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REPARABLE ITEM SUPPLY-READINESS ASSESSMENT USING MICAP DATA

MAY 1984



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The report concludes that although pipeline models beginning with break rate and repair time data may have a place in the analytical world, readiness assessments in this way have not proven correct as presently implemented. The Supply Readiness Diagram is a much more reliable and simple technique for readiness assessment.

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MAY 1984

PREFACE

This paper was written in early 1983, over a year ago, and distributed in "draft" to a fairly large group of researchers and practitioners working with dynamic pipeline theories. Much of the material had also been presented at the Second Annual Logistics Capability Assessment Symposium held at the USAF Academy, the 50th Military Operations Research Symposium held at the US Naval Academy, and the Seventh Airpower Symposium held at the Air University.

The ideas in the paper were somewhat new and, it turned out, controversial. The Dyna-METRIC model, developed by the Rand Corporation, was being widely implemented, courses were being set up, and numerous officers were being schooled in its application. We, in effect, said: "Whoa! It gives wrong results insofar as it is used (with its 'standard' data base) to predict the readiness of a Tactical Fighter Wing." Various respondents raised many questions, many of them just semantic; but we tried to respond in all cases and held off on going public while we checked out some additional aspects. That didn't take a year, but the press of other projects caused the manuscript to languish, a procrastination which could be rationalized by saying that most of the key players had been informed of the content. Nevertheless, the time has come to publish a "for the record" copy and make it more broadly available.

We have found little reason to change our original text, although minor editing has been done. We want, however, to make our caveat with regard to semantics. In the report, our words tend to link the model (Dyna-METRIC) and its data base and treat them as an entity. To the extent that the term Dyna-METRIC refers to the present computer programs implemented within the Air Force and to the extent it requires a specific set of data (which may be flawed in many ways), we think the shorthand phraseology is justified. To those who want to use the term Dyna-METRIC to refer to general dynamic pipeline theory, all future computer programs based on that theory, and to all possible improvements in the data bases to support the programs, or to just the computer model itself excluding the data base, our usage will seem narrow. The reader may choose as he wishes. We hope our intent will not be misperceived: we are dealing only with present implementations and their data bases and have "arbitrarily" treated them as a package. We trust the reader will be sophisticated enough to separate the model and the data if he feels a need to do so. We will reserve our judgments on future implementations and their data bases until they appear on the scene as actual or proposed implementations.

ABSTRACT

This paper serves two main purposes and several minor ones. The dominant theme arises out of our continuing search for techniques to assess combat readiness of tactical fighter wings with regard to the supply support they are provided. How can we make that assessment economically, effectively, and correctly? We have recently found a framework -- the so-called Supply-Readiness Space -- within which it is relatively easy to portray the detailed supply picture for repairable parts and show how the picture changes as dynamic shifts occur in stock levels, sortie rates, and repair times. The first objective, to which we devote considerable space, is explicating the properties of the S-R Space so that it may be used in the second objective of the report, namely to show that the peacetime condition of a Wing may be estimated and portrayed in the S-R Space through a novel use of routinely collected MICAP data. The initial data points when coupled with a full understanding of S-R Space dynamics, permit an easy-to-obtain understanding of combat capability projection for the Wing and, of course, its limitations.

The prevalent technique for readiness assessment for the past several years has been the computer model named "Dyna-METRIC," which has been developed by the Rand Corporation. The model requires a great deal of input data which has been generally obtained from the D029 data base. The data base is relatively static, for it is updated only annually. Both Dyna-METRIC and MICAP estimates meet in the S-R Space so the question inevitably arises: Do they give the same results and lead to the same conclusions? We show data for two tactical fighter wings which compares the two approaches. The results are clearly, even dramatically different.

In our present tentatively held views, the MICAP approach directly captures influences and factors which Dyna-METRIC does not and does so by using a more economical, time-sensitive, and accurate data base than D029. The report comments at some length on possible reasons for the different results and suggests still others which need to be researched.

It is obviously important to make a correct judgment on which is the best way to pursue readiness assessment in the future: MICAP estimates, Dyna-METRIC, or both? The Air Force Logistics Command has been moving ahead at full speed for the past year in developing Dyna-METRIC as the centerpiece of their very important and much needed Combat Analysis Capability. Our results, as reported herein, were briefed to AFLC as soon as they were obtained and AFLC has been continually updated ever since. They intend to implement the estimates we propose in parallel with Dyna-METRIC and continually to assess their relative merits and contributions.

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I. BACKGROUND AND INTRODUCTION

Dyna-METRIC, developed by the RAND Corporation, is a contemporary computer model that is becoming more and more widely used in logistics studies throughout the Air Force. It was designed and is used to predict the probability distributions of aircraft reparable spares in the repair pipelines when the spare-part demands and the repair process are functions of time. A transition from a low-flying to a high-flying rate could occur, for instance, when a Tactical Fighter Wing goes into a wartime surge after pursuing a less intense level of peacetime training flying. The repair of the broken parts also may be sped up when the surge begins, making it, too, a time-dependent process. By knowing the distributional properties of each of the several hundred kinds of reparable parts (NSNs) that go into a fighter aircraft, an analyst can in principle obtain many kinds of useful information:

- (1) On the planning side, the model can process estimates of future break-rate and repair-time data to determine the probability, NSN by NSN, that a given stock level for each NSN will be adequate for a specified wartime flying program. Clearly, this kind of information permits the design of an "authorized stock" that will meet the needs of a combat scenario to whatever level of "insurance" is desired.
- (2) Another use of the model lies in exploring ways to improve the responsiveness of the repair system itself and to express the benefits in terms of reduced number of "holes" in the supported Wing's aircraft.
- (3) Yet another application of Dyna-METRIC has been readiness assessment based on availability of reparable item stocks. Using the break-rate, repair-time, and actual owned stock data of a Wing, the probabilistic statements that can be made about stock adequacy provide a means of assessing how well the Wing can do under various scenarios.

The validity of each of the above applications depends on how well the model and the data that drive it produce valid and useful results. If the model fits what goes on in the real world of supply and maintenance, if its underlying assumptions are met, and if the large amount of data it requires are accurately and correctly obtained, then its output and the inferences based on that output should be useful indeed.

While developing a PACAF-unique model built on the same precepts as Dyna-METRIC and while using Dyna-METRIC itself in numerous applications, we continually have revisited the critical questions:

- Does the model fit the circumstances being studied?
- Are the underlying assumptions met?
- Are the input data correct?

We have found no broad and easy answers. Nevertheless, we have felt reasonably comfortable in using the model for some planning applications, for some functional behavior discussions, and for some parametric explorations. We have always felt least comfortable about using Dyna-METRIC in readiness assessment applications simply because our answers to these questions have to be hedged. Of them all, we worry most about the validity of the data base in readiness assessments.

Most present-day applications of Dyna-METRIC within the tactical air forces (TAF) draw on a worldwide data base used in D029--the process which is used for determining War Readiness Supply Kits (WRSK) or Base Level Self-Sufficiency Spares (BLSS) to be used in wartime.

That data base is itself derived from another--D041. Each data compilation contains huge amounts of information. To run Dyna-METRIC for a PACAF unit, for instance, requires the following data:



INPUT DATA

FOR THE WING:

- A FLYING PROGRAM
 - PAA
 - SORTIE RATE (BASED ON CALENDAR DAYS)
 - SORTIE DURATION

FOR EACH OF 302 NSNs:

- INITIAL STOCK LEVEL
- AVERAGE DEMANDS PER FLYING HOUR
- PROBABILITY OF BASE REPAIR
- REPAIR CYCLE TIME IN BASE REPAIR
- PROBABILITY OF CIRF REPAIR
- ADMINISTRATIVE AND ROUND-TRIP TRAVEL TIME TO THE CIRF
- REPAIR CYCLE TIME AT THE CIRF
- PROBABILITY OF BEING SENT TO DEPOT FOR REPAIR
- ADMINISTRATIVE AND ROUND-TRIP TRAVEL TIME TO THE DEPOT
- DEPOT REPAIR CYCLE TIME
- QUANTITY PER AIRCRAFT

We have in PACAF four different kinds of fighter aircraft, each of which must have its own data base. Estimating each input quantity for each NSN is no trivial task. In many cases the spare-part demands occur infrequently, giving rise to a severe sample-size problem which makes the estimates very uncertain. Many of the data items are neither routinely nor easily available from standard reporting systems and are often estimated by small-sample peeks or, even more blatantly, assigned "nominal" values. Depot "Order and Ship times" in our PACAF data base, a very important set of numbers, it turns out, are almost all nominal values. Collecting all data into a worldwide base can, to some extent, ameliorate the sample-size problem by combining data from PACAF, TAC, and USAFE. That process, however, wipes out PACAF-unique information, or USAFE-unique information, and treats each as a hybrid. The break-rate data are based on 15-month running averages, again in the interest of gaining a larger sample-size, again at the cost of hiding late-breaking trend information. Aside from the formidable problems of estimating the needed data from small samples, just plain old errors also occur. In our own experience with developing and using Dyna-METRIC data bases, we have found that the underlying information may

be routinely reported but there is little, if any, continual attention given to error-detection, cross-checking, and auditing that is needed to produce a valid data base.

All of the potential limitations, to whatever extent they exist, can be tolerated for some applications more than others. In planning for WRSK and BLSS, we need to look at least a year ahead and do so on data which may be a year old. We may not like it, but there is no alternative. And the results even may not be too bad. The uncertainties of the future and the details of the actual scenario are large enough so that the data base uncertainties are considerably mitigated. Of even greater comfort when designing a WRSK or BLSS is the sure knowledge that the stochastic nature of demands will, in the actual event, really determine whether a kit measures up or not. Finally, the inherent flexibility of a tactical fighter wing can make up shortfalls by cannibalization in the near term, and one can hope that logistics crisis management will respond to the really bad errors in the longer term. In any case, the planned (i.e., authorized) levels of stock are set high enough so that a stock "disaster" is not very probable. Whatever problems are caused by prediction errors are pretty much swamped out by the insurance stock that is allotted. Consequently, when Dyna-METRIC is used in planning/design applications, it operates in a context which assumes that all parts will be well behaved, that the design levels of stock will be made available to the Wing, that the "insurance" levels will cover most estimating errors, and that logistics crisis management will deal with others.

In readiness assessment, on the other hand, we do not necessarily deal with well-behaved systems that function according to planning data. The real-world of supply which we are trying to assess is filled with maverick

NSNs which for one reason or another do not behave as planned. The mavericks, as one would expect, are the ones that greatly influence a Wing's overall readiness. Consequently, any scheme pretending to readiness assessment must focus on the maverick NSNs, not on the well-behaved ones. There is, at the very least, a reasonable doubt as to whether a worldwide data base that is based on long-duration running averages and is updated only once a year contains relevant and timely information on the maverick parts.

Our going-in assumption for the past several years has been that the D029 data base is inappropriate for readiness assessment. But how to test its adequacy or inadequacy has long eluded us.

Recently, however, we have been exploring ways of presenting Dyna-METRIC results in comprehensive, easily understood ways. Some early results were presented at the Air University's Seventh Airpower Symposium on 1 March 1983, held at Maxwell AFB, and at the 1983 Logistics Capability Assessment Symposium on 16 March 1983, held at the US Air Force Academy (ref 1). As often happens, a new way of looking at model outputs can trigger a new approach to getting the same information. In the present case, we recognized that Dyna-METRIC outputs for peacetime could be independently estimated from the MICAP data base. Each method of making the estimates is equally valid theoretically; and if the two data sets are consistent (and the model correct as well), they should give the same results. Thus, we have found a way of "testing" the Dyna-METRIC (DM) model/D029 data base in a readiness-assessment role. In a portion of the remainder of this report, we will show extensive data which says that DM/D029 fails the test.

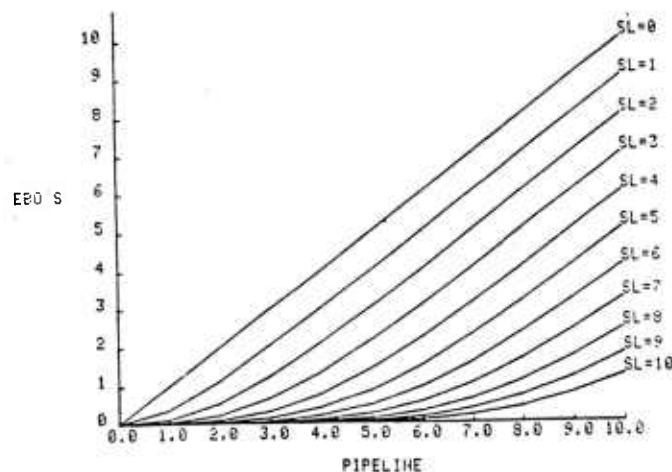
In a fundamental way, however, the development of Supply-Readiness (S-R) Space as a framework to portray and assess readiness is a more

important result than the mere testing of DM/D029. That test is just analytic fallout in the process of searching for better models. Within the S-R space, it is easy to visualize all of the principal behavior of supply that is captured by Dyna-METRIC. The S-R space makes it quite easy for those who set policy and make decisions to get a comprehensive and detailed grasp of what is going on and asks the right questions about real-world manipulations of the the supply process. Equally important, theoreticians and all those who would improve existing models can use the S-R space with good effect in posing various tests or modeling alternatives. A number of these issues are also touched on in this report.

II. THE SUPPLY-READINESS SPACE

The framework within which we will eventually compare the D029 and MICAP data bases is the diagram shown in Figure 1 below. It is also a convenient framework for portraying all the principal results of the DYNAMIC METRIC model.

Figure 1
The Supply-Readiness Space

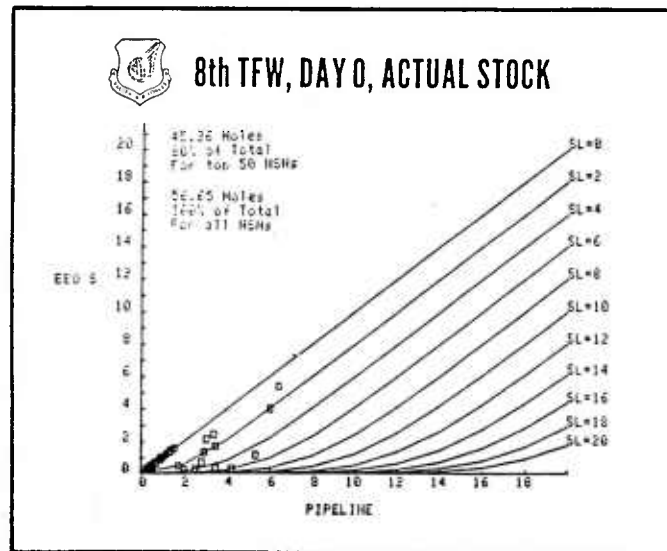


The name S-R Space is perhaps a little pretentious, but it's the best we've come up with and it does describe what we're up to.

In order to draw the space -- i.e., draw the curves showing the relationship between expected pipeline quantity (EPQ), stock levels (SL), and expected back orders (EBO) -- we need make only one assumption. That assumption is that the number of each NSN in the repair line is described by a Poisson distribution. A more detailed elaboration in Appendix A shows inter alia that the Poisson assumption, itself, is not very important in the region of interest.

Since the Dyna-METRIC model itself intrinsically asserts that pipeline quantities are Poisson distributed, it follows that the output of any Dyna-METRIC model run can be plotted in the S-R space. One such plot is given in Figure 2. Each NSN, i.e., each repairable LRU, is plotted according to its EPQ and SL coordinates. The EPQ for each was determined by a Dyna-METRIC run, and the SL was extracted from PACAF reports. The Dyna-METRIC input data were taken from the extant D029 data base. Day 0, in our terminology, refers to a steady-state, peacetime training flying program of 0.6 sortie per PAA per calendar day. We have shown only the top 50 highest-EBO parts in the interest of clarity, although data were available for 302 LRUs. All those not shown have EBOs less than all that are shown.

Figure 2



Each of the fifty NSNs plotted is in some sense a bad actor. To so label them, we should say what constitutes a good actor, i.e., a well-behaved part. An EBO of 0.1 -- which at the scale shown is hard to distinguish from

the X-axis itself -- implies a stock effectiveness of about 90% if by stock effectiveness we mean the percentage of times a request for the NSN is filled by the stock clerk. A stock effectiveness of 90% is a reasonable objective for each NSN but is not at all high. An EBO of 1.0 implies a stock effectiveness of 50%...which is clearly poor performance...and says the stock is inadequate to the Wing's needs.

The picture portrayed in Figure 2 is not a favorable one, especially when one recalls that it represents peacetime training flying for a 48-PAA wing and that the SLs are the combined POS and BLSS levels. Altogether the DM computation predicts nearly 60 holes in the Wing's assigned aircraft due to unavailable parts. Were cannibalization prohibited, almost every aircraft would have a part missing, for parts generally break only when aircraft are flown and multiple breaks are not all that common. Obviously the consequence of a no-cann policy would be an intolerable NMCS rate. So cannibalization must be a way of life in such a Wing. In an actual Wing, enough cannibalization is done (if possible) so that sufficient aircraft are available to produce adequate sorties for the flying training schedule. If the Wing is also determined to get as many aircraft into a mission-capable (MC) condition as possible -- as could be its goal in wartime -- it will attempt to cannibalize until it is not possible to reduce the NMCS status of its fleet any further.

The minimum NMCS condition occurs when all of the holes have been moved into the "smallest" group whose size is determined by the one NSN which creates the most holes. There is no way to fill a worst-part hole without creating another hole. If we think of the group of worst parts as stochastically competing with each other to determine which NSN gets the worst part title, it will usually turn out that there's not much of a

contest. The NSN which is just a little worse than the others usually wins. (See Appendix B.) It's therefore easy to tell from the S-R diagram which NSN will be the dominant bad actor: it is most probably the one with the highest EBO expectation. If there are several NSNs having about the same EBO values, one or another will win; and the computed expected NMCS will be a little higher than for any of them alone.

Although the worst part sets the lowest NMCS that can be achieved, the Wing may not choose to strive for that lowest NMCS value, or may not be able to reach it for want of manpower to do the cannibalizations. Even so, the goal to which the Wing can aspire is still a useful analytic construct. We call it the minimum-bound (or min-bound) NMCS or occasionally, following RAND terminology, the NMCS (100% cann).

From Figure 2, then, we get at a glance:

- o The total number of holes
- o The one NSN (or small set of NSNs) that determines the min-bound NMCS
- o The value of the probable min-bound NMCS
- o A good feel for how much an individual NSN's stock level must be augmented to move it out of contention for "worst actor". (Adding stock moves the point vertically to a new SL curve.)
- o How many are left to be dealt with when the worst bad actors have been fixed.

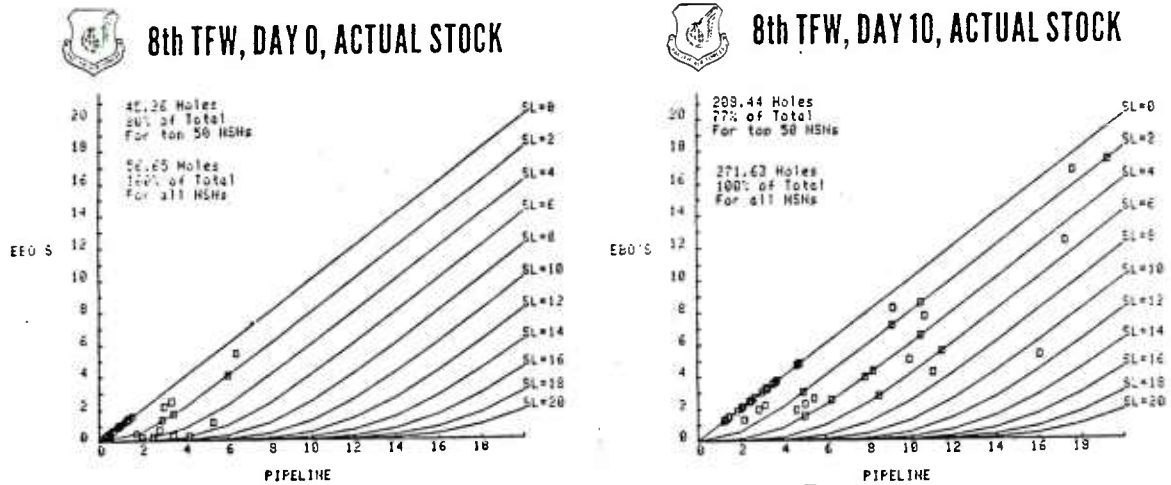
We can also obtain an estimate of how many cans per day are required to keep the NMCS at or near its minimum bound.* Nevertheless, it is important to judge whether a Wing can do the necessary cans if one is trying to gauge whether it can produce its sortie objective.

*Note added (May 84): The subject of estimating cannibalization from the same kinds of data used by DM turned out to be a very large subject in its own right. A thorough treatment has been worked out and a separate paper has been written.

Well, that pretty much portrays the major results of a Dyna-METRIC run and shows with considerable clarity the overall driving factors and NSNs that determine the unit's stock adequacy.

It doesn't show, in the single diagram, what happens when the Wing goes into a combat surge. That can be done by making another Dyna-METRIC run to determine the EPQs, NSN by NSN, for the surge day in question and to plot them. Figure 3 shows such a plot for Day 10 of a 3.0* surge, and also repeats the pre-surge data for ease of comparison. The holes have skyrocketed up to about 270 and the min-bound NMCS has moved up to the neighborhood of 20 (in a 48-PAA wing!). The dominant part may be determined just as before.

FIGURE 3



Up to this point, we have done nothing but plot Dyna-METRIC outputs, NSN by NSN, and give a simple rule for determining the min-bound NMCS. Has that moved us ahead? Yes, to some extent. The picture of how the NSNs

*3.0 sorties per aircraft per day.

look relative to one another is useful, as is the sense of how much stock is needed to improve each NSN.

To move ahead and free ourselves from total reliance on the computer, and on the D029 data base, we take two more steps:

- o The first is to describe the dynamic movement of the plot as we move from peacetime through a surge operation, and to do it without an extensive data base or computer manipulations.
- o The second is to find an alternate method of estimating the S-R plot for the peacetime critical parts.

When these two steps have been accomplished, we will essentially have all the insights obtainable from the model without having to run a computer to process all that data.

III. S-R SPACE DYNAMICS

This section will develop a few simple, easy to apply rules-of-thumb for estimating how each NSN's point moves in the S-R Space when the stock levels and the demand/repair process are perturbed. The perturbation could be due to a sudden increase in sortie rate as was illustrated in the pages just past; or it could be due to a change in the repair times for some NSNs, possibly higher, possibly lower; or due to changes in the break rates for some NSNs. We could make a Dyna-METRIC computer run for parametric variable changes, but it is far easier and far more powerful to understand what happens functionally to the results as the inputs change. The rules set out below help us fully understand what happens and even why it happens. The results are somewhat approximate, but judgments rarely require precise numbers as such.

In giving the rules-of-thumb below, we concentrate on stating them simply and defer technical discussion to Appendix A.

Rule 1: Changes in Stock Level

Adding to or taking away stock causes the NSN's point to jump along a vertical line through the present EPQ.

Rule 2: Changes in EPQ

When the EPQ changes, with the SL constant, the point for the NSN is constrained to move on its constant SL "track".

Other than stock level changes, all other perturbations cause changes in the pipeline quantity. In each case, whether the change is due to sortie rate, to a different break rate, to an improvement (or worsening) of the repair time, the EPQ will eventually stabilize at a new value after

a long enough time. We will soon discuss how long "long enough" is, but first we estimate the new value of the EPQ.

Rule 3: Estimating A New Stationary-State EPQ

The eventual final value of the EPQ is proportional to the initial value and to the ratio of the parameter change that caused the perturbation:

Example: Sortie rate is doubled.

$$\text{Eventual EPQ} = \text{Initial EPQ} \times 2$$

Example: Repair cycle time is cut in half.

$$\text{Eventual EPQ} = \text{Initial EPQ} \times 1/2$$

(Note: If both changes occurred concurrently, they would cancel each other.)

The question arises: How long does it take for the pipeline to settle down to its new "stable" value? We use the term "settling time" to denote the duration of the transient period. The value of the settling time depends upon the pipeline dynamics and thus may be different for each NSN. An NSN repaired on base with an RCT of 3 days has a settling time of 3 days approximately; an NSN repaired at the CIRF (10 day RCT) has a settling time of 10 days approximately; if it is repaired partly at the base and partly at the CIRF, it will settle in two steps, first at 3 days and finally at 10 days; and so forth. Without introducing excessive error, one can use an overall settling time between the two, about in proportion to the fraction repaired at each. A proportional rule such as this one is no trouble to apply, but it does require additional information about each NSN -- an estimate of the settling time.

Rule 4: Changes in Pipeline During Transient Period

At intermediate times during the transient period, the EPQ moves from its initial value toward its final value proportional to the ratio of "time into the transient" divided by the "settling time."

Applying all these rules is easy: Pick the initial EPQ; estimate the eventual "stabilized" EPQ from rule 3; estimate the EPQ for the time in question by moving along the interval between the initial and eventual EPQs proportional to the ratio of the time-into-the-transient vis-a-vis the settling time.

When one is looking at an S-R diagram, it is almost no trouble at all to form a mental picture of what will happen to the NSNs as external forces act on the supply system. Precision is rarely needed when the objective is to think your way through a potential change in the supply system. By understanding and applying these simple rules of supply dynamics in the S-R space, we are able not only to discuss and define supply problems in cogent ways, we can also come pretty close to the answers. In a very real way, the S-R space provides the constructs to define in simple terms some pretty complex problems.

An example of such an application is the following demonstration that leads to a conclusion important enough to call a principle. The statement is so obvious in S-R space terms that it becomes almost self-evident.

Principle: The only NSNs which can seriously hurt the readiness of a Wing are those with high pipeline quantities.

First, we note that a zero SL creates the worst case for causing EBOs. (It's the "highest" SL line along the EBO scale.) Second, we note that EBOs are never greater than the corresponding EPQ, and therefore low EPQ items are necessarily low EBO items. If there are a lot of these, they do contribute to the total number of holes in the Wing's aircraft and are therefore irritants in that they increase the number of cans that need to be done. Even so, they never individually become dominant and determine the min-bound NMCS which ultimately limits the unit's combat capability. In

pursuing these lines of thought, we are led to another observation which we also elevate to the principle level.

Principle: The dominant NSNs in a surge are those which have high peacetime EPQs.

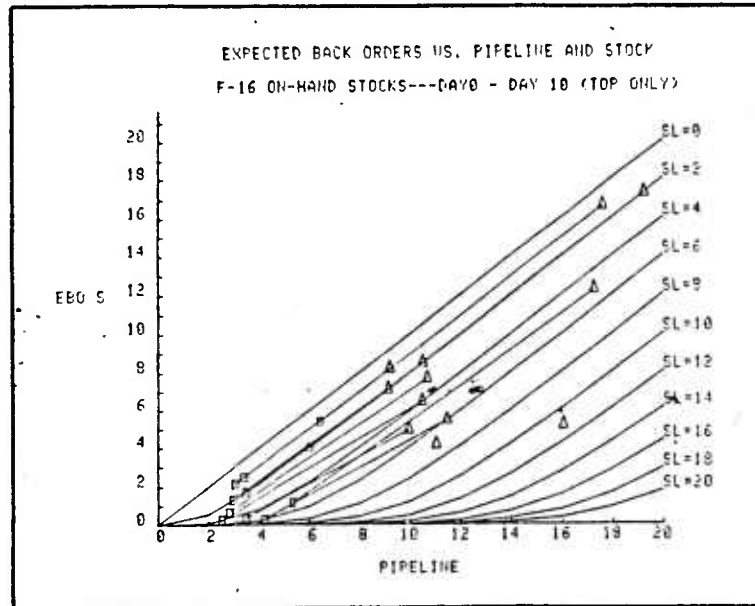
Because of Rule 2, high EPQ NSNs enjoy a kind of multiplier effect over low EPQ NSNs. As a parallel to the old saying "the rich get richer," the supply analogy during a surge is "the bad ones get badder"...and emphatically so! Suppose that the data are such that the EPQ for an NSN doubles during the surge. If the EPQ was 10 to start, it becomes 20; and if the EBO value is in the straightline portion of the track, the surge will add 10 more holes. If the EPQ had been only 2 at the start, it would move only to 4; and, even though doubling, the "holes" will at most increase by 2. Thus, the multiplier effect leads us to concentrate a lot of attention on high EPQ parts when we're assessing readiness simply because they are the ones with the greatest potential as troublemakers.

This can be seen in Figure 4 where the two charts of Figure 3 have been combined to illustrate the above effects. The initial plots (peacetime, 0.6 sortie rate) are shown by the squares, and the surge plots (day 10, 3.0 sortie rate surge) are shown by the triangles. Each member of a pair is connected to the other.

The group of points in the region of 3-to-4 EPQ transforms into the points lying in the range of 9-to-12 EPQ. The group with an EPQ around 6 moves into the group with EPQs from 18-to-20. (We show here only the top 12 NSNs to keep the diagram uncluttered.) The ratio of EPQs in all cases is about a factor of 3. All of these NSNs are predominantly repaired at the depot (RCT and settling time approximately 22 days); although a portion are repaired at the CIRF (settling time approximately 10 days) for an overall

average repair time for each of about 20 days. Hence, the EPQ grows by about a factor of 3.

Figure 4



Aside from illustrating the rules-of-thumb and the surge dynamics, we could also recognize here that the depot response shapes the 8TFW min-bound surge NMCS almost completely. Local- and CIRF-repaired NSNs are not among the critical ones.

The two triangles without an "origin" illustrate the caveat we made earlier. We had limited the tables from which these plots were made to the "top-50" troublesome NSNs. The two triangles were plotted without an origin because they weren't in the top 50 before the surge began . . . yet here they have moved into the top 12. This illustrates again the multiplier effect. These two NSNs had enough stock (POS & BLSS combined) to be benign under the peacetime flying rate, although they must have been marginal. Nevertheless, they were active; and under the additional

stress of the surge, the pipeline quantities went way above the available stock. Even though in this instance they did not dominate the overall picture -- the two NSNs that determined the min-bound NMCS in peacetime stayed dominant through the surge -- it didn't have to be that way. Consequently, when assessing a Wing's ability to support a surge, we must be especially concerned with high EPQ parts whether they cause large peacetime EBOs or not.

IV. AN ALTERNATIVE METHOD OF ESTIMATING PEACETIME S-R PLOTS

Now that predicting how points meander in the S-R space is well in hand, we turn to the second task: How to estimate the peacetime S-R plot for a real-world unit without using the Dyna-METRIC model and its associated large data base.

To get an estimate of the peacetime S-R plot, we recognize that it can be obtained either:

(1) By plotting EPQ versus SL and letting the EBOs fall where they may, as happens when Dyna-METRIC models calculate the pipeline quantities (which is what we have done up to this point) or

(2) By estimating the EBOs directly from existing MICAP data (the estimated EBO along with the SL lets us place a point for each NSN in the S-R space)

The EPQs then fall where they may. Which we choose to estimate, EPQ or EBO, is just that -- a matter of choice. We may make the choice according to whatever criteria appeal to us. In the present instance, we prefer estimating EBOs to estimating EPQs because it is simpler to do and the data which we need are much more accurately kept and reported.

A moment's reflection will make it clear that if a unit keeps a careful monthly record of the hours each NSN causes 0, 1, 2, . . . holes in aircraft (and calls the sum the MICAP hours), the average number of holes for the month caused by that NSN is given by

$$\text{EBO}(\text{NSN}_i) \text{ estimate} = \frac{\text{MICAP HOURS FOR THE MONTH for NSN}_i}{\text{HOURS IN THE MONTH}} .$$

This estimate, in principle, is in no way inferior to that obtained by the laborious and detailed pipeline calculations of Dyna-METRIC. If

both sets of data were consistent, equally valid, and the model correct, they would have to give the same end result. If they do not, we must choose between them on the basis of judgments concerning which is the more fundamentally correct and accurate predictor.

Many readers will already have noted that we can't use the MICAPs as an estimator for EBOs for NSNs which don't produce MICAPs. This process can't be used, then, to make estimates for every part . . . and that is required when developing WRSKs and BLSS. The Dyna-METRIC process or some alternative pipeline estimator is then the only recourse.* But when assessing readiness is our objective, it is the MICAP parts that dominate and all the others are of little or no interest. (As with most firm statements, this one needs a caveat: Certain high-activity NSNs which have marginally adequate stock levels in peacetime can rise to dominance after an extended period of surge flying. The previous section on S-R Space dynamics has conditioned us to be alert to all high activity parts.)

*The process can be extended to include parts which cause no MICAP hours yet draw from resources beyond POS, such as the WRSK or BLSS. These parts can be identified in MICAP data by their large number of WRM withdrawals. For these parts, an estimate of EBO can be obtained by comparing total stock levels with estimated pipeline quantity. In this case, pipeline quantity must be estimated from supply data (add up due-ins from maintenance, other due-ins, units awaiting parts, units in transit, etc). This value of peacetime EPQ can then be used for extrapolations to surge conditions.

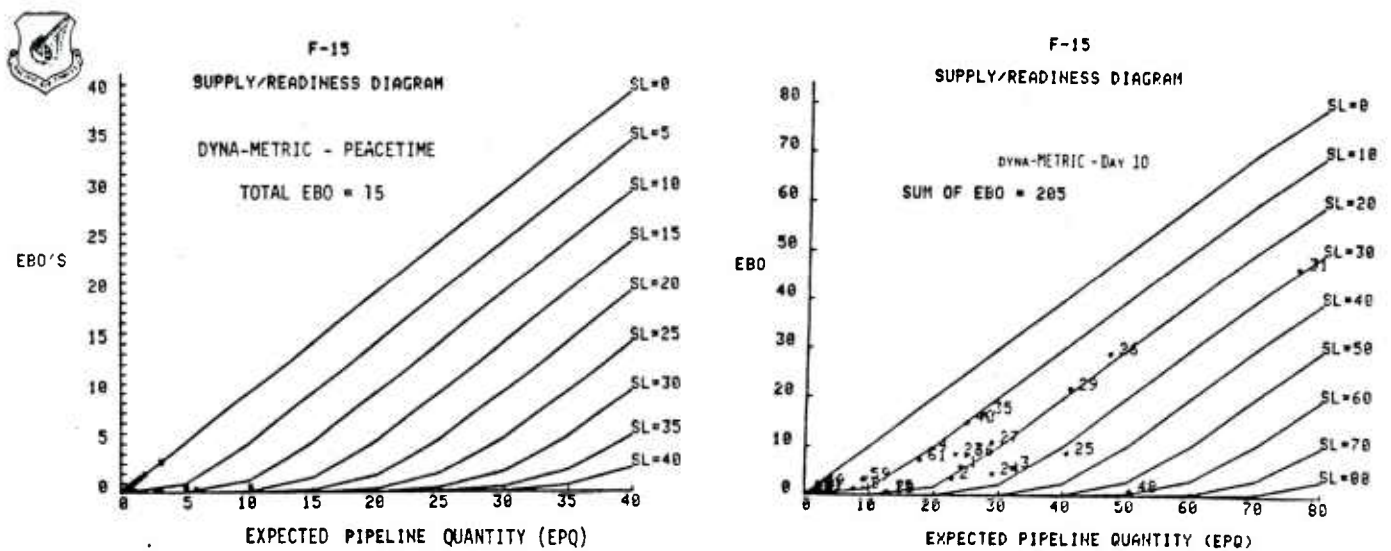
V. A COMPARISON OF DYNA-METRIC/D029 RESULTS WITH MICAP ESTIMATES OF EBOs [18th Tactical Fighter Wing (18TFW)]

In this section, we will contrast the Dyna-METRIC/D029 plots in the S-R Space with those alternatively obtained by estimates based on MICAP-hour data. Observing that they paint very different pictures, we then explore some reasons for the differences.

A. 18TFW Supply Readiness Assessment from DM/D029

Figure 5 shows Dyna-METRIC (D029 data) generated S-R plots for the 72-PAA F-15 Wing based at Kadena.

Figure 5
18TFW S-R PLOTS (Dyna-METRIC/D029)



The plot for a 0.6 peacetime sortie rate looks really good: There are very few holes and the min-bound NMCS would be not more than 5 aircraft. By the tenth day of a 3.0 surge, many of the parts, however, have climbed to high individual EBOs and collectively produce many holes in the fleet. The min-bound NMCS is over 20 aircraft.

B. 18TFW Supply Readiness Assessment Estimates from MICAP Data

MICAP data and stock level data were obtained on the dominant trouble-makers for the period June 1982 through March 1983. The EBOs, i.e., the average number of holes, for each NSN were calculated and plotted in the S-R space by pairing each estimate with its stock level for that month. The plots are shown in Figure 7. The numbers annotated by the points have been arbitrarily assigned to identify the part without having to use the full NSN in the diagram. The code is given in Figure 6 and is consistent throughout all plots for the Wing. Seven of the NSNs are "XB3" items, which means that they are not reparable which fit the model's precepts. Even so, we have shown them because they contribute to the MICAPs and it helps to size their overall importance.

The legend "Sum of EBO = " gives the total holes caused by the plotted NSNs. The plotted NSNs, however, are not the only ones that caused holes; in each month there are other MICAP NSNs as well. Our rule for selecting those to be plotted was simply to select all the NSNs that caused more than 1.0 EBO in any one month. The "total EBO" gives the average number of holes due to all the MICAP NSNs, plotted or not.

Several of the S-R plots also have the legend "Other Parts" which lists NSNs that fall outside the plotted region. We could have expanded the plot enough to include them, but that would have "squeezed" the presently plotted points. The other parts are important because of their high EPQs. Because of the multiplier effect, they definitely are candidates for the bad actor award during surges.

Collectively, the plots show a rather high degree of change from month to month even though there is also some degree of stability.

- o Total EBOs: High = 390 (Sep); Low = 150 (Oct)
- o It's interesting that the high and the low occur in adjacent months
- o Min-bound NMCS: High 35 (Jan); Low 8-10 (Jun) or 10 (Oct)
- o Sorties ranged over a factor of 2: 844 in Nov to 1841 in Mar.

We will elsewhere explore the correlation between flown sorties and observed EBOs; but for here, we will note that the straight month-to-month correlation does not appear to be very strong.

In general, the dominant NSNs are the ones with high EPQs, high EBOs, or both. By looking at the monthly plots, we arbitrarily produce a list which includes:

<u>CODE NUMBER</u>	<u>NAME</u>
1	HUD Display Unit
2	Signal Processor
23	Radar RCVR
28	Radar Processor
29	Radar Transmitter
33	Control Navigator
37	D/G Gyro
43	Power Supply
49	Ejec, Regulator
53	Control, Engine
56	Switch, Sensitivity
63	Servocylinder

It is a simple matter to plot the time behavior of each of these NSNs, and this is done in Figure 8 where the numbers beside the points now designate the month (Jun/82=6 through Mar/83=3). As can be seen, some NSNs rise into prominence, stay there for awhile, then fade into semi-obscurity. The plots also show some pretty clear "trends", not just random variations. It would be interesting to have the histories that drove these NSNs to those particular paths. The histories, however, are not readily available at HQ PACAF; they really reside with the AFLC item managers.

If we apply the rules-of-thumb developed earlier and suppose the same changes in the data as the DM computations*, the S-R plots show that a 10-day surge at a 3.0 sortie rate would have a severe impact on the Wing. The EPQs for the dominant parts would be forced to much higher values -- a factor of 2 or 3 -- so the min-bound NMCS could get very large, as would the cannibalizations needed to move the holes into the min-bound NMCS group. Both the cannans and the NMCS growth could very well prevent the Wing from achieving its sortie objectives.

C. Comparison of Dyna-METRIC/D029 and MICAP Estimates

It is clear from the presented data that the two alternative estimates of supply readiness yield very different pictures.

Dyna-METRIC/D029 presents a relatively benign picture in Figure 5. The peacetime flying generates very few holes and the min-bound NMCS is quite low. The 10-day surge picture does show a lot of holes and a moderately high min-bound NMCS. That means pretty clearly that the combined POS and WRSK stocks are comfortable but near the margin for peacetime flying.

The S-R Plots of Figure 7 show a dramatically different picture for peacetime flying than does Dyna-METRIC. The actual peacetime S-R plots obtained from MICAP data look about as bad as the Dyna-METRIC portrayal of the tenth surge day. Of course, if the S-R peacetime plots are extended to day 10 by the rules described earlier, the picture is gloomy indeed.*

*Note added (May 84). We should have, but did not emphasize in the original script that the rules-of-thumb used for DM-type extrapolations may not apply to real-world pipelines. Most simply, it is possible for a large number of pieces of a given NSN to appear in the MICAP SRA plot due to a long-standing breakdown of the repair pipeline. The nature of the "breakdown" can be sought once the troublemaker has been identified in the SRA plot and when the reason is known, the "correct" way to extrapolate becomes obvious. This is one of the advantages SRA has over DM in readiness assessment. SRA/MICAP discovers the problem and then seeks reasons and consequences. DM must have the reasons input in order to "discover" the problem.

Figure 6
18TFW

SUPPLY READINESS DIAGRAM (SRD) PART CODE

SRD NO.	NAME	NSN	SRD NO.	NAME	NSN
1	HUD DISPLAY UNIT	1270 0101 88267	41	INDICATOR ELECTRIC	6620 0014 87306
2	SIGNAL PROCESSOR	1270 0104 05948	42	CABLE ASSEMBLY	1005 0028 86245
3	GYRO, LEAD COMPUTER	1270 0104 69884	43	POWER SUPPLY	1440 0105 19763
4	CONVERTER-PROCESSOR	1280 0104 23952	44	ANTENNA	1560 0103 04159
5	HOOK ASSEMBLY	1440 0105 03470	45	RUDDER ASSEMBLY	1560 0107 49254
6	NOSE COVER	1440 0105 54814	46	FOAM BLOCK ASSEMBLY	1560 0109 00541
7	FRAME, FORWARD SUPPORT	1440 0108 41551	47	CONTROL ASSEMBLY	1650 0013 86325
8	RAIL, MISSILE LAUNCHER	1440 0109 67470	48	LIQ CONVERTER	1660 0056 78852
9	RESERVOIR BOOT	1650 0053 16029	49	EJEC, REGULATOR	1660 0101 55017
10	ELECTRIC ACTUATOR	1650 0106 57768	50	LOGIC UNIT	1680 0103 25251
11	REEL, SHOULDER HARNESS	1680 0105 30071	51	OIL PUMP SWITCH	2835 0101 43611
12	SHAFT, STUB GEARBOX	2835 0031 21220	52	CONTROL, UNIFIED	2915 0106 45946
13	DUCT, EXHAUST TURBINE	2835 0053 89284	53	CONTROL, ENGINE	2915 0107 53518
14	JET FUEL STARTER	2835 0103 44772	54	GRIP, LEVER, THROTTLE	2995 0111 85195
15	GEARBOX, ACCESS	2835 0103 46948	55	VALVE, SOLENOID	4810 0100 70536
16	VALVE, POPPET	2915 0106 53149	56	SWITCH, SENSITIVITY	5930 0104 69771
17	HEAT EXCHANGER	2915 0106 53500	57	GENERATOR, HYDRAULIC	6115 0112 13632
18	VALVE, FLOATING AI	2915 0111 60968	58	GENERATOR, ELECTRIC	6610 0014 91134
19	VALVE, ROTARY	4820 0031 33307	59	SIGNAL PROCESSOR	6610 0102 18908
20	CLAMP, BLOCK TUBE	5340 0106 40605	60	INDICATOR, LIQ	6680 0106 84284
21	SELECTOR, ANTENNA	5821 0105 46424	61	CAMERA, MOT	6710 0101 82007
22	RADIO AND MOUNT	5826 0105 52140	62	RETAINER, FAIRING	1560 0028 21083
23	RADAR RCVR	5841 0104 86312	63	SERVOCYLINDER	1650 0110 55523
24	POWER SUPPLY	5841 0105 05979	64	ACTUATOR, ELECTRIC	1680 0050 89183
25	RADAR PROCESSOR	5841 0105 88180	65	CONNECTOR ASSEMBLY, FUEL	4730 0012 32728
26	ANTENNA	5841 0106 30855	66	CONTROL, RADIO	5895 0105 05170
27	RADAR PROCESSOR	5841 0107 22684	67	TRANS, RADIO	6680 0106 69003
28	RADAR PROCESSOR	5841 0107 83230	68	BOX ASSEMBLY, VERT	1560 0112 31852
29	RADAR TRANSMITTER	5841 0110 07363			
30	AMP RADIO	5865 0106 68075			
31	CONTROL, OSCILLATOR	5865 0110 03770			
32	RCVR TX	5895 0111 26380			
33	CONTROL NAVIGATOR	6605 0109 40775			
34	INERT, MEAS	6605 0109 54208			
35	CONTROLLER, AIR	6610 0012 26625			
36	INDICATOR, COURSE	6610 0104 24831			
37	D/G GYRO	6615 0030 36728			
38	INDICATOR, FAN	6620 0104 82889			
39	TRANSDUCER	6685 0106 81480			
40	COMPUTER, DIGITAL	7021 0106 35567			

PREPARED BY: ROBERT T. LANDIS
HQ PACAF/OA, 449-6325
MAY 1983

Figure 7
18TFW S-R Plots (MICAP Data)

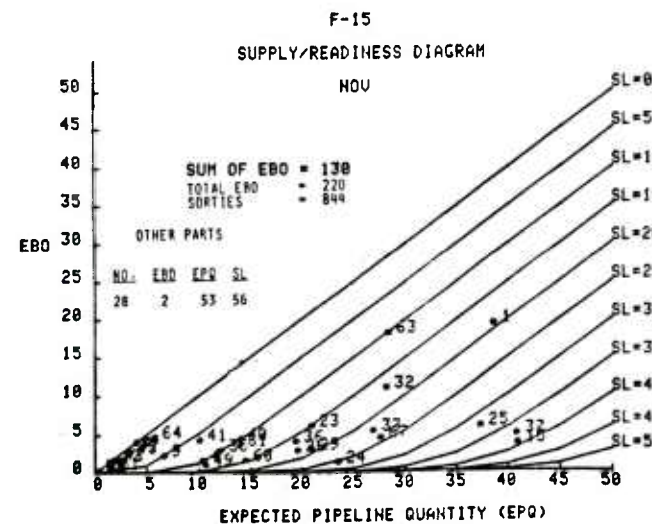
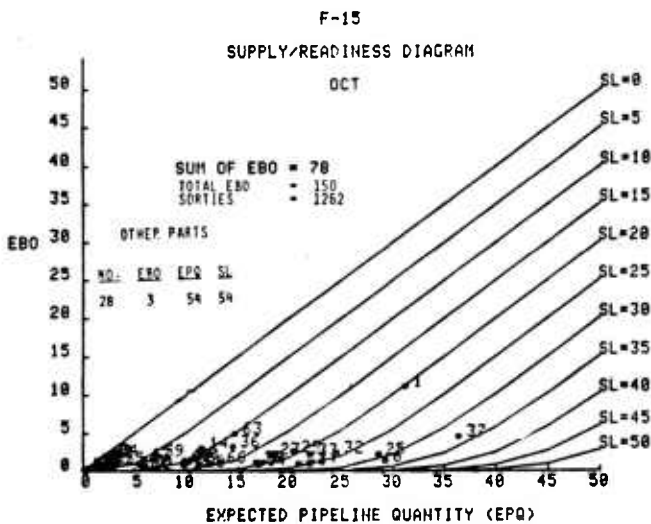
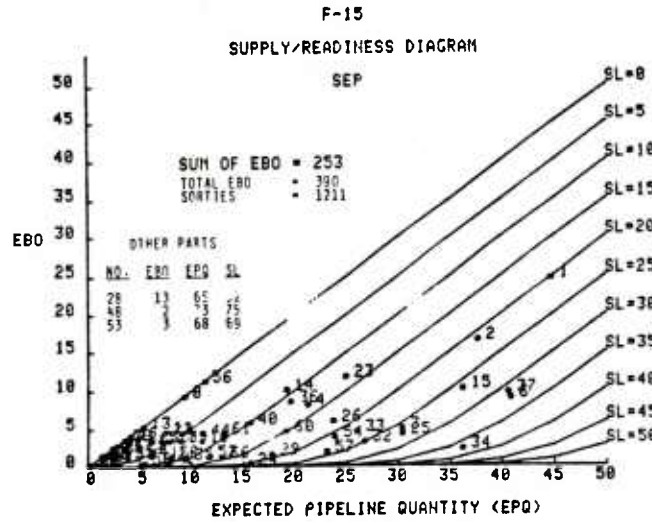
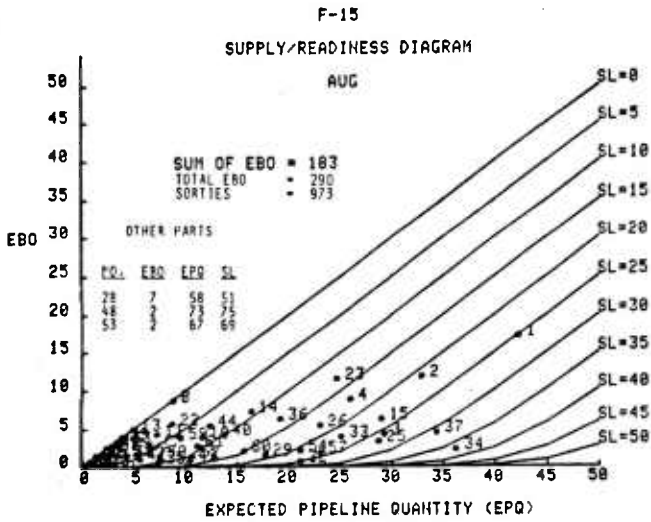
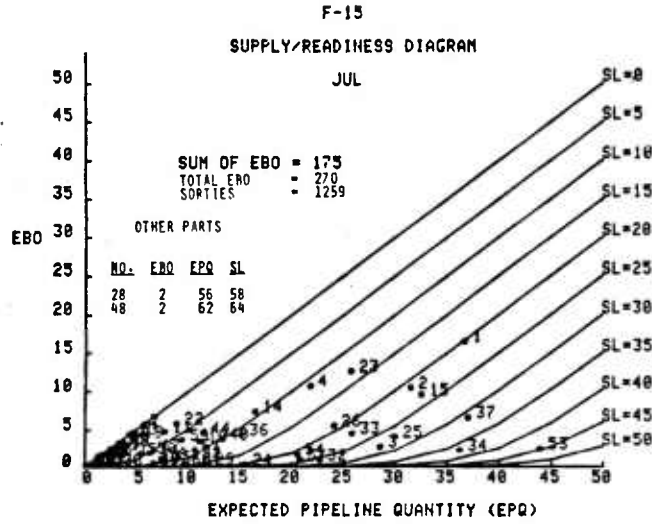
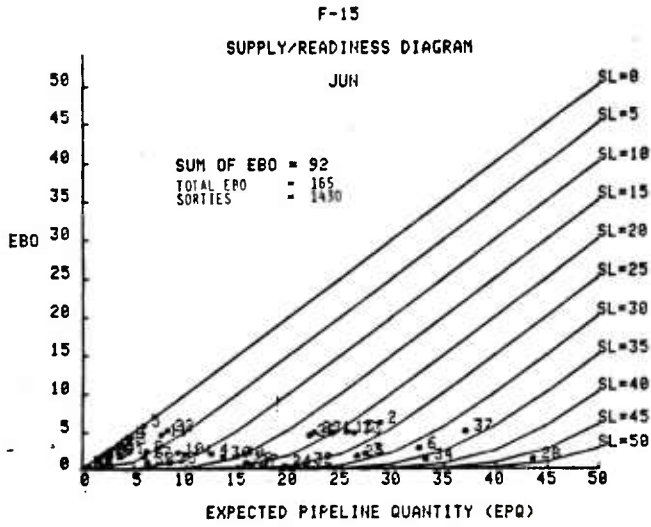


Figure 7
18TFW S-R Plots (MICAP Data)
(cont'd)

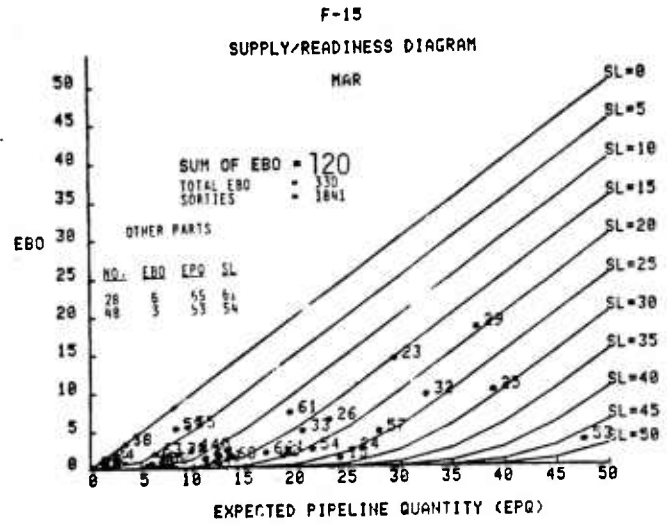
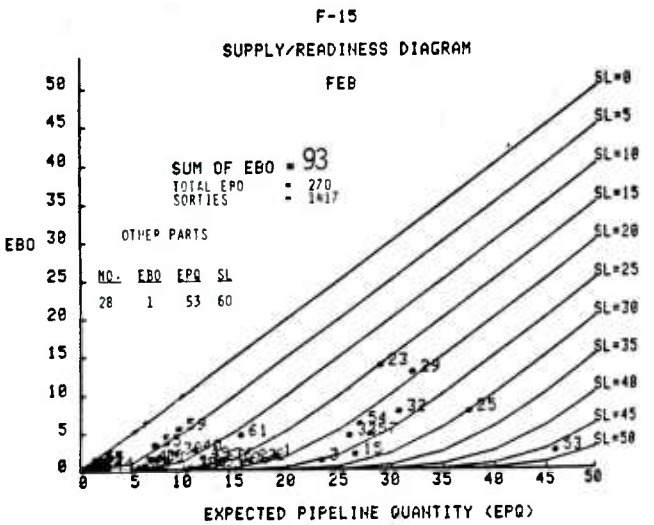
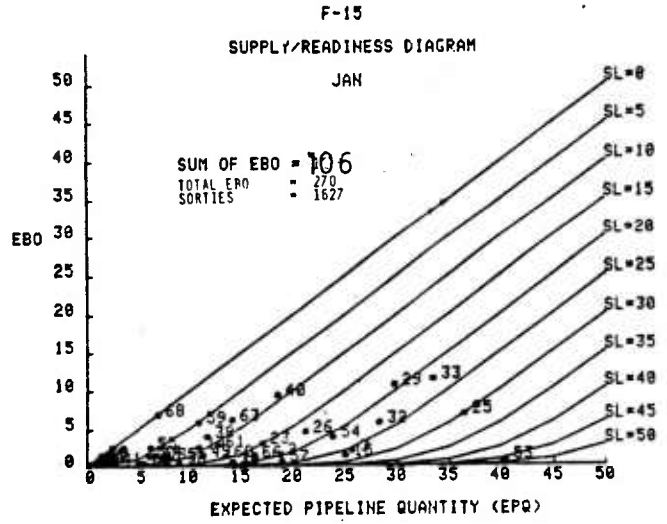
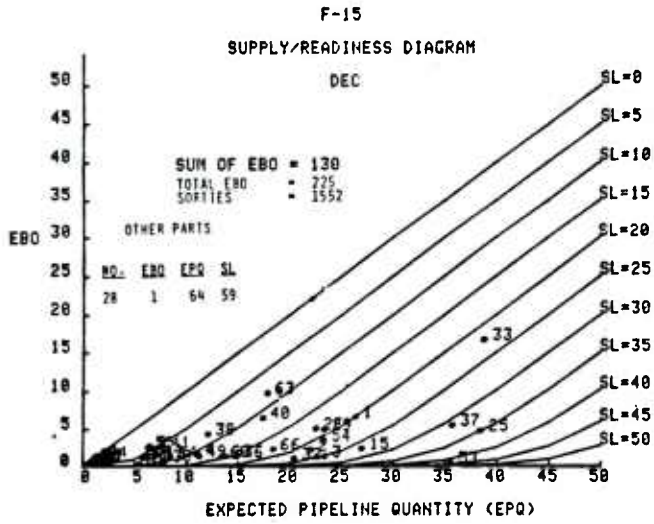


Figure 8
18TFW S-R Plots Individual Parts

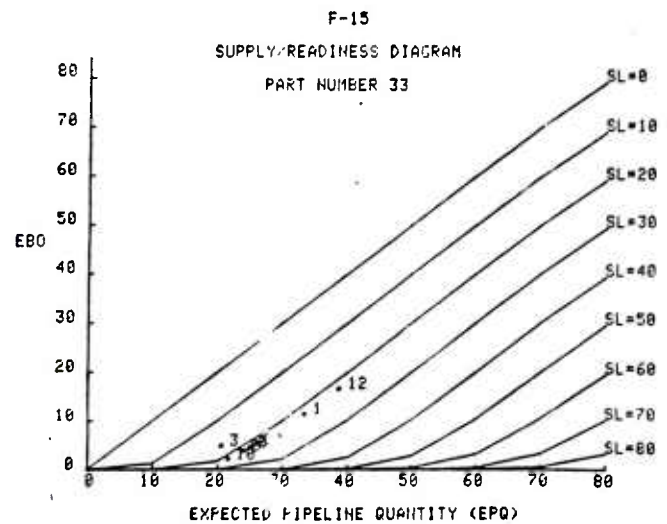
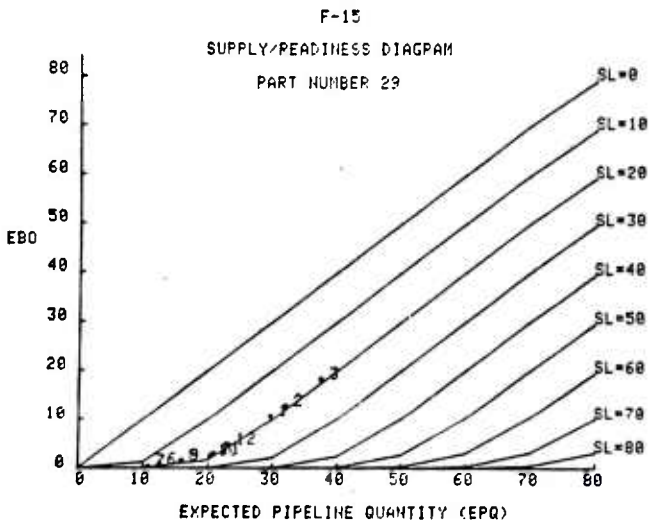
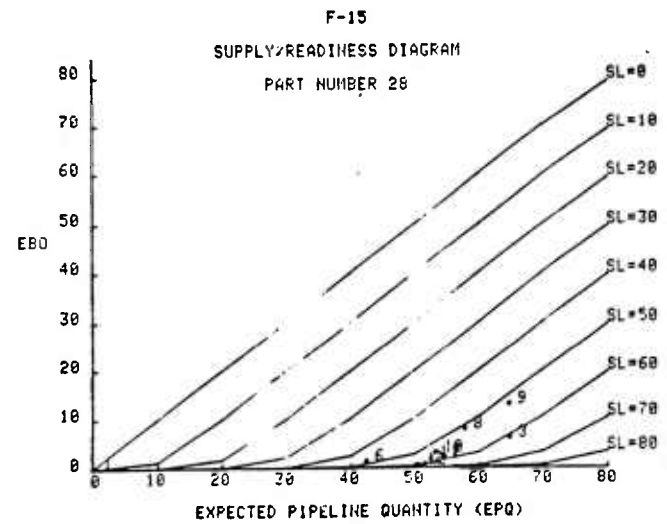
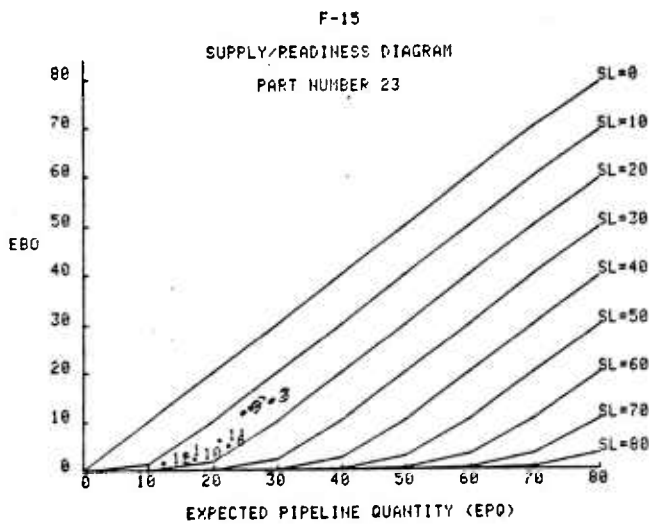
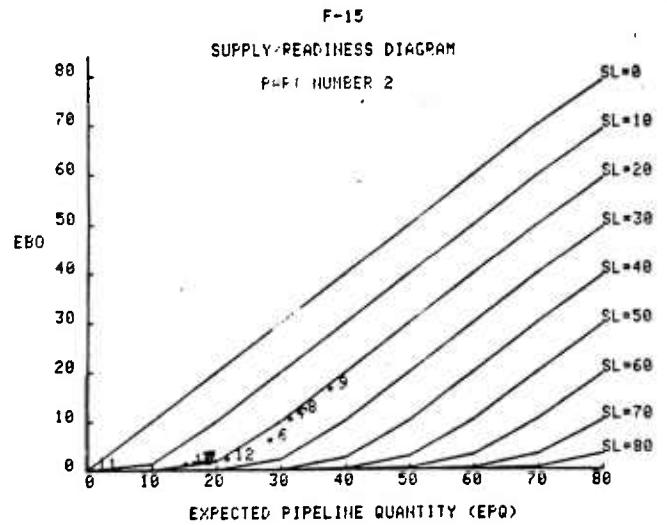
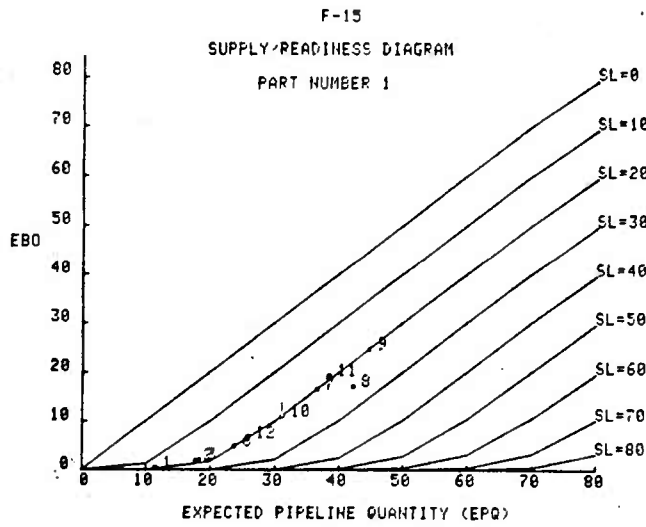
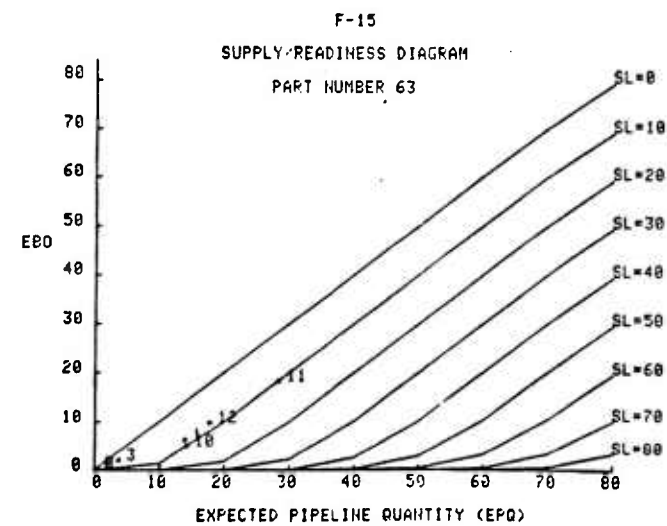
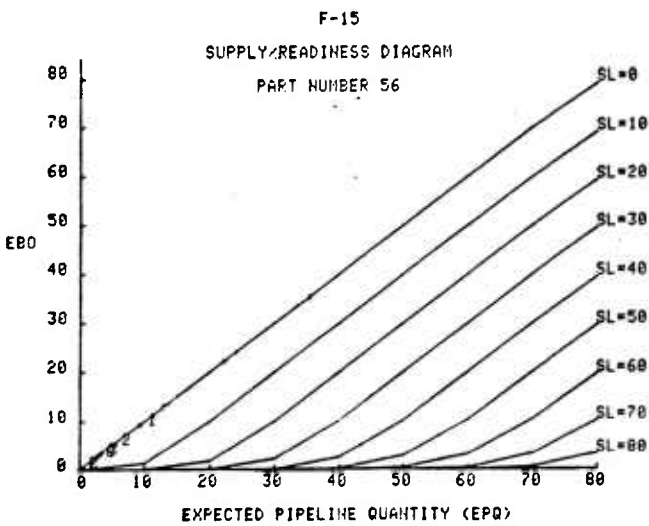
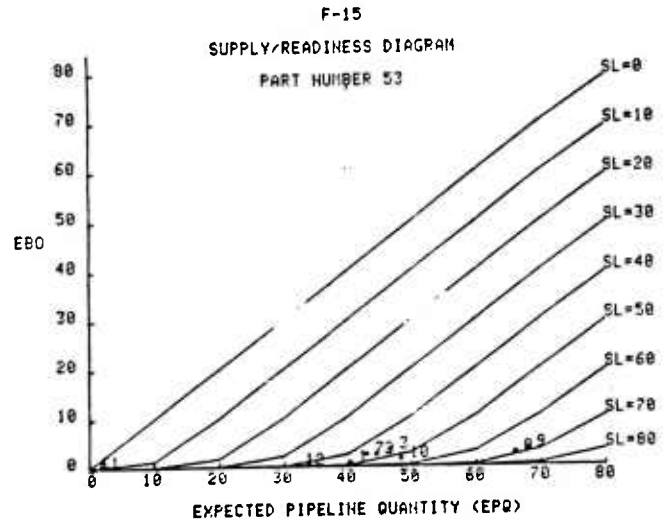
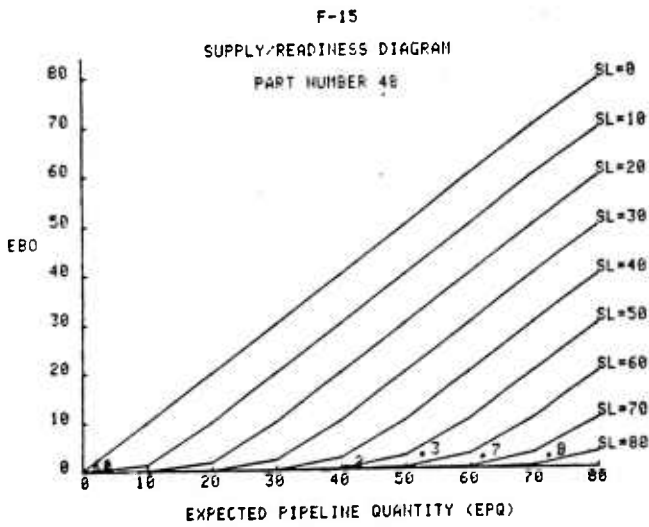
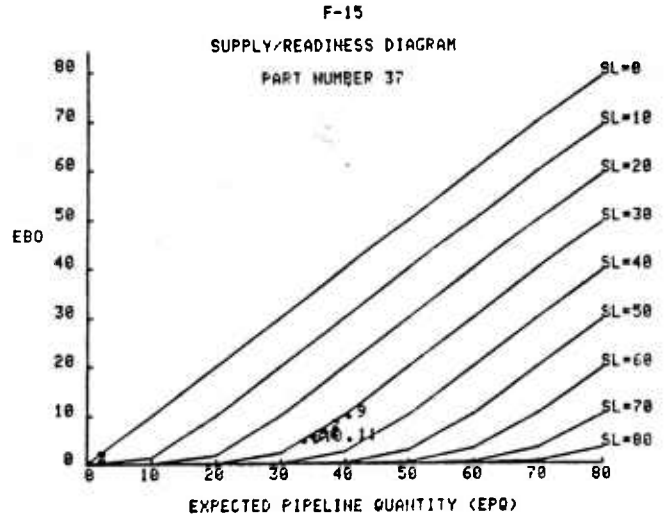
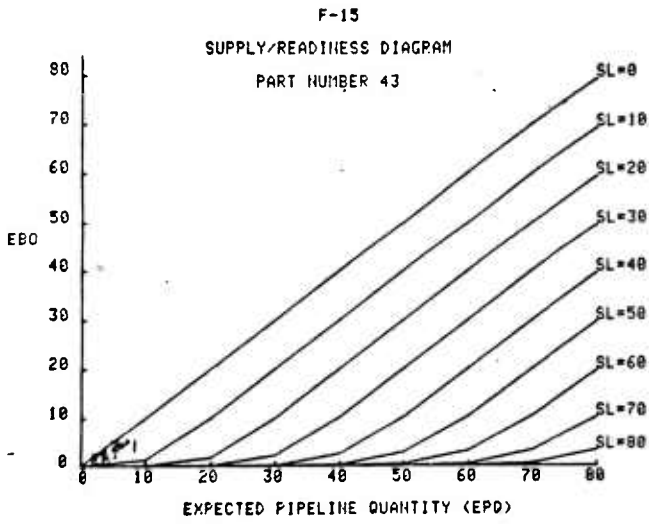


Figure 8
18TFW S-R Plots Individual Parts
(cont'd)



D. Why Are the Estimates Different?

In attempting to explain the large difference between the pictures portrayed by DM/D029 and MICAP estimates, there are quite a few possible factors that need to be discussed.

1. LRU-SRU Indenture Relationship:

First, our DM/D029 computer runs have not exercised the full DYNAMIC model--we have not included that part that manipulates the SRU data to estimate the delays in repair because of "awaiting parts." Leaving that part of the model out does cause an underestimate of the EPQ for those LRUs that depend on SRUs. And, indeed, LRUs having SRUs tend to be the critical ones. We have not routinely included the SRU/AWP portion in our runs because we have been unsure of the validity of their treatment in the computer programs.

To assess the consequences of this deficiency, we made some estimates of the maximum contribution of the AWP (Awaiting Parts) to the repair pipeline. For some parts, the AWP calculation can nearly double the non-AWP pipeline quantity. It is obviously an important part of the problem. The discussion here is in doubt because, according to RAND, the DM program itself is unreliable in this portion. See Appendix C for details.

2. Cannot Duplicate:

Another factor comes from all those removals which the repair shop labels as "cannot duplicate" or "CND". Under the reporting rules all CNDs are purged from the initial data before they are even reported into the D041 system which is the parent of D029 data. This "purging" results in an automatic underestimate of the demand rate insofar as "holes" are concerned: the removed LRUs are real even though the LRU may later be labeled "CND" and

treated as if it never happened. The end result is that DM/D029 projects an EPQ that is too low because the removal rate has been underestimated.

We have surveyed the demand data on many of the critical F-15 LRUs and have found that extensive CNDs are common. Many LRUs have as many or more CNDs as the "real" breaks. We are shaping the data in a form that will soon let us demonstrate that fact. For now, it appears that this factor can contribute a factor of 2 to an EPQ underestimate.

3. MICAP Sample Size:

Another possible difference between DM/D029 and MICAP estimates comes from the fact that each MICAP estimate of EBOs has been based on a one-month sample. As will be shown in Appendix D, that one-month sample appears to be equivalent to between two and five statistically independent samples and would therefore show moderate random fluctuations. Dyna-METRIC, on the other hand, bases its prediction of EPQ on essentially an "infinite" sample. The practical result is that random sampling excursions make the MICAP-derived data show more scatter.

In the absence of any clear bias -- and we don't know of any -- the scatter caused by the sampling process should make some points higher, some points lower, while not changing the overall position of the "cloud of points" very much. Since the min-bound NMCS, however, does depend only on a single point, or at most a small group of points, it is susceptible to random fluctuations. Appendix D, which explores the sampling statistics of the EBO estimate can help form a useful "feel" on how much uncertainty there may be. If the estimate appears to be too jumpy due to random effects, it is always possible to increase the sample size by pooling two or three month's worth of data. That, of course, will reduce sensitivity to trend detection.

4. D029 Timeliness:

The D029 data base is updated annually. An immediate consequence is that the pipeline portion of the Dyna-METRIC calculation remains effectively static for the year. Although the model can be fed changes in planned peacetime flying programs and changes in stock held by the Wing, neither of these appears to be as dominant as the factors describing demand rates and the repair process which are the principal content of D029.

Whether the static nature of the D029 data base can be tolerated can be judged by looking at how the S-R plots vary over a year's time.

5. D029 Averaging:

The D029 base contains "average" values in that (1) they are based on long-term averages, and (2) the data from PACAF, USAFE, and TAC are pooled. Time trends and theater-unique effects are inevitably suppressed.

6. D029 "Nominal" Values:

Many of the values in D029 are not obtained from collected field data; they are nominal values based on guesses. Depot order-and-ship times (OST) which can be really influential are, more often than not, just nominal guesses used for all NSNs that are repaired at the depot. Clearly, this cannot be correct for all NSNs.

7. Adequacy of the Model:

There is not much we can say with assurance about the adequacy of the Dyna-METRIC model. Like most models, it can be modified as required, at least within broad limits. Nevertheless, there are a couple of areas in the model that we have a hunch could be troublesome. We will raise them in the form of questions:

- Do we ever reach in peacetime the theoretical peacetime "stationary state" on which Dyna-METRIC computer programs are based? Or do the Wing's observables behave more nearly like those of a system that is continually in a transient condition?*
- Are the demands, and by extension the repair pipelines, Poisson distributed with a mean-to-variance ratio of 1.0? Or do the variances of the "critical" parts (we can ignore the non-critical ones) greatly exceed the expected values?
- In light of the above, which also could apply to SRUs as well as LRUs, is the LRU-SRU indenture relationship correctly modeled?

The questions themselves are suggested in large part by the data we have been looking at in this report. All of the possibilities raised by the questions could have very strong effects on Dyna-METRIC output results should they turn out to be strongly operative. If that happens to be the case -- and we're not yet sure it is -- the DM model probably could be modified to some extent to accommodate them. Even so, such model extension would require additional data to characterize each effect, thereby adding to an already complex estimating problem.

*Note added (May 84). It turns out that this speculation is the strongest factor that leads to the observed differences. The repair pipeline can and does show very strong temporal perturbations.

VI. COMPARISON OF EBO ESTIMATES [8th Tactical Fighter Wing (8TFW)]

We include here, without much comment at the moment a set of data for an F-16 Wing of 48 PAA. The differences between Dyna-METRIC and MICAP estimates are not as dramatic as in the F-15 case, but the differences are still significant.

Figure 9
8TFW

SUPPLY READINESS DIAGRAM (SRD) PART CODE

SRD NO.	NAME	NSN	SRD NO.	NAME	NSN
1	ANTENNA, RADAR	1270 0109 32174	41	POWER DRIVE, LEADING EDGE	1650 0104 10477
2	TRANS, RADAR	1270 0109 32256	42	SENSOR, CONTROL	1660 0105 25354
3	RADIO, FREQUENCY	1270 0110 22962	43	PANEL, POWER DIST	1680 0105 13052
4	RADIO, FREQUENCY	1270 0110 22965	44		1680 0113 58998
5	UNIT ASSEMBLY	1270 0110 22966	45		2835 0109 86705
6	REMOTE INTERFACE UNIT	1280 0108 03978	46	JET CONTROLLER	2835 0111 50306
7	ELECT COMPUTER	1280 0110 96916	47	VALVE, REGULATOR	4810 0113 07379
8		1280 0112 87598	48	RCVR-TX	5895 0111 26380
9		1560 0104 79645	49		5930 0110 22783
10	TANK, FUEL	1560 0105 42800	50	INVERTER, CONTR	6110 0110 82690
11		1560 0109 98086	51	GENERATOR ALTERNATOR	6115 0104 47144
12		1560 0111 54613	52	BVD 06	6115 0109 55500
13	WING FAIRING	1560 0111 81058	53	HUD UE	6605 0109 47743
14	VALVE ASSEMBLY	1630 0108 48399	54	COMPUTER, FLT	6615 0109 49384
15	DRIVE, CONSTANT SPEED	1650 0108 52887	55		1560 0106 15092
16	OUTLINE CONTROLLER	1680 0107 18358	56		1560 0108 61328
17	CONTROL ASSEMBLY	1680 0108 41544	57	FILTER ELT	1630 0111 83642
18	ACTUATOR, ELECTRONIC	1680 0108 54423	58		1650 0107 39304
19	PANEL, RECORDER	1680 0108 77674	59	ELECT ACTUATOR	1680 0109 51750
20		1680 0112 16572	60		1680 0110 57111
21	MOTIONAL TRANSDUCER	2835 0105 41331	61		2925 0111 50306
22		2835 0107 38989	62		5310 0111 39843
23		2835 0107 78995	63		5330 0105 59230
24	SEAL, AUGMENTOR	2840 0106 02793	64		1270 0104 53976
25	CABLE, ASSEMBLY	2925 0110 31066	65	RADAR COMP RADC	1270 0113 15706
26	VALVE, FUEL SHUT	2995 0106 08514	66	COUNTERMEASURES REVR	5865 0104 46387
27	VALVE, ASSEMBLY	4810 0105 55935	67	DET AMP	5865 0042 63144
28	VALVE, REGULATOR	4810 0107 14753	68		5930 0111 47054
29	VALVE, SOLENOID	4810 0106 87863	69		6220 0107 19273
30	VALVE, P&V	4810 0112 37254	70	HUD EU	6605 0112 29955
31		5330 0106 96356	71		1280 0111 06483
32	CHASSIS, ELECTRICAL	5865 0106 48289	72		1280 0111 06484
33	BATTERY CHARGER	5965 0109 84448	73		1560 0112 60296
34	INERT NAV UN	6130 0105 17518	74	GRIP ASSEMBLY	1680 0111 46248
35	DISPLAY UNIT, P	6605 0108 76645	75		1680 0111 90952
36	ACCELEROMETER	6605 0109 48505	76		6610 0108 91018
37	TRANSMITTER, AOA	6610 0103 97817	77	FLIGHT COMPUTER	6615 0111 43500
38	ELEC COMP AMP	6610 0105 25584	78		6620 0102 01722
39	TANK, FUEL	6610 0111 22345			
40		1560 0110 26385			

Figure 10
8TFW S-R Plots (MICAP Data)

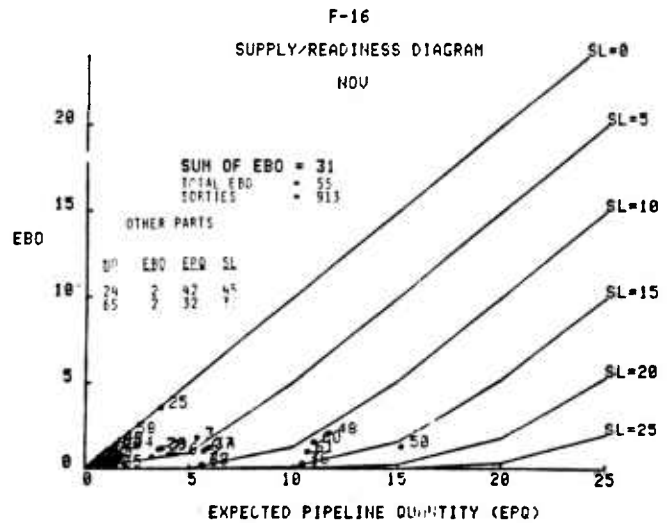
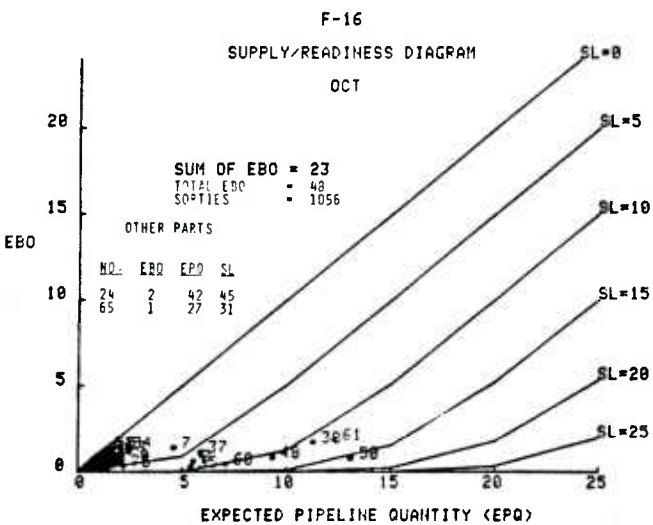
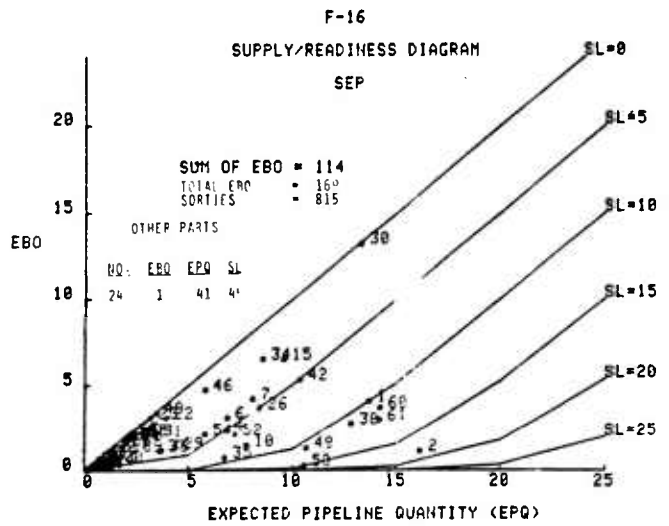
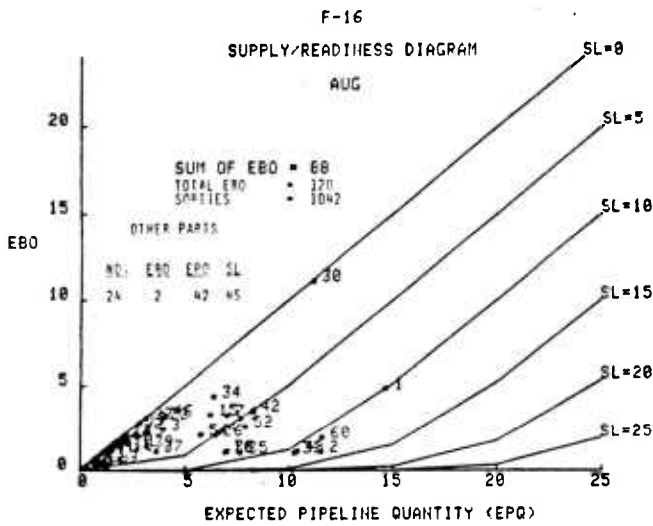
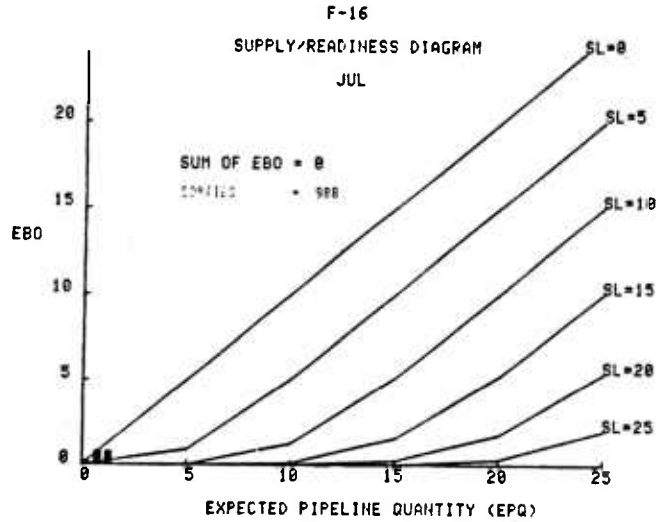
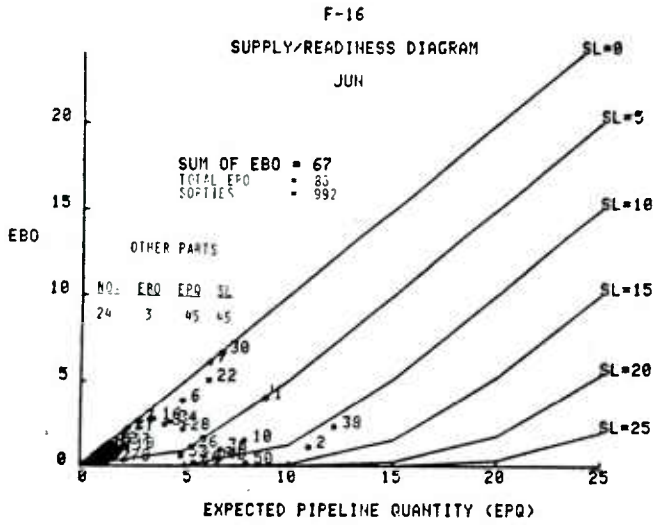


Figure 10
 8TFW S-R Plots (MICAP Data)
 (cont'd)

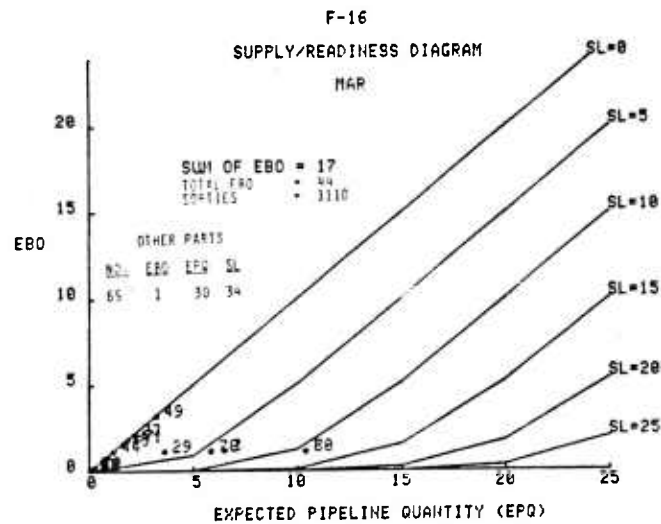
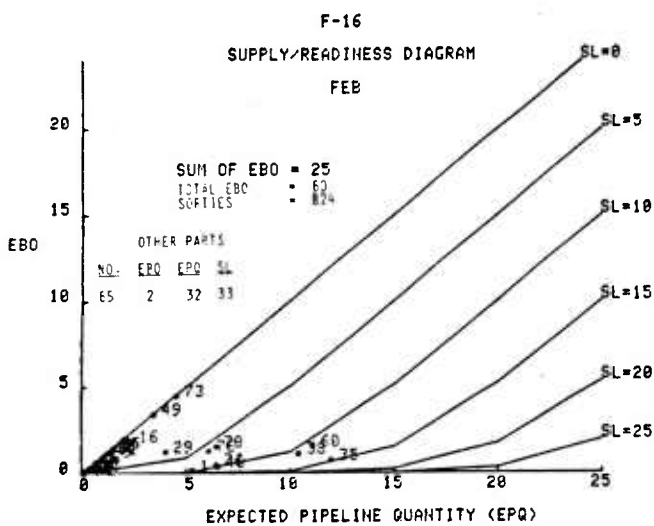
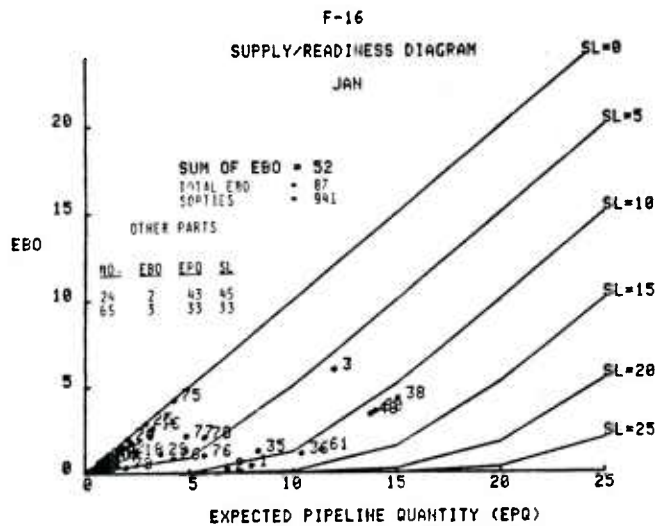
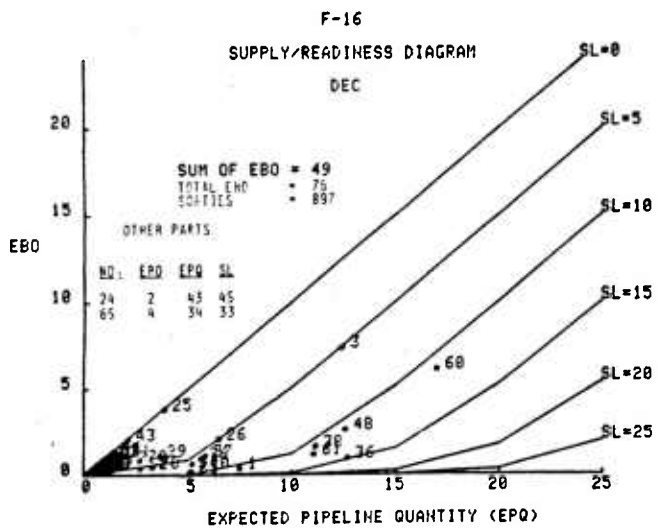
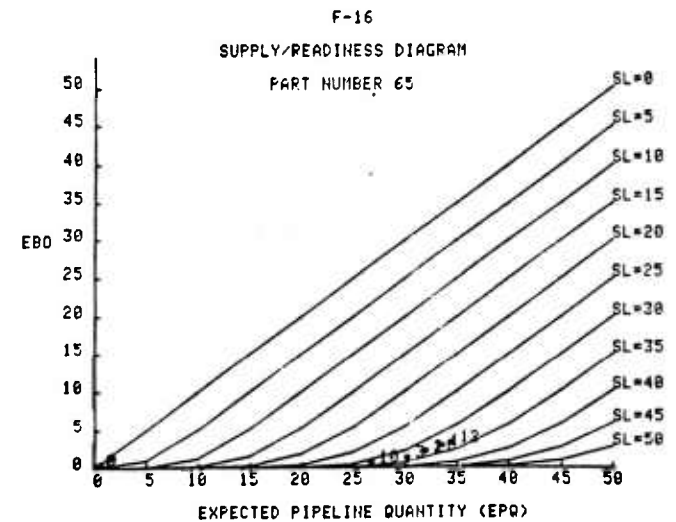
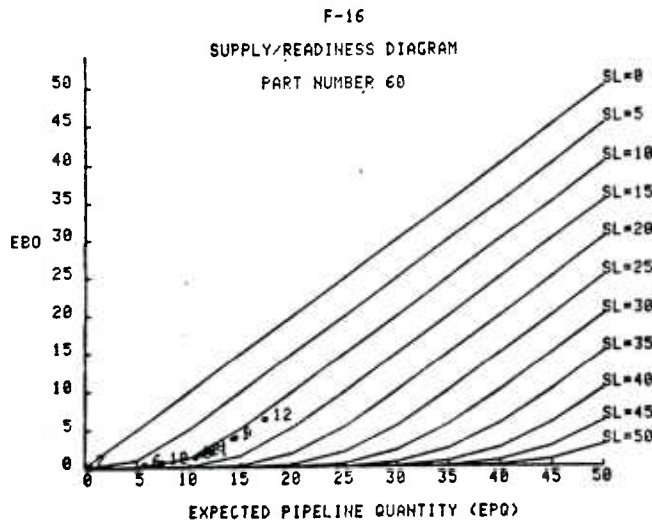
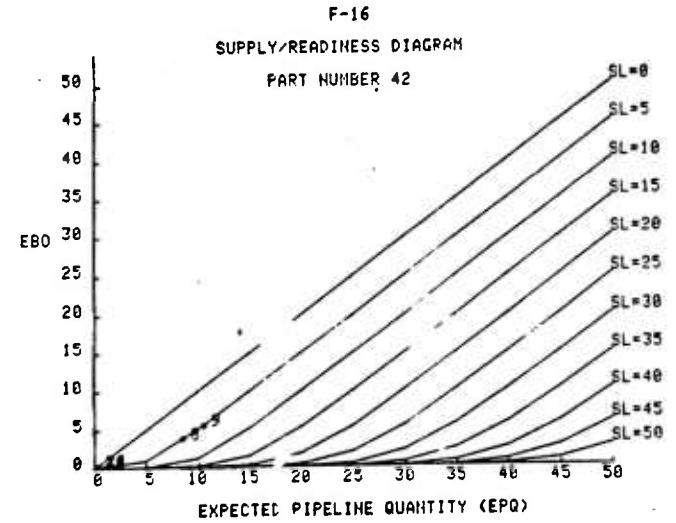
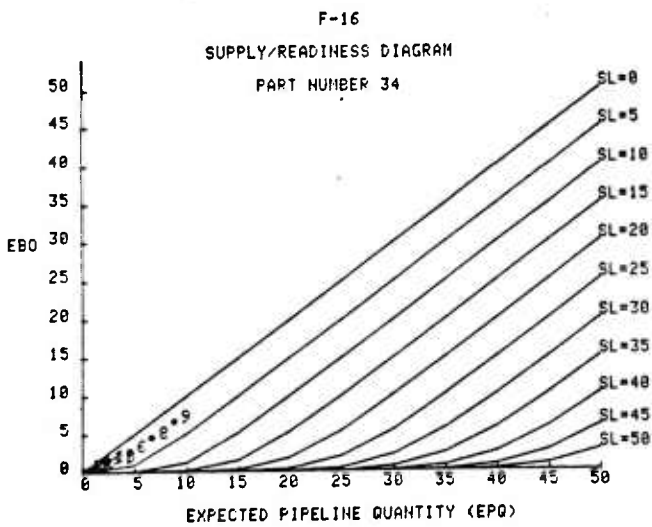
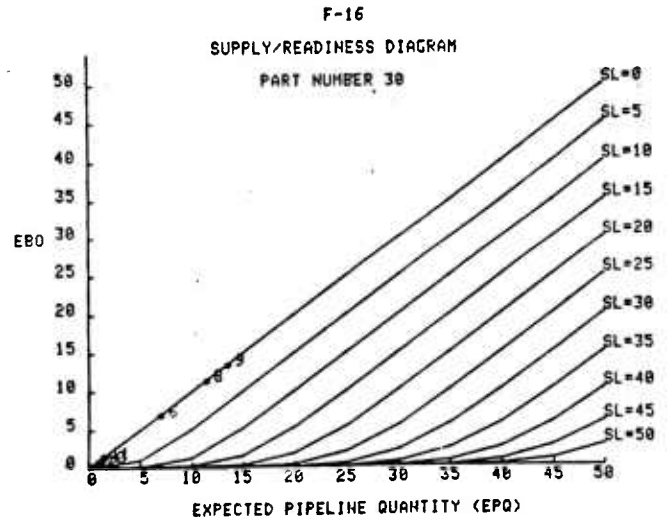
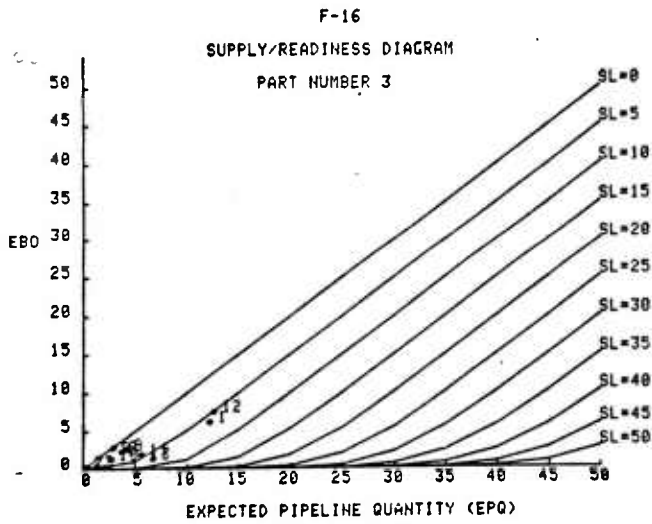


Figure 11
8TFW S-R Plots (Individual Parts)



VII. OVERALL SUMMARY AND CONCLUSIONS

Our comparisons of estimates based on the Dyna-METRIC model using the D029 data base vis-a-vis equivalent estimates based on MICAP data show that they portray markedly different pictures.

Our judgment is that the data drawn from MICAP-based EBO estimates portray the more nearly correct readiness assessment picture. The D029 data base which is updated only once a year has timeliness problems in tracking what is a volatile, changeable picture. Absolute errors leading to underestimates of both "total holes" and min-bound NMCS occur because CNDs are purged from the low-level data inputs that eventually feed D029. Awaiting parts (AWP) time is also purged from the low-level report feed but this is to some extent overcome by Dyna-METRIC's treatment of the LRU-SRU indenture relationship. [The Dyna-METRIC runs portrayed in the main text of this report do not include that part of the model. We have, therefore, biased the comparison to a small extent (less than 50% change in EPQ), as we discussed in Appendix C. This factor alone cannot account for the very large observed differences.]

We have also raised questions about some of the underlying assumptions and the mathematical treatment in the present-day computer programs that implement the Dyna-METRIC model, not because we are convinced the model is wrong, but because the S-R plots themselves strongly suggest a time dependency that is not presently captured. These matters require further investigation.

The S-R Plots can with equal validity portray either Dyna-METRIC or MICAP estimates of EBOs. They are, in their own right, especially useful portrayals of the supply readiness posture of a Wing. By showing at one and the same time the overall "cloud" of points representing the more

critical NSNs, each deficiency in stock levels is immediately apparent. The total number of holes suffered by a Wing, easily summed and stated, is a good measure of the overall stock adequacy. The highest EBO, i.e., the "worst" part, gives a clear indication of the min-bound NMCS which is the best a Wing can aspire to by doing all the possible cannibalizations. Rough estimates of the daily number of canss needed to maintain the min-bound NMCS can also be obtained.

More importantly, the S-R plots can be extended through easy approximate rules-of-thumb to portray what happens to the unit as changes are effected in sortie rate and average repair times. We call particular attention to the "multiplier" effect which emphasizes the importance of high-activity parts in affecting a Wing when it surges. The combination of the "multiplier" effect with the "worst-EBO" interpretation that leads to the min-bound NMCS gives a very good picture of where the Wing's supply troubles will be found.

Although the rules-of-thumb are somewhat approximate, a review of how the data changes from month-to-month makes it pretty clear that there are other, stronger effects that would make high precision hard to achieve in any event.

The upshot is that for readiness assessment almost all of the principal benefits of Dyna-METRIC can be enjoyed without having to use a computer to manipulate the massive amounts of data contained in D029. A moderately skilled manager or commander can read quite well the S-R plots derived from fundamentally more accurate MICAP data and project the plot into the Wing's probable wartime surge supply position. Furthermore, this readiness assessment can be had without the lag times involved in collecting data and formatting it into shape for DM.

For these reasons, we think it appropriate that S-R plots be obtained monthly at each TAF Wing, be provided up-line to higher headquarters, and ultimately be made a part of AFLC's system for Combat Analysis Capability.

Appendix A

S-R SPACE MATHEMATICS AND PROPERTIES

The relationship between the expected pipeline quantity (EPQ), the stock level (SL), and the expected back orders (EBO) is fully defined by the relationship

$$\text{Eq (1)} \quad \text{EBO} = \sum_{k=1}^{\infty} kg(\text{SL}+k)$$

when the probability function $g(n)$ has been specified. In the body of this report, we have used the supply-readiness (S-R) space appropriate to the Poisson distribution which has the mathematical form

$$\text{Eq (2)} \quad g(n) = \frac{\lambda^n}{n!} e^{-\lambda}, \quad n = 0, 1, 2, \dots$$

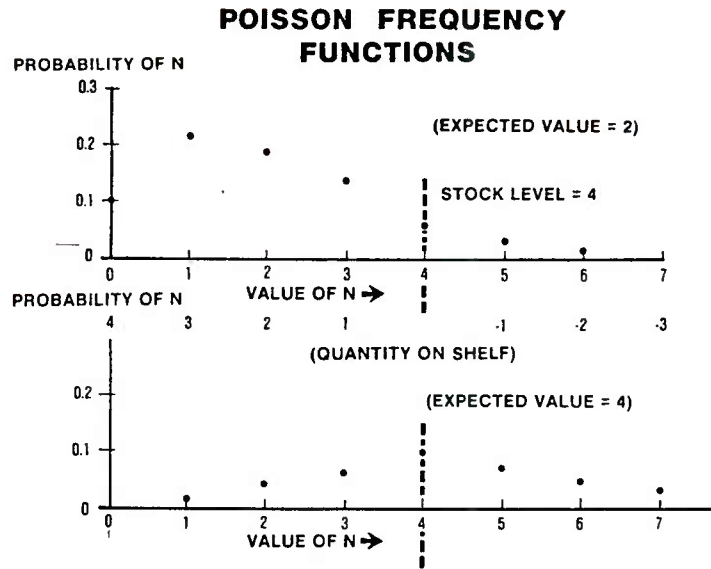
The parameter, λ , is the expected value of the distribution (i.e., "average value") and

$g(0)$	=	probability of 0 parts in the repair line
$g(1)$	=	" " 1 part " " " "
$g(2)$	=	" " 2 parts " " " "
etc.		

The expected value, λ , of the distribution is just equation (1) evaluated for $\text{SL}=0$.

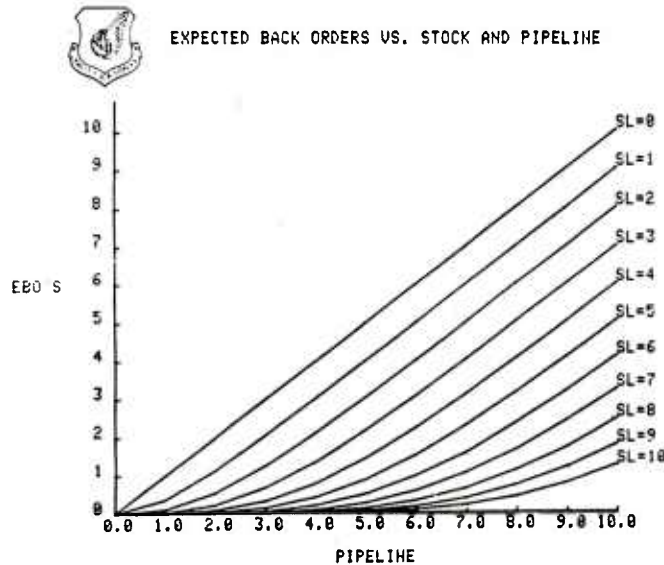
Figure A-1 is an illustration of these relationships. The top half of the illustration shows points representing $g(n)$ for $n = 0, 1, 2, \dots$. The expected value equals 2. A stock level of 4 is also shown. The EBO is given by $1g(5) + 2g(6) + \dots$ and computes to 0.21. In this case, the right hand "tail" of the distribution extends into the region of pipeline quantities that exceeds the stock level and causes holes in aircraft. A higher value of stock level would decrease the expectation and a lower stock level would increase it.

Figure A-1



In the bottom half of the figure, the expected value of the distribution is now set at 4. The distribution has now spread out and has become more symmetrical; the most probable value, (i.e., the $\max g(n)$), now occurs at 4. If the stock level is still 4, then more of the distribution's tail extends into the "hole" region, actually about half of the distribution, and the EBO calculates to be 1.25.

Figure A-2



For distributions characterized by higher expected values, i.e., by higher EPQs, the $g(n)$ with values significantly different from zero will cluster in the neighborhood of the EPQ but will stretch out to some extent. More and more of the distribution will fall into the "hole" region for a

fixed stock level and the EBOs will rise correspondingly. The region where the distribution lies on either side of the stock level gives rise to the curved portion of each specific SL curve. When the distribution lies completely in the hole region, i.e. pipeline quantities with significant non-zero probabilities lie entirely above the SL, each increment to the EPQ causes an equal increment to the EBO; this is the region of the S-R space where the parallel 45-degree lines occur. In the "45-degree" region, we reasonably can say that the behavior is independent of the distribution.

In the "45-degree region," we have the wonderfully simple relation

$$\text{Eq (3)} \quad \text{EPQ} = \text{EBO} + \text{SL} .$$

This can be verified by appeal to Figure A-2, but it can also be shown by rewriting equation (1):

$$\begin{aligned} \text{EBO} &= \sum_{k=1}^{\infty} kg(\text{SL}+k) \\ &= \sum_{j=\text{SL}+1}^{\infty} (j-\text{SL})g(j) \\ &= \sum_{j=\text{SL}+1}^{\infty} jg(j) - \text{SL} \sum_{j=\text{SL}+1}^{\infty} g(j) \\ &= \sum_{j=1}^{\infty} jg(j) - \text{SL} \sum_{j=1}^{\infty} g(j) + \sum_{j=1}^{\text{SL}} (\text{SL}-j)g(j) . \end{aligned}$$

$$\text{Since } \sum_{j=1}^{\infty} jg(j) = \text{EPQ} \text{ and } \sum_{j=1}^{\infty} g(j) = 1 ,$$

$$\text{Eq (4)} \quad \text{EBO} = \text{EPQ} - \text{SL} + \sum_{j=1}^{\text{SL}} (\text{SL}-j)g(j) .$$

Equation (4) is one of the forms shown in the Rand paper* authored by Hillestad and Carillo. It is in good computational form by virtue of the

*Models and Techniques for Recoverable Item Stockage When Demand and the Repair Process are Nonstationary -- Part I: Performance Measurement, N-1482-AF, May 1980, The Rand Corporation

finite sum, but is also serves our present purpose. The "45-degree region" of the S-R space is that where

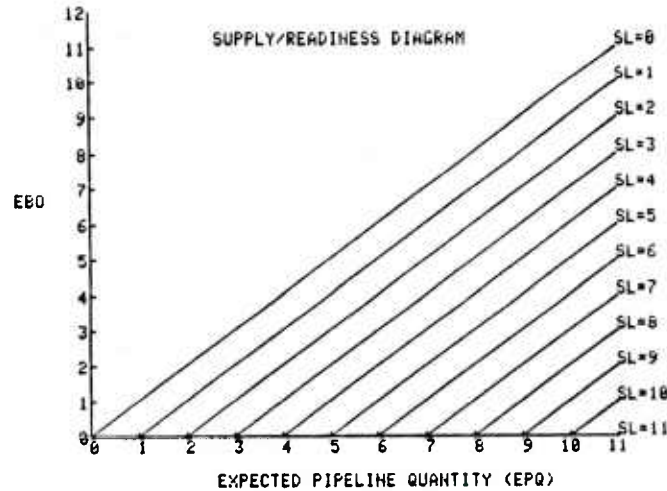
$$g(0) \simeq g(1) \simeq \dots \simeq g(SL) \simeq 0 ,$$

i.e., where most of the non-zero part of the distribution is to the right of the stock level. The finite sum vanishes for this condition and equation (3) follows.

As an abstraction, then, we could look upon a fundamental S-R space as one consisting of only 45-degree lines originating from the EPQ equal to the labeling SL as in Figure A-3. This space is represented by the case of a spike pipeline quantity function.

Figure A-3

SPIKE DISTRIBUTION: $VTM = 0$



Other distributions which do not match the fundamental space will produce the curved portion that fillets the angles of the fundamental space. The shape of the filleting curve depends a great deal on the variance of the distribution, i.e., upon its spread around its average value. Figures A-4a through A-4d show some examples.

Figure A-4a

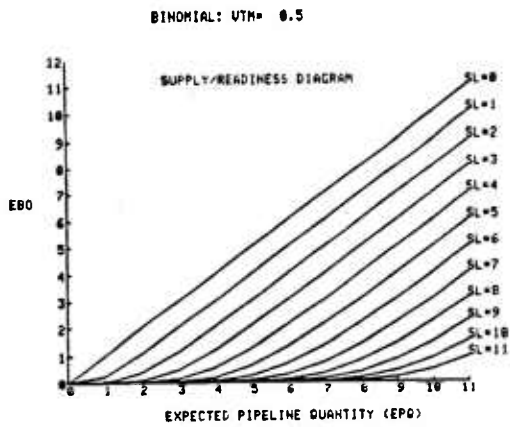


Figure A-4b

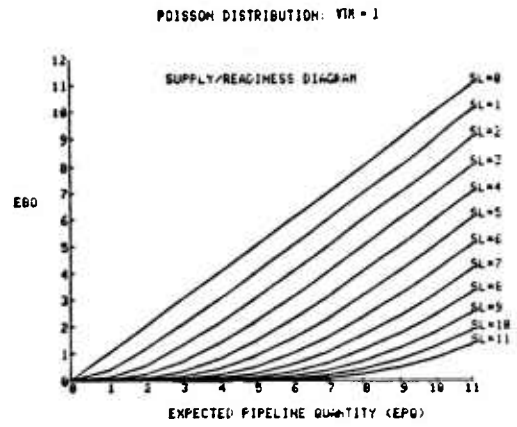


Figure A-4c

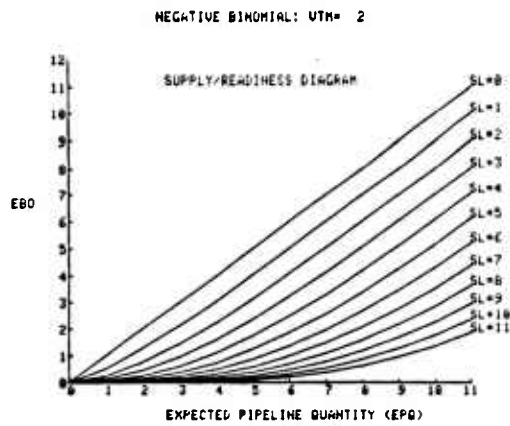
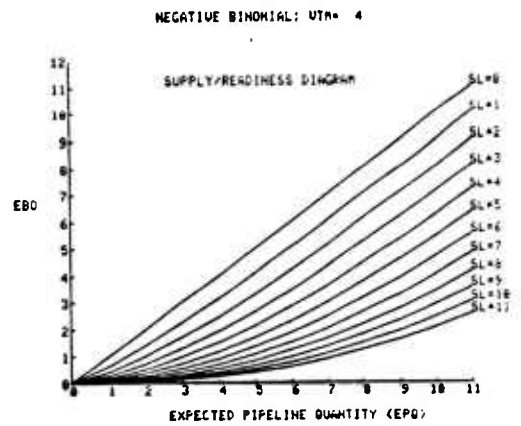


Figure A-4d



Appendix B

OBSERVATIONS ON MIN-BOUND NMCS

The probability distribution for the lowest possible value of NMCS which can be achieved by performing all needed cannibalizations can be obtained rather straightforwardly. Hillestad and Carillo of the Rand Corporation derive it as follows*:

Denote the probability that the j th NSN causes k or fewer backorders by $P_j(BO \leq k)$ and note that

$$\text{Eq (1)} \quad P_j(BO \leq k) = \sum_{n=0}^{SL+k} g(n) \quad \text{where} \quad g(n) = \frac{(EPQ)^n e^{-EPQ}}{n!}.$$

Under the assumption that the NSNs are independent, the probability that all NSNs have k or fewer backorders is

$$\text{Eq (2)} \quad P(\text{Min-Bound NMCS} \leq k) = \prod_j P_j(BO \leq k),$$

where the product is taken over all NSNs. Finally, the probability density function is given by

$$\begin{aligned} \text{Eq (3)} \quad P(\text{Min-Bound NMCS} = k) &= P(\text{Min-Bound NMCS} \leq k) \\ &\quad - P(\text{Min-Bound NMCS} \leq k-1). \end{aligned}$$

When one thinks of the several hundred NSNs that constitute the reparable parts in an aircraft, the min-bound NMCS seems hard to visualize because it depends on all of them. Actually, however, the function is usually quite simple because the "worst" part, or at most a small group of "worst" parts, completely dominates the others. We have expressed it elsewhere by noting that 100% cannibalization can be thought of as a process of trying to move all the holes into the smallest possible number of aircraft. At any given point in time, the smallest possible number is determined by the one (possibly two or three) NSN which creates the most holes. The worst part determines the min-bound NMCS simply because there is no way to fill a worst-part hole without making some other aircraft NMCS.

Thus, the min-bound NMCS distribution is determined essentially by the competition among the close competitors for the worst-part title; and the chance that a non-competitive NSN will rise above the others is

*Models and Techniques for Recoverable Item Stocakge When Demand and the Repair Process are Nonstationary -- Part I: Performance Measurement, N-1482-AF, May 1980, The Rand Corporation

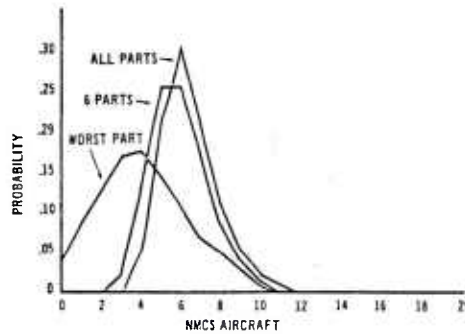
remote. In the Honolulu Marathon, there are over 8000 runners, but those who can hope to win and set a record amount to 10 or so. So it is with aircraft parts in the real world. It doesn't have to be that way, but it actually works out that way when we look at real-world data.

In past briefings, we have illustrated the dominance of a small group by displaying the min-bound NMCS probability density for all parts, and then contrasting that with the probability density for a very small group of bad parts and, finally, with the worst part. Using some previous data for the 48-PAA 8TFW, we obtained Figure B-1. The curve labeled "All Parts" was based on the actual stock levels for all NSNs; to obtain the curve labeled "6 Parts," we gave infinite stock to all NSNs except the six worst. As can be seen, the

Figure B-1



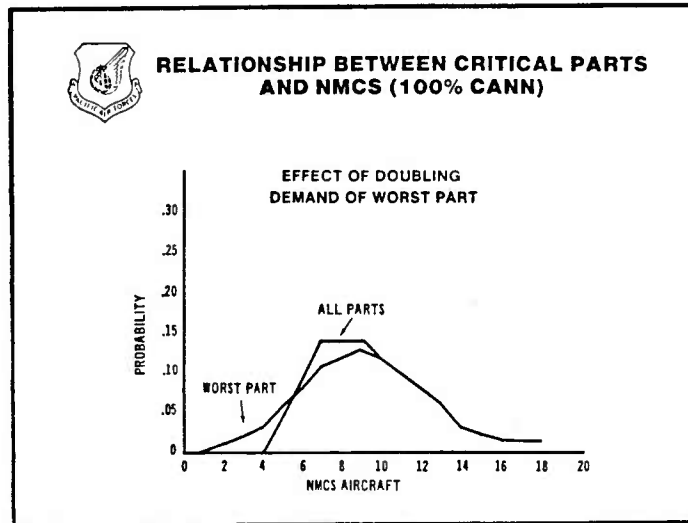
RELATIONSHIP BETWEEN CRITICAL PARTS AND NMCS (100% CANN)



min-bound NMCS density function hardly changed, showing that the six parts were dominant. For the curve labeled "Worst Part", we gave infinite stock to all NSNs except the worst one. The distribution now changed which shows that the "worst part" does not always win and does have some competition from the other five.

Figure B-2 shows another variation on the theme. Here the demand of the worst part has been doubled. As can be seen, it now dominates all the others.

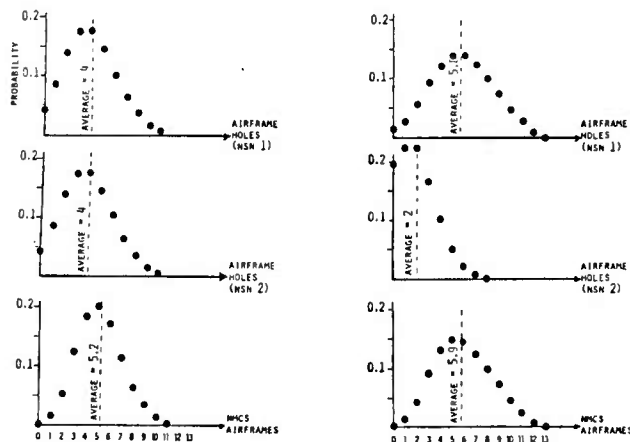
Figure B-2



Another illustration we have used is shown in Figure B-3. The left-side set shows two NSNs with identical backorder distributions. Applying equations (1), (2), and (3) yields the density function shown at left bottom. The average NMCS is a little greater, 5.22, than the 4.0 it would have been had there been only a single dominant part. The right-hand set of diagrams shows what happens when there is no very close competition to the worst part. Here the competition is between a 5.8 EBO NSN and a 2.0 EBO NSN. The min-bound NMCS is affected hardly at all by the 2.0 EBO NSN, although there is a little increase (from 5.8 to 5.9) due to the small probability that NSN 2 will cause more holes than NSN 1.

Figure B-3

The NMCS Competition



In Figure B-4, we expand the right-hand side of Figure B-3 to show more explicitly the numerics.

Figure B-4
Calculation of Min-Bound NMCS

k =	0	1	2	3	4	5	6	7	8	9	10	11	12	13
NSN 1	0.003	0.021	0.072	0.170	0.313	0.478	0.638	0.771	0.867	0.929	0.965	0.984	0.993	0.997
NSN 2	0.135	0.406	0.857	0.857	0.947	0.983	0.995	0.999	1.0	1.0	1.0	1.0	1.0	1.0
PRODUCT	0.000	0.009	0.146	0.146	0.296	0.470	0.635	0.770	0.867	0.929	0.965	0.984	0.993	0.999
DIFFERENCE	0.000	0.009	0.097	0.150	0.150	0.174	0.165	0.135	0.097	0.062	0.036	0.019	0.009	0.004

NSN 2 does affect somewhat the shape of the min-bound NMCS probability density below $k = 5$ but it has little effect above $k = 5$ where the values of NSN 1 dominate. The extension to many NSNs is obvious, where the only significant NSNs with regard to the min-bound NMCS will be the ones with non-unity values at high hole-levels.

Since no very great significance attaches to the precision with which we estimate the min-bound NMCS from the plots in the S-R Space, the above illustration makes it quite plausible that we are rather close to the correct value by taking the dominant part if one part dominates; if two or three compete for domination, the NMCS caused by the worst one could be increased by 20-30% for estimating purposes.

It is worth noting in passing that these calculations do not depend on the Poisson assumption although we used it in the illustrations. Any pipeline distribution is all right as long as the NSNs behave independently.

We have illustrated in Figure B-3, right-hand side, that if one NSN has lots of holes and the next NSN has less than half that amount, the "final NMCS" figure consists almost entirely of the holes from the one dominant NSN. The non-dominant NSN contributes almost nothing of significance to the "final NMCS".

We all know that it is extremely unlikely for any two NSNs to have the same number of EBOs. In most instances, one NSN will have more EBOs and other NSNs will have fewer EBOs. That's nature; EBOs aren't evenly and fairly distributed among NSNs. Nevertheless we consider for the moment a situation in which several (N) NSNs have identically the same Poisson pipeline distributions and identically the same non-zero number of EBOs. We consider all other NSNs on an airframe to contribute zero holes; e.g., they never break. In Figure B-5 we show the cumulative NMCS distribution had there been $N = 1, 2, 4, 6, 8,$ or 10 identical NSNs with

non-zero EBOs. In this example, $SL = 1$ and $EPQ = 5$; therefore $EBO \approx 4$. From the median (50th percentile) we see that each additional pair of NSNs contributes marginally less and less to the "final NMCS". Figure B-6 shows the discrete NMCS probability density functions corresponding to the cases shown in Figure B-5. We emphasize here that it is extremely unlikely for there to be as many as 6 or 8 or even 10 NSNs with identical numbers of EBOs. In that unlikely event, though, these extra NSNs with identical expected holes together marginally contribute no more than 2 1/2 times the NMCS that the single, first NSN contributes.

Another important point is that a "cluster" of NSNs with practically or very nearly all the same EBOs can be aggregated into a single NSN (for the purpose of NMCS calculation) with a resultant cumulative hole distribution such as the one shown for $N = 4$ in Figure B-5. That $N = 4$ cumulative hole distribution, referring to equation (2), is the $N = 1$ curve multiplied against itself ($N = 1$) four times. The $N = 4$ curve of Figure B-5, though, is also the Figure B-5 curve $N = 2$ curve multiplied against itself ($N = 2$) twice. We have conceptually aggregated two NSN cumulative hole distributions into one hole distribution and then multiplied that "aggregated hole distribution" by another "aggregated hole distribution" where the aggregation of the "cluster" of two identical NSNs was done according to equation (2). There is, of course, no need for NSN "clusters" to contain identical backorders or hole distributions. We wish to make the point that a "cluster" of points in S-R Space can dominant the "final NMCS" figure just as can a single high EBO trouble-maker NSN.

When a "cluster" of bad-actor NSNs stands far above other not-so-bad NSNs (badness measured in EBOs), the marginal increase in NMCS from all the other not-so-bad NSNs is small as a consequence of the examples illustrated in Figures B-1, B-3 (right side), and B-5. For a good example of such a "cluster" see the basic text's Figure 7 January S-R Diagram (page 27).

Figure B-5

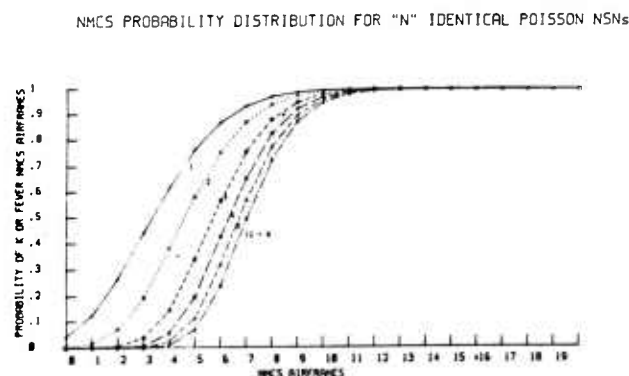
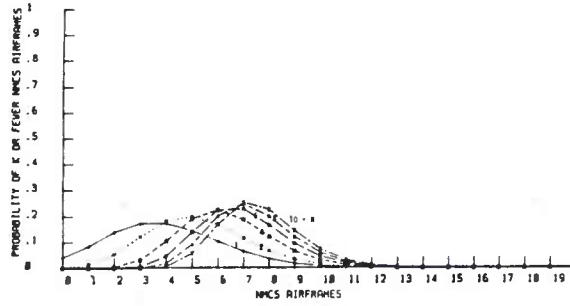


Figure B-6

NMCS PROBABILITY DENSITY FOR "N" IDENTICAL POISSON NSNs



Appendix C

MODELING OF INDENTURE RELATIONSHIPS

The Dyna-METRIC (DM) runs which we used for comparing to the MICAP estimates did not exercise the model's built-in capability to assess LRU awaiting parts time (AWP) caused by possible shortages of SRUs. In this appendix, we explore the contribution of the indenture relationship to the pipeline quantity and through them to the EBOs.

We ran Version 3.04 of Dyna-METRIC both with and without the SRUs modeled. For the runs which incorporated the SRU-LRU indenture relationship, we set the SRU stocks to zero. We did so because: (1) we do not have "good" stock level data on SRUs and (2) SL=0 serves as a bounding case (i.e., predicts the maximum AWP due to SRUs) because the real stock will generally be greater than that.

The results are shown in Figure D-1 for the 18TFW F-15s with the principal comparison being between the two columns under "Total Pipeline." "W/O SRU" means that SRUs weren't included at all, and that is equivalent to having as many SRUs as needed. "Zero SRU Stock" means the SRUs were modeled under the assumption that there was no stock, a condition that generates higher AWP than a run using real SLs. The difference between these two show the effect of modeling the indenture relationship. In some instances the AWP increase the pipeline by as much as 80 percent. Of course, had we used the actual SRU stock levels, the difference would have generally been still less. Nevertheless, some of the NSN's EPQs should probably have been increased by 50 percent or more in the Dyna-METRIC run for an apples-with-apples comparison with the MICAP data.

The EBOs are quite low in either case, especially compared to the values estimated from MICAPs, which is the point this appendix illustrates.

A fifty-percent increase would have little effect on the 18TFW Dyna-METRIC S-R diagram itself, simply because all of the NSNs plotted (50 of them) fell in the low EPQ/low EBO region. This fundamental Dyna-METRIC/D029 output is evident from the "pipeline" and "EBO" columns, both of which show low values.

How well does the Dyna-METRIC model capture the LRU-SRU indenture dynamics? The "AWP" column shows the "max" DM AWP quantity and compares it to the "historical" data of some seven months. In two instances the historical data show about three to four times as many NSNs awaiting parts as the DM run. In a few instances, on the other hand, DM shows more in AWP status than the historical data. And these observations bring us face-to-face with yet another question, which we address below.

What cannibalization policy should be applied to LRUs which are awaiting parts? Just as in the model of a Wing where we defined a min-bound NMCS by assuming holes were maximally consolidated, so too here can we postulate a 100 percent cann mode being applied to LRUs. That consolidates the SRU holes into the fewest LRUs so that only some of them are held in

Figure C-1

AV NO OF PARTS TOTAL PIPELINE		EBO										DEMAND/FLY HOUR ^a		RCT (DAYS)	
NSN	STOCK LEVEL	ZERO SRU STOCK		W/O SRU STOCK		ZERO SRU STOCK		AV NO PARTS MICAP		AV NO PARTS AWP		D029 HIST		D029 HIST ^b	
		W/O SRU	SRU	W/O SRU	SRU	W/O SRU	SRU	MAX.	AVG.	D-M	HIST	D029	HIST	D029	HIST ^b
1270 01 018 8267	19	8.39	10.29	0.0	0.01	0.0	0.01	24	10.2	1.57	7.04	0.00641	0.00744	12	11/28
5841 01 100 7363	19	6.21	11.24	0.0	0.0	0.0	0.0	18	5.4	3.55	1.99	0.01316	0.01221	5	3/ 6
1270 01 040 5948	20	7.24	11.25	0.0	0.0	0.0	0.0	16	5.0	2.95	13.80	0.00641	0.01004	11	3/27
6605 01 012 8598	16	7.32	8.22	0.07	0.01	0.07	0.01	16	6.0	0.70	0.14	0.00571	0.00895	10	5/ 5
5841 01 048 6312	13	8.29	12.21	0.01	1.19	0.01	1.19	14	8.0	3.63	11.9	0.00688	0.00694	13	7/37
5841 01 044 7134	48	16.28	18.51	0.01	0.0	0.01	0.0	13	3.6	2.08	0.62	0.01389	0.01991	11	4/ 5
5895 00 539 1911	17	10.86	13.21	0.06	0.27	0.06	0.27	11	4.4	2.10	0.78	0.00971	0.00979	10	2/ 4
2835 01 034 4772	9	3.11	3.12	0.0	0.01	0.0	0.01	10	3.2	0.81	0.81	0.00294		9	
2835 01 034 6948	21	4.65	4.25	0.0	0.0	0.0	0.0	10	4.4	0.67		0.00500		6	
5841 01 058 8180	27	12.20	17.32	0.0	0.01	0.0	0.01	10	4.9	3.82	7.09	0.01111	0.01430	11	5/14
1280 01 042 3952	8	4.58	6.11	0.07	0.27	0.07	0.27	10	3.5	1.25	1.17	0.00500	0.00644	7	6/ 9
6610 00 122 6625	10	12.67	14.13	3.09	4.19	3.09	4.19	8	2.9	1.29	1.56	0.00500	0.00582	11	3/ 6
5841 01 063 0855	17	13.79	16.19	0.43	1.02	0.43	1.02	6	3.9	1.89	2.67	0.01333	0.02091	11	2/ 5
6610 01 021 8908	3	3.26	5.76	0.83	2.34	0.83	2.34	6	2.9	1.94	2.05	0.00252	0.00368	13	8/18
6710 01 018 2007	9	5.55	9.12	0.10	1.07	0.10	1.07	4	2.5	3.23	5.54	0.00500	0.00703	12	10/24

NOTES:

- a. Historical demand rates, RCT, AND AWP data come from PACAF's OTCS (operational tracking and control system) from June 1982 through January 1983 and include CNDs; D029 demand data does not include them. Historic AWP and RCT data values are understated in that only returned parts are included in the computation. Some as yet-unrepaired parts have accumulated many days in the repair cycle or awaiting parts.
- b. Historical RCTs shows "without/with" awaiting parts time.
- c. Blanks indicate no data available.
- d. NSNs were chosen for display in this table by arranging them according to the maximum observed MICAP value of each. The ones which did not have associated SRU indentures were then deleted. We look only at the top fifteen of the list.
- e. D029 data were used for all SRUs. Wartime SRU OSTs were used and these are longer than the peacetime OSTs, a choice which emphasizes the indenture relationship.

AWP status. That is, in fact, the option we used in the DM run on AWP's, and it has the effect of generating the smallest-sized AWP that we can achieve. In the absence of such assiduous canning, the AWP numbers could easily be many times greater if no or few cann's were done.

To illustrate the alternative model -- no SRU cann's -- we reran DM with the switches set up that way. When we made the "cann/no cann" comparison, we got the surprising result that the "no cann" in some cases gave fewer AWP than the "cann". In consultation with RAND, we were told these subroutines were unreliable in Version 3.04 but they had been fixed in the most recent version. To some extent, then, we are unsure about the entire LRU-SRU modeling results reported here.

When we look at the "Demand/Fly Hours" data in Figure D-1, the D029 and "Hist" columns seem reasonably consistent, especially when one notes that the Hist data (a 7-month average) also includes CND's not present in the D029 data.

The "RCT" column contains interesting data. The "Hist" column shows the average repair cycle time for the NSN under two conditions: time spent awaiting parts is (1) excluded (2) included. Note that in most instances, the RCT with AWP time included pretty much accounts in both directions for the difference in AWP between "DM" and "Hist". For the DM run we used the SRU wartime order and ship time (OST) of 23 days specified in D029 instead of the peacetime values of 7-14 days. Since we also were working with an assumed zero stock level for each SRU, the AWP was directly driven by OST's. We chose to use the higher wartime OST in order to show the largest effect. That appears to have been too little in some cases, too much in others. The high RCT when AWP time is included and its correlation with "Hist" AWP's along with the fact that it is a potential explanation of the DM/MICAP differences make it tempting to speculate that at least a part of the discrepancy lies in incorrect SRU's OST's. However, we also realize that less-than-100% cann's would also generate the same effects, so we can't pick either.

In summary, an haruspex looking at these data could conclude that DM/D029 modeling of AWP's would not account for a significant part of the DM/MICAP discrepancies. In addition, there is more than a little possibility that either the data (SRU OST's) or the model (cann policy?) is not capturing what is going on.

Appendix D

THE SAMPLING STATISTICS OF EBOs ESTIMATED BY MICAP DATA

In general when a statistic (in our case the EBO) is estimated from a limited amount of data (in our case MICAP-hours accumulated over a month's period), the estimated values will vary from month to month to a degree determined by the intrinsic variability of the process. Increasing the sample size (i.e., basing the estimate on N months of data instead of on a single month) diminishes the variability of the estimate if random effects alone account for the variability.

We have seen in figures 8 and 11 that the estimated EBOs for a particular NSN do change from month to month. The question inevitably arises: Are the fluctuations random or are they due to non-random real-world influences? A step along the road to answering that question will be taken when we can say to what extent random effects alone would cause the estimate to vary from month to month. In this appendix we will move usefully along the road and obtain a "feel" for the answer.

We take the Dyna-METRIC model as a starting point: It asserts that the pipeline quantity for an NSN has a Poisson distribution. Moreover, we know that the variance of a Poisson distribution is numerically equal to the expected value; that the standard deviation (s.d.) is the square root of the variance; and that in a single sample of the pipeline the observed quantity will be within ± 1 s.d. with approximately a 0.66 probability, or within ± 2 s.d.'s with a 0.95 probability. For a numerical example, consider the pipeline EPQ to be 16. The s.d. would be 4; and with probability 0.66 we would expect single observation to yield a value between 12 and 20, or with probability 0.95 a value between 8 and 24.

If instead of taking a single sample, we took N independent samples and averaged the values, we would usually find the average lying closer to the EPQ. In fact,

Variance of N-observation average = (Variance of single observation) \div N.

In our previous example, if we took 16 independent samples and averaged them, the variance of the average would be 1, as would the s.d. Hence the average of the 16 independent observations would lie within the range 15 to 17 with probability 0.66 or 14 to 18 with probability 0.95.

The above several paragraphs make assertions about variances of pipeline quantities, but we are mostly interested in the EBO variance. The connection of the pipeline variance with the EBO variance is quickly made, however, in the 45-degree region: The variances are numerically equal. Indeed, since a "MICAP sample" is equivalent to a "pipeline sample", we should expect estimates based on MICAPS to behave (in the 45-degree region) like estimates based on observations of pipeline quantities. Thus, by averaging N independent samples of backorders, we should reduce the variance by $1/N$.

If the points do not lie in the 45-degree region, the EBO variance will be less than that of the pipeline. The SL curves serve to "map" the pipeline quantity into a backorder quantity, and in regions other than the 45-degree one have lesser slopes.

When we base estimates on Wing-reported data, a difficulty unfortunately arises: Samples of MICAPS taken at hourly intervals are not statistically independent; and because of that, the simple division of the variance by N is no longer the correct way to calculate the variance of the averaged estimates. That the MICAP value observed at one hour for an NSN is correlated to the previous hour's MICAPs, and to the hour's before that, is intuitively obvious. When samples are correlated, then each additional observation contributes some new information, but much of it is not new and was contained in prior observations. Thus N correlated observations are not as valuable, statistically, as N uncorrelated observations. How much value is lost depends on how strong and how long the correlations are.

The correlation between the present period of time and an earlier period is determined by the common events they share. Today's pipeline quantity would be higher if there were a random occurrence of high demands three days ago which have not yet been repaired. Indeed, the correlation with past events gets fainter the further back we go, and there is no correlation with a period when demands have all been repaired. It's a pretty good approximation to think of the present period's correlation being very weak with periods farther back than the average repair time. Thus, base repair lines have short memories, the CIRF has a longer one, and the depot repair lines generally have the longest.

To get a feel for "how many samples we get in a month's worth of MICAP data," we resorted to a quick simulation of the statistical process:

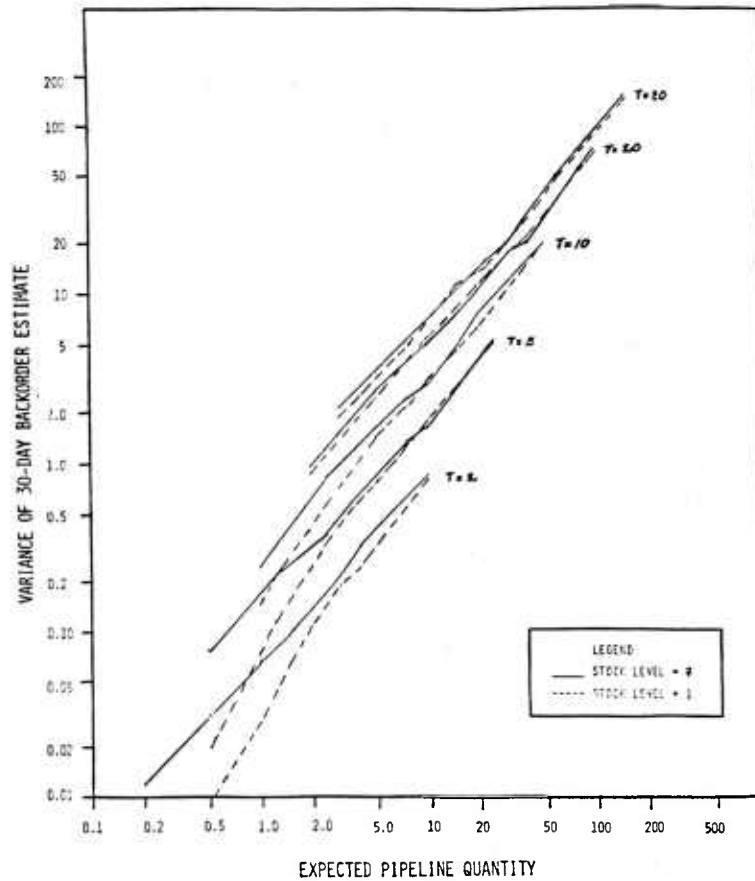
- o A Poisson random number generator produced a string of "daily demands" according to a specified EPQ.
- o We postulated a fixed repair period T , so that the pipeline quantity (PQ) on a given day was the sum of the recent T days of demands.
- o We set a stock level (SL), and hence the backorder (BO) value on a particular day was $PQ - SL$, negative values were set equal to zero.
- o For each day, the number of BOs gave the MICAP-days.
- o We accumulated the above MICAP-days (which changed from day to day) for one month (30 days) and divided by 30 to get the average "holes per day" for that month for that NSN.
- o We let the process run for 400 months and computed the average of the 30-day averages as well as the variance of the 30-day averages.

- o We then changed the parameters of interest and re-ran the simulation to explore the sensitivities.

The results are plotted in Figure D-1. Even with a 400-month simulation for each point, there is still appreciable variation of each point from the smooth curve we would anticipate from an infinite sample size. Even so, the principal behavior is clear. For a given EPQ, a larger repair time produces a larger EBO variance simply because less information is obtained from a one-month sample of data.

Figure D-1

VARIANCE OF 30-DAY ESTIMATE OF EBO
(400-Month Simulation per Point)



In the 45-degree region of the S-R plots, i.e., for EPQs large vis-a-vis the stock level, the variance of the 30-day average is independent of stock level, although at low EPQs it is clearly SL-dependent as we would expect. We extracted the data shown in Figure D-2 from the line through EPQ = 10.

Figure D-2

Effective Sample Size for 30-day Estimates

<u>Repair Time (days)</u>	<u>Variance of 30- day EBO Average</u>	<u>Effective Sample Size</u>
2	0.84	11.90
5	1.70	5.88
10	3.00	3.33
20	5.40	1.85
30	7.00	1.43

Since for single observations the variance of the observed EBO would have been 10, we define the "effective sample size" to be the number of independent observations that would have yielded the same variance reduction as the 30-day average of the correlated data. The effective sample sizes shown in the figure are somewhat less than 2 for depot-repaired NSNs (20 to 30 days repair time), 3 or 4 for CIRF-repaired NSNs (10 days repair time), or about 6 for on-base repairs.

These are not very large sample sizes, and considerable variation of the month-to-month MICAP data estimates would be expected due only to random effects alone under a Poisson pipeline assumption.

We noted in Appendix A that the 45-degree region of the S-R Space is distribution independent--and it is, insofar as we are concerned with expectations such as EPQ and EBO. Such theoretical expected values, crudely speaking, are calculated for an infinite sample size and consequently enjoy zero sampling variance. Quite clearly at something less than infinite sample sizes, the sampling variance of an EBO estimate will depend on the underlying variance of the pipeline distribution. Such variances could, in practice, be either larger or smaller than the simple Poisson distribution intrinsic to Dyna-METRIC. Obviously, the question of the underlying pipeline distribution is of great importance. In spite of the very great mathematical benefits that conveniently flow from the Poisson's properties -- and on which Dyna-METRIC intrinsically depends -- the pipeline distributions of the important NSNs may quite possibly not be Poisson. Indeed, a non-Poisson variance may ultimately be more significant than a non-Poisson EPQ.

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