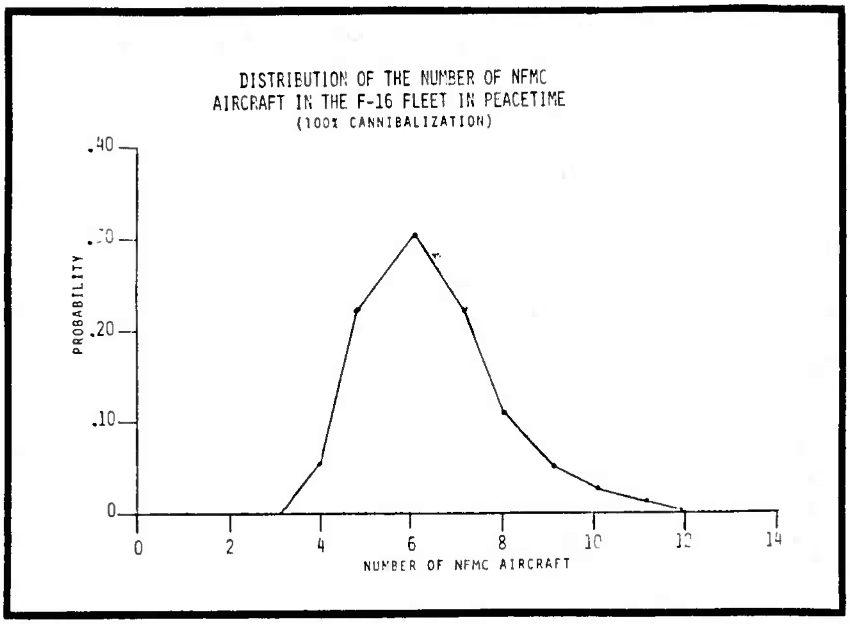


Again, the data is for day zero using stock option 1. The axes are the same as the last graph--backorders on the horizontal axis and probability on the vertical axis.

The graph shows the probability of less than or equal to the number of backorders shown on the horizontal axis. It is again evident that the number of fleet backorders will probably not be lower than 75 and not higher than 135.

The next chart addresses the third performance measure -- the number of NFMC aircraft.

CHART 14: DISTRIBUTION OF NFMCS AIRCRAFT



Under a 100% maintenance cannibalization policy, this graph shows the peacetime point probabilities of NFMC aircraft. The spread is from about three NFMC aircraft to about twelve. The most likely or average number of NFMC is 6.2.

Because 100% cannibalization is optimistic (if not impossible), these figures are the best we could hope to do in peacetime. In reality our NFMCS would be higher. This applies to the next chart also.

Until now we concentrated on peacetime processing and output. The next and final chart is a summary over all thirty days of the war.

CHART 15: WARTIME PERFORMANCE

WARTIME FLEET PERFORMANCE

STOCK OPTION 1

DAY OF WAR	AVERAGE BACKORDERS	AVERAGE* NFMC
0	102.0	6.4
5	231.1	10.4
10	230.8	12.5
15	276.0	12.0
20	273.2	11.9
25	289.2	12.4
30	308.3	13.0

*UNDER 100% CANNIBALIZATION

This chart shows how the supply system might perform during a short war using stock option 1. The backorders rise quickly along with NFMCS aircraft. The supply system begins to perform a little better after the wartime surge terminates on day ten. However, both backorders and NFMC aircraft begin to rise again after day twenty due to the complicated dynamics associated with long order and ship times from the depot.

SUMMARY

The Vector model developed by PACAF provides a useful advancement in our ability to quantify the impact of spares shortages and repair delays. It provides detailed matrices which show what's happening on a part-by-part basis.

- The 100% cannibalization assumption is the best use we can expect.
- 20% of the parts cause 80% of the problem.
- EBOs and NFMC aircraft are averages.

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